APPLICATION OF USER EQUILIBRIUM TRAFFIC ASSIGNMENT IN EVACUATION MODELLING

By

ChangKyun Kim

Thesis submitted to the faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirement for the degree of

Master of Science

in

Civil Engineering

APPROVED:

DR. A. G. Hobeika, Chairman

DR. D.R. Drew

Antonio Trani

DR. A.A Trani

August 1, 1991

Blacksburg, Virginia

APPLICATION OF USER EQUILIBRIUM TRAFFIC ASSIGNMENT IN EVACUATION MODELLING

by

Changkyun Kim

A.G. Hobeika, Chairman

Civil Engineering

(ABSTRACT)

The Mass Evacuation (MASSVAC) model was originally developed for analysis and evaluation of evacuation plan in a specific area facing natural disasters. It was later applied to deal with the problems of evacuation around nuclear power stations (MASSVAC 3.0). The purpose of this model is to simulate the network clearance time and evacuation routes. In the process, it employs the Dial's or the all-or-nothing method to assign the traffic on to the network.

The major effort in this research is to include the user equilibrium assignment method to reduce the evacuation times and to improve highway network performance. Evacuation routes, number of links used, and evacuation times etc. are found to be influenced by the user equilibrium assignment method. Transportation System Management (TSM) strategies have also been incorporated in this enhanced model (MASSVAC 4.0) to improve the network performance during evacuation. The trip distribution process and the shortest path algorithm has been modified appropriately to suit the user equilibrium assignment.

MASSVAC 4.0 was applied to compute network clearance time, identify the congested volume, evaluate traffic management strategies, and determine the run times for the model for the Emergency Planning Zones (EPZs) of the Surry nuclear power station in Virginia. The results of the evacuation model (MASSVAC 4.0) using user equilibrium assignment are compared to those from Dial's algorithm (MASSVAC 3.0). The evacuation times and the degree of congestion on the links have been compared and discussed, and the advantages and disadvantages of the models are included.

ACKNOWLEDGEMENT

The author wishes to express his deep appreciation and gratitude to his advisor, Dr. Antoine G. Hobeika for his continued guidance and financial support.

His acknowledgement is extended to Dr. Donald R. Drew and Dr. A.A. Trani. They helped him enrich knowledge in Transportation Engineering. All his colleagues working in Center for Transportation Research need to be thanked for their friendship and cooperation. Dr. Sigon Kim, Byungjong Kim, and Siva are especially thanked for helping his thesis.

His wife can never be forgotten for her thorough understanding, assistance, and sacrifices during his study.

Most importantly, appreciations goes to author's parents for their intellectual, financial, and emotional support.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER 1.0

Introduction

Trip assignment is the procedure of determining a route and allocating the trips to these routes. The trip assignment method can be classified in two groups : non-capacitated assignment methods and capacity-restraint assignment methods.

Non-capacitated assignment method does not recognize the dependence between flows and travel times. All-or-Nothing assignment is a non-capacitated assignment that does not consider the capacity of the link. Examples of capacity-restraint algorithms are "repetitive all-or-nothing", "modified repetitive all-or-nothing", "incremental" assignments, and Dial's algorithm, which is a stochastic user equilibrium assignment method which has been utilized for solving the evacuation problems in MASSVAC (MASS eVACuation). In order to test whether Dial's algorithm is efficient or not handling the evacuation problems, the User Equilibrium (U-E) assignment method is applied to the same evacuation situation. The goal of the user equilibrium algorithm is to make the travel time equal on any path from the origin to the destination on the whole network. The condition of the algorithm is reached when "no traveler can improve his or her travel time by unilaterally changing routes." While Dial's algorithm is based on the assumption that each motorist might perceive a different travel time and respond accordingly, the user equilibrium assumes that all the motorists are knowledgeable of the travel times on different routes

(37). As a result, evacuation time, computer run time, and the number of congested links etc, of the application will vary depending on the assignment method used. The addition of the user equilibrium algorithm provides an option to adopt an appropriate assignment method during evacuation planning. The total number of vehicles to be evacuated on the entire network, the number of links on the network, and the classification of the evacuation area, predominantly affect the evacuation performance during an entire evacuation process. These factors must be considered in choosing an assignment method, due to their inter-relationships with the assignment algorithm.

1.1 Research Objectives

The MASSVAC computer simulation model has been originally designed for evaluating evacuation problems under natural disaster conditions. Through the accomplishment of MASSVAC 3.0, the model is capable of estimating network clearance times and evaluating highway network performance for evacuations in natural disasters, and around nuclear power stations.

The principal objective of this study is to apply the model in the area of trip distribution and trip assignment, to simulate evacuation situations for nuclear related accidents using user equilibrium assignment method in addition to Dial's and all-or-nothing method. This applied version is called MASSVAC 4.0. The user equilibrium assignment method has been used for the urban traffic control. However, since evacuation must be completed in a short period of time, the user equilibrium may be treated in a different way. Thus, the user equilibrium assignment method is intended to be applied to the evacuation situation using the same techniques and algorithms of the previous MASSVAC. It is focused on how the user equilibrium assignment performs for evaluating the evacuation problems. In addition, the user equilibrium traffic assignment method has been added primarily to compare the total computer-simulation time and the actual evacuation time between those assignment methods. The clearance time and computer-simulation time are determined by the traffic assignment method chosen. Dial's algorithm and all-or-nothing methods have been utilized as traffic assignment algorithms in MASSVAC 3.0. However, Dial's algorithm has been found to be insensitive in a specific application of MASSVAC. Therefore, user equilibrium assignment method (MASSVAC 4.0) has been incorporated with the intention of overcoming the shortcomings of the model with Dial's algorithm. The All-or-Nothing algorithm is not included in the comparison since it is unrealistic due to its non-consideration of capacities.

The purpose of evacuation planning is to move the evacuees out of the Emergency Planning Zone(EPZ), as opposed to reaching specifically designated, capacity constrained shelters. In the earlier version of MASSVAC, trip destinations were ordinary highway nodes outside the emergency planning zone(EPZ), and were assumed to be of infinite capacity. The evacuation processes within the EPZ is assumed to be unaffected by traffic problems on the highway network outside the 10-mile area. These assumptions are assumed to hold good for the new model(MASSVAC 4.0).

Another objective is to investigate the performance of MASSVAC, with regard to trip distribution and trip assignment. The iterative selection of destinations, based on current travel times, for each trip producing-origin is closely related to trip assignment. The feature of trip distribution in the previous MASSVAC is that it is dictated by considerations of travel time away from the center of the evacuation area. The selection of destination is due to the topology of the area and geometric elimination techniques. The best model for a specific case can be obtained by applying several distribution options. After the selection of destination in terms of topology of the area, the other selection method in terms of the travel time between the origin and the destination are implemented. On the other hand, in MASSVAC 4.0 it is assumed that all the destinations on the entire network can be candidates for any origin to evacuate the vulnerable area. This assumption provides more opportunities of routes for loading and assignment process. But all the links in the EPZ (Emergency Planning Zones) may not be available for distributing trips during a nuclear related accident, since the motorists are not to be directed towards the central point of the evacuation area. Thus, a few links will be eliminated during the distribution process, because these links may not be used during the entire procedure. At last, the model is applied to the Surry nuclear power station in Virginia. The application focuses on 5-mile area and two 10-mile areas in the entire network.

1.2 Organization of Remaining Chapters

Chapter 2 reviews the literature pertinent to evacuation history, and the general methodologies of evacuation planning. Computer models related to the evacuation problems are also described in the chapter. The traffic assignment method is classified and discussed in detail. The comparison of Dial's assignment and U-E assignment is focused in the chapter. Chapter 3 describes the earlier version of MASSVAC. Chapter 4 details the theoretical aspects of the model, including the development of the new trip distribution method for user equilibrium assignment. The assignment procedure is also explained in detail. Additional algorithms for the main process are also developed in this chapter. In addition, the explanation of algorithms in MASSVAC 3.0 are included to compare with the new models. Chapter 5 explains the technical aspects of the model, describing the functions of all the subroutines along with their role in the model. Model application, Comparison, and the results are presented in Chapter 6. Finally conclusions and recommendations for the further research are contained in Chapter 7.

CHAPTER 2.0

Literature Review

2.1 Evacuation

Since the beginning, men have experienced a number of hazards and disasters that destroyed their lives and properties. Most hazards were caused by natural disasters such as earthquakes, hurricanes, and floods, and by man-made dangers such as wars and nuclear related accidents.

On April, 1986, unit No.4 of the Chernobyl nuclear power station, located in the Ukraine Republic of the USSR, suffered a major accident which caused a prolonged escape of a vast amount of radioactive products into the atmosphere (28). According to Vladimir Chernousenko, the plant's senior scientist, the disaster claimed 10,000 lives and 3.5 million people were exposed to radiation levels hundreds of times higher than the safe limits. Chernousenko said the city of Kiev, which is nearby the accident site, should have been evacuated, and the focus should have been on the task of saving people (34).

In the United States, the Three Mile Island nuclear plant began to release radioactive gases into the surrounding environment in the early morning hours of March 28, 1979. It directly affected the lives of nearly 15,000 people who felt panic from a threat which was invisible, odorless and soundless. On March 30, 1979, the authorities finally issued an advisory evacuation notice to pregnant women and pre-school children residing within a five-mile radius of the plant (31). Although these events are rare, an incident at a nuclear facility which can cause radiation exposure to the public can take place, and appropriate protective measures must be identified in order to substantially reduce or avert the exposures. One of these protective measures is to evacuate the public from the affected area. This is one of the requirements, set up by Nuclear Regulatory Commission (NRC), for the licensing of nuclear power plants with respect to general public safety. NRC requires that all electric utilities in the United States develop evacuation plans for the areas surrounding their nuclear power stations.

On the other hand, natural disasters in general are part of our daily living. They proved to be costly with long term effects on stricken communities and individuals. For example, the earthquakes which happened in Mexico city, on September 19, 1985, left as many as 20,000 dead and up to 150,000 homeless. Recently the San francisco Bay area, which is the fourth largest metropolitan area in the United States with about 6 million people, was shaken by a powerful earthquake measuring 7.1 on the Richter scale. It was named the Loma Prieta earthquake after the highest topographic point adjacent to the fault zone. The office of Emergency Services (OES) reported that the earthquake caused 62 deaths, 3757 injuries, 116,000 homeless, and property damage worth $8 billion (39).

The eruption of the volcano Nevado del Ruiz on Columbia, on November 13, 1985, also left at least 20,000 dead or missing in a steaming, mile-wide avalanche of gray ash and mud within hours (30). Recently at least 101 people had died as a result of the eruption of Mount Pinatubo. The role of evacuation planning was so critical to reduce the extent of damage, because the volcano is located at the people-condensed area (27). The above examples illustrate the need for evacuation planning in areas and communities that are threatened by natural and man-made disasters.

2.1.1 Evacuation planning

2.1.1.1 Human Behavior Studies

Perry (30) has classified emergency management into four phases which are Mitigation, Preparedness, Response, and Recovery. Mitigation is activities which eliminate or reduce the probability of the occurrence of a disaster. Preparedness planning refers to what should be done in case a disaster occurs. Response activities follow a disaster, and are designed to provide emergency assistance, and to reduce the likelihood of secondary damages. Recovery involves restoring affected areas to normalcy. In these four steps, evacuation planning and operation are the major activities in the preparedness and response step of emergency management.

Quarantelli (33) has studied the same evacuation process with four possible patterns: warning, withdrawal movement, shelter, and return. He has also introduced the human behavior in evacuation situations. Among those behaviors related to transportation area:

1. The automobile is the prime transportation mode used to withdraw from danger.
2. The withdrawal movement is always orderly with no wild panic or

disorderly flight.

3. Traffic accidents or automobile breakdown are minimal.
4. In the withdrawal movement, several researchers concluded that there is no instant bolting into flight by masses of individuals upon perception of danger. People assess the emergency situation, obtain confirmation of immediate and personal danger, then usually leave with members of their families -their most important social group.
5. Not everyone leaves, except in the most catastrophic situations.

In another study, Mileti et al. (26) outlined the components and factors that determine the level of preparedness in a community:

1. Prior disaster experience
2. Planning, action for vulnerability reduction
3. Planning for post-impact response
4. Level of preparedness
5. Post-warning actions and mobilization
6. Post-impact response

2.1.1.2 Evacuation Methodologies

Evacuation is not a new phenomenon, it is probably as old as human settlement, however, scientific studies and engineering approaches to evacuation methodologies as part of emergency preparedness is fairly recent.

The methodologies reviewed in this section are limited to nuclear related accidents. A number of methodologies have been developed to plan for emergency evacuations around nuclear power plants. These methods primarily differ with respect to the area over which evacuation must take place. Emergency Planning Zone (EPZ) around a nuclear power plant is considered to include all areas lying within (a circle of) 10 miles of the power station. Census tract information is used to aggregate socioeconomic data over Protective Action Zones (PAZ) within the EPZ. Evacuation analysis is usually carried out for four population groups: 1) permanent auto-owning population; 2) transient population 3) non-auto owning population and 4) institutionalized population (prisons, hospitals, school etc) (20).

NRC and FEMA (Federal Emergency Management Agency) requires the following general approach in modelling the evacuation process around nuclear power plants:

1. Delineate Plume Exposure EPZ and subareas to be studied
2. Establish categories of people to be evacuated from the EPZ and its subareas
3. Estimate time required to prepare to evacuate
4. Conduct an assessment of the Transportation network.
5. Code Evacuation Network
6. Develop Vehicle Loading Distribution
7. Estimate Evacuation Time Distribution for General Public
8. Estimate Evacuation time for the Public Transport Dependent Population

9. Estimate Evacuation Time for special Facilities
10. Estimate Evacuation Time Distribution for Prevailing Wind Directions
11. Document Analysis, Results and Presentation

Most evacuation models follow the issues listed above. However, the Graded Response Strategy has been proposed as a preferred evacuation strategy for nuclear power plants (29). The basis of this strategy is that nuclear power plant accidents are far less likely to occur than non-nuclear ones and would typically evolve slowly, giving ample time for off-site responses.

The graded response strategy which focuses on members of the public most at risk, tailors protective actions to the specific conditions being faced and implements them in a logical, manageable sequence. The essence of this strategy is to first evacuate an inner zone 2 miles from the plant while advising other people in the farther zones to stay only in the shelter and to wait for instructions on TV and radio. The control center make a decision of the nature of the radioactive plume, then the people sheltered in the EPZ are carefully relocated to areas away from the direction of plume. The amount of time required and risk involved in this method is argued to be of a far lesser degree than a whole-scale 10-mile evacuation.

Evacuation, at any rate, is one of the basic jobs of emergency management. It is the strategy most predominantly used to protect people from disasters, and most importantly, it is a controllable one. In spite of other mitigation activities, dealing with disasters at the source, such as better siting and engineering designs, evacuation in many cases is inevitable. The development of transportation evacuation models to calculate the evacuation times and the most efficient evacuation routes is only part of the process. The evacuation data-base management, the computer processing system, and the computer-based software that can incorporate and synthesize model results and expert knowledge in ways that can assist the user in his or her decision under various conditions, constitute a major part of the entire process. The development of a decision support system for evacuation planning and operation that includes all the above elements, is necessary to achieve a comprehensive approach of an integrated emergency management system.

2.1.2 Evacuation Models

Traffic engineers and researchers are using computers for simulating various traffic and transportation situations and scenarios. Computer simulation facilitates the evaluation of different candidate solutions particular to a certain transportation problem. This approach has a couple of advantages over empirical. It is possible to test and evaluate various alternatives under the same situations. Traffic researchers can easily get the best solution through several trials with a computer. The facilities that have not been done yet can also be tested. In case of an emergency, such as nuclear power accident or natural disasters, computer simulation can evaluate future situations well in advance. Another merit of simulation is that it could be applied to different situations by changing the inputs.

There are two approaches to simulating traffic flow ; macroscopic and microscopic. The macroscopic approach considers the traffic stream as a continuous flow. In other words, the model would study the relationship between speed, flow and density. On the other hand, the microscopic model observe the traffic from the driver's point of view with respect to other vehicles in the stream. The car-following theory might be regarded as one of the typical microscopic model.

There are several simulation models for solving transportation problems today. The models are designed to analyze and resolve traffic problems in regular operational conditions. A few models are applied to solve the traffic situation under special conditions such as evacuation.

2.1.2.1 Traffic Simulation Models

The following traffic simulation models are selected and reviewed, since they could be modified for evacuation application.

1). NETSIM

It is an abbreviation of NETwork SIMulation. This model developed by KLD Associates, Inc., is designed as a microscopic, stochastic highway traffic simulation model. The purpose of this model is to simulate the traffic performance under different control strategies and under very congested traffic demand in downtown urban areas. The main idea of NETSIM is that a road network can be considered as a series of links connected by nodes which represent the intersection of these links. A new micro version of NETSIM which requires a very detailed input and substantial computer requirement, has been introduced in 1989. But NETSIM has some drawbacks in simulating evacuation problems. The model needs detailed input data to on links to estimate clearance time. Besides, the capability of the model is comparatively small to handle a large network. However, this traffic simulation model was utilized for establishing the evacuation model (NETVAC).

2). TRAFLO

TRAFLO means TRAffic FLOw simulation model developed by FHWA. This model is modified for evaluating the evacuation problems around nuclear power plant. The modified evacuation simulation model is called DYNEV (DYnamic Network EVacuation), which will be discussed in the next section. Positive aspects of TRAFLO model include (7):

1. Traffic assignment and simulation are accomplished within a single run.
2. Good statistics are produced for analysis and evaluation.
3. Input data are printed out in an easy-to-use format.
4. A good overall level of traffic assignment calibration is achieved with a reasonable number of computer runs.

However, this has some negative aspects to be a good evacuation simulation model :

1. The required input data are detailed.
2. The traffic assignment model does not consider the effect of traffic signal on link capacities.

3. The costs of running the program is relatively high.

2.1.2.2 *Evacuation Simulation Models*

A few traffic simulation models have been developed for evacuation planning under disaster situations. Among those are:

1. CLEAR

The CLEAR (Calculating Logical Evacuation And Response) model was developed by the pacific northwest laboratories for the United States Nuclear Regulatory Commission (24). This model estimates the time required for a specific population density to evacuate an area using a specific transportation network. It is a microscopic model which traces each vehicle in the EPZ. This model needs accurate data from each zone for simulation, but it is difficult to get the data for the geometric zones. Because the loading methodologies is based on roughly determined mathematical models of link service under different flow conditions, this model has a problem when applied to different scenarios of evacuation.

2. DYNEV

DYNEV (DYnamic Network EVacuation) has been developed by KLD Associates, Inc. It is also a microscopic model which derived through the enhancement of the TRAFLO model. The DYNEV model has the capabilities to provide detailed information, both in graphic and tabular form, about the operational performance of each network link. This model has been used extensively to develop evacuation plans for nuclear power plants for years and has shown both advantages and disadvantages.

The complex input increases computer run time and requires a large amount of memory. That does not make the model useful in a microcomputer. The other disadvantage is the integration of trip distribution and traffic assignment which limits the user's options. The user has the option of bypassing the trip distribution step and providing his own O-D table as input for the traffic assignment procedure in most other models. Equilibrium principles used for traffic assignment procedures is not reasonable under emergency situations such as nuclear power accidents, because evacuation takes place over short time periods and people do not seek the equilibrium state during the evacuation. Equilibrium logic also assumes that everybody knows the shortest path between origin and destination. In fact, evacuees may not even be familiar with their route conditions (23).

3. NETVAC2

The NETVAC2 (NETwork emergency eVACuation) has been developed by M.I.T. to estimate the network clearance time for areas surrounding nuclear power plants. The NETVAC2 model is a macro traffic simulation model sensitive to network topology, intersection design and control, and provides a wide variety of evacuation management strategies. The model could handle a large network at modest computational costs. The model computer costs are a half amount of the NETSIM in terms of core requirement and

C.P.U. time (11). Therefore, it can be used in a planning model as well as in the analysis model. The efficiency of the model stems from the sophisticated list processing method used to represent the evacuation network as a series of links and nodes. The benefits of NETVAC2 is that it has a dynamic traffic assignment algorithm. Owing to the dynamic route assignment mechanism, approach capacities are updated at each simulation interval, to account for the changing turning movement. The model could be processed under multiple scenario analysis. The database can be used to assess the merits of various traffic management measures aimed at developing an effective, site-specific evacuation plan. The model also accounts for the detailed distribution of vehicle demand and provides thorough documentation of results. NETVAC2 has also a capability providing a means for examining a complex problem in a structured manner; and can readily address the solution for evacuation problems such as evacuation time and the routes used on the network.(38)

4. The EVAC PLAN PACK model

The PRC Voorhees model is a computer program developed for simulating traffic flow during evacuation and for calculating the evacuation time for a given population, road network, evacuation rate, and control measures. The package is composed of five elements: a) demand estimation, b) evacuation departure rate estimation, c)evacuation volume and capacity estimation, d) evacuation time estimation and congestion points estimation, and e) bus / automobile evacuation time estimation. The major characteristics of the model are behavior considered, probabilistic, and sensitive to control measures.

However, this model also has some shortcomings like other evacuation models. The model assumes that the time distribution of completing each action is a conditional probability dependent on the completion of the previous action. This assumption may not be true in a real evacuation process in a large urban area in which events can take place independently from one another.(32)

2.2 Traffic Assignment

The final step of the urban transportation planning system (UTPS) deal with the assignment of the interzonal, modal trips to the various routes of each mode. FHWA (Federal Highway Administration, 8) defined traffic assignment as the process of determining a path or paths of trip and allocating the centroid-to-centroid trips to these paths. The result of the traffic assignment is an estimate of user volumes on each segment(link) of a transportation network (FHWA, 9). The uses of traffic assignment techniques include:

1) The development and testing of alternate transportation systems.
2) The establishment of short range priority programs for transportation facility development.

3) The detailed study of traffic generators and their effects on the transportation system.

4) Location analysis of facilities and service within a transportation corridor.

5) Development of design volume.

6) Provision of necessary input and feedback to other planning tools.

Input to the traffic assignment process, regardless of the type of network to be considered (transit, highway,rail,etc.) includes:

1) Network Geometry: A description of the interconnections and segments of the network representing the transportation system under consideration.

2) Network Parameter: The required network segment parameters (impedances) that allow for the selection of routes in an assignment through the network under study. Examples of the impedance are travel time, distance, travel cost, or, a combination of these.

3) Interchange Value: The trip unit to be loaded onto the transportation network through the assignment process. Examples of the interchange are vehicles, persons, or tons of cargo.

The traffic assignment process consists of loads on each of the segments of the transportation network. These would be 24-hour vehicular highway traffic volumes, peak hour transit volumes, or yearly volumes of freight flow. There are two major steps included in the traffic assignment process.

1) The determination of the assignment routes through the network.

2) The allocation and accumulation of travel (O-D trips) on the links along the assignment routes.

The first step is a critical one if one realizes that there are thousands of possible alternate routes between each pair of zones even in a network with moderate size. The second step has its focus on the algorithm that determines the allocation of trips among different routes. In addition, the second step records the accumulation of trips to individual facility segments (9). Dickey et al. (5) described that travel times, costs, comfort, and levels of service are the factors that lead people to choose one route over another. Travel times are used almost exclusively in all modes of route choice or trip assignment, due to the relative ease by which travel times as opposed to the other three variables, can be measured. In addition, these four variables are interrelated to some degree, so that one can often be used to represent the whole group.

2.2.1 CLASSIFICATION OF TRAFFIC ASSIGNMENT

There are two big groups for an algorithm for assigning vehicles on the paths from origins to destinations.

1) All-or-nothing assignment, in which all trips are assigned to the least cost path between each origin and each destination, regardless of the available

capacity on the path.

2) Capacity restrained assignment, in which trips may be assigned to more than one path between each origin and each destination in order to prevent over-saturation on links within the network. The cost function is a function of volume.

Of the two assignment approach, the capacity-restraint assignment is most useful in allocating trips in urban transportation networks, but for inter-city planning, where peak-period congestion on the links is of less concern, non - capacitated assignment models generally provide satisfactory results (25). However, the capacity-restraint assignment method is applied to the congested urban networks.

There are two generic capacity-restraint assignment models, which are iterative assignments and incremental assignment. The heuristic equilibrium assignment includes repetitive all-or-nothing assignment in which the travel times resulting from the previous assignment are used in the current iteration. However,it is necessary a countless iteration to reach the equilibrium state for repetitive assignment, therefore, a new form of the algorithm was adopted by the U.S.Federal Highway Administration. The modified capacity restraint algorithm used weights of 0.75 and 0.25 for averaging process. The incremental assignment for attaining the user-equilibrium solution assigns a portion of the origin-destination matrix at each iteration. The travel times are then updated and an additional portion of the O-D matrix is loaded onto the network. In this manner, the general shape of the link performance functions can be traced with the successive assignment.

These three capacity-constraint methods explained above are all heuristic methods for attaining the user-equilibrium solution. The heuristic methods discussed thus far may not converge to the equilibrium solution. However,using a convex(nonlinear) objective function and a linear constraint set, the equilibrium U-E program could be suitably solved since the direct-finding step can be executed quite efficiently. One more existing traffic assignment model is stochastic User Equilibrium. This model assumes that the motorists' perception of travel time is random. This model generalizes the all-or-nothing network loading mechanism. Stochastic network loading models are a special case of discrete choice models. To apply these models, the probability distribution function of the perceived travel time on each path has to be known so that the path choice probability can be calculated.

2.2.2 Traffic Assignment Method

2.2.2.1 All - or - Nothing Algorithm

In the all-or-nothing assignment method the trip interchange volumes are assigned to the minimum path tree independent of the traffic capacities of the links that constitute the minimum path tree (16). The process of executing an all-or-nothing assignment consists of two basic steps:

1. The application of a shortest route algorithm to identify the minimum independence routes between each centroid pair.
2. The loading of the trips between each centroid pair onto the shortest route

connecting them.

There are two ideas to perform this algorithm. One is the skim tree method which is a diagram illustrating the minimum paths between an origin node and all possible destination nodes, and the other one is a minimum path algorithm which means that a logical set of rules is used to find the shortest path through a complex network.

The advantage of this method is that it is easy to understand and apply. Also an all-or-nothing algorithm is suitable enough to be applied to the rural network which does not have that many congested links. However, the repetitive all-or-nothing method falls short at providing a congestion output among different iterations. The modified repetitive all-or-nothing assignment is criticized for not incorporating a human element in route selection, although it does provide a better convergent result. This algorithm takes a crucial role in the capacity constraint method and user equilibrium. Especially, U.E could not be processed without an all-or-nothing method based on the shortest path algorithm.

2.2.2.2 Dial's Algorithm (Stochastic User Equilibrium)

Due to the effects of trip volumes on travel time and the tripmaker's non-deterministic choice function on route selection, All-or-Nothing assignment is known to contradict the actual trip behavior. Dial (4) introduced a few specifications to represent a stable model which yields realistic assignment.

1. The model should give all reasonable paths between a given origin and

destination a non-zero probability of use, while all unreasonable paths should be given a probability of zero.

2. All reasonable paths of equal travel time have to have an equal probability of use.
3. When there are two or more reasonable paths of unequal length, the shorter path should have the higher probability of use.
4. The model's user should have some control over the path division probabilities.
5. The assignment algorithm should not explicitly enumerate paths.

The algorithm by Dial offered immediate advantages over the "all-or-nothing" traffic assignment method in that it distributed trips to alternative reasonable paths in a way which is related to the length of these paths. In addition, the procedure required a modest additional computational effort when compared to the "all-or-nothing" assignment method (2).

This multipath model is one of probabilistic traffic assignment. The stochastic user equilibrium is reached when no traveler believes that his or her travel time can be improved by unilaterally changing routes. This algorithm can be called a generalized form of the deterministic network loading mechanism (all-or-nothing). The stochastic model focuses on the fact that each motorist on the whole network is assumed to use the route with the lowest perceived travel time. And the flows under stochastic network loading models are random variables. The output includes the means of these random variables

(37).

2.2.2.2.1 Implementation of Dial's Algorithm

Dial's algorithm effectively implements a logit route model at the network level. It is identified as the set of "efficient" paths connecting each O-D pair. The flows are assigned to these paths using logit formula with parameter θ . The "inefficient" paths would not be considered in the assignment. The execution of this algorithm is described below:

Step 0

1) Compute the minimum travel time from node r to all other nodes. Determine r(i) for each node i.
2) Compute the minimum travel time from each node i to node s. Determine s(i) for each node i.
3) Define θi as the set of downstream nodes of all links leaving node i.
4) Define τi as the set of upstream nodes of all links arriving at node i.
5) For each link i → j compute the "link likelihood", L (i → j), where

$$L(i \to j) - \exp^{r(j) - r(i) - t(i \to j)} \quad \textit{if } r(i) < r(j),\ s(i) > s(j)$$

$$L(i \to j) - 0, \qquad \textit{Otherwise}$$

In this expression t (i → j) is the measured travel time on link i → j.

Step 1

1) consider nodes in ascending order of r(i), starting with origin node r.

2) For each node i, calculate the "link weight" w(i→j), for each $j \subset \theta i$ (for each link emanating from i), where

$$W(i \to j) = L(i \to j) \qquad \textit{if } i = r \textit{ (if node is the origin)}$$

$$W(i \to j) = L(i \to j) \sum_{m \subset \tau i} W(m \to i) \qquad \textit{otherwise}$$

3) When the destination node (s) is reached, this step is completed.

Step 2

1) Consider nodes is ascending order of s(j), starting with destination (s).

2) When each node j is considered, compute the link flow x(i → j) for each $i \subset \tau i$ (for each link entering j) as follows:

$$X(i \to j) = q_{rs} W(i \to j) / \sum_{m \subset \tau i} W(m \to j) \quad \textit{for } j = s \textit{ (if node is the destination)}$$

$$X(i \rightarrow j) = [\sum_{m \subset \theta_j} (x_j \rightarrow m)]\, W(i \rightarrow j) \,/\, \sum_{m \subset \tau_j} W(m \rightarrow j) \text{ for all other links } i \rightarrow j$$

2.2.2.2.2 Deficiency of Dial's Algorithm

As has been reported by Florian and Fox (10), the traffic flow patterns in Dial's assignment method are not reasonable when routes overlap heavily and it is sensitive to network presentation. The flaw of Dial's model is that the of the probabilities of choosing one route is independent of the probability of selecting other available alternatives in what has been called "independence of irrelevant alternative axiom". Provided the routes are slightly related to each other, Dial's algorithm would have no problems executing the assignment procedure. The shortcoming of the algorithm could be approached in the following way. Dial's flow allocation formula is not sensitive to network topology, but sensitive only to route length and to motorist's ability to accurately perceive travel time. If there are three routes between the origin and the destination, 1 / 3 of the total production are assigned from the origin on each route regardless of overlapping on the links between the other two routes in Dial's algorithm.

Another shortcoming of the algorithm is to determine the θ value in the formula. θ is a non-positive parameter of diversion. When it equals zero, all the paths are chosen, when it equals negative infinity only the shortest paths are selected. All intermediate values are possibilities (35). However, even if the use of the parameter can extend the flexibility of the model, the additional values are needed to adjust and refine θ in the model calibration procedure. And the nature of the link likelihood function might also result in some disadvantages in the use of the model. The use of θ value is a very important factor in choosing the routes. The decrease of the value can divert trips from the shortest route to longest one. Thus, the assignment process depends on the single value of θ utilized in the network (25). Schneider (36) summarized that the main objection to the model is that it does not lend itself to flow-dependent assignment, which means that Dial's algorithm ignores the congestion phenomenon of the links on the network.

2.2.2.2.3 Tobin's Model

Dial's model has been modified to overcome the deficiency that Dial's multipath approach does not consider congestion effects. The more general path selection models which based on a simple model of tripmakers' likelihood of perceiving differences in alternative routes, has been introduced in the new model. The model was calibrated through the study of motorists' behavior on a limited set of trips rather than through the study of origin and destination patterns and link flows on a large network. In most traffic assignment models, travel time is regarded as the most critical factor. However, for several reasons, the tripmaker could not generally identify the minimum time path. It has been hypothesized by the new model that each individual trip-maker places different values on such criteria as the number of stops, variability in trip time, scenery, road quality, etc. The above values will lead the trip-maker to choose a route which is not the minimum. The longer the trip, the more the travel time of a chosen route may deviate from the travel time of a minimum time path (41). The Dial's likelihood function generated some unlikely assignments because the diversion to alternative routes is a function of the difference relative to the total length. For example, the trips allocated between paths A and B when the travel times are 28 and 32 respectively are the same as when the travel times are 1 and 5 respectively. In the first case, it makes sense that tripmakers may not perceive a difference between A and B. However, in the second case, it does not seem likely that a trip maker would select B over A. Those explanations sufficiently demonstrate why Dial's model has a difficulty in the real network system.

Tobin (41) has introduced "turn likelihood assignment", in which the route choice is dependent on the number of routes connected to the first destination from the origin. But this shows that the volume on the same route is different from each other corresponding to the starting point. The other new concept by Tobin is to test the sensitivity to small changes in the network. The Tobin's model also indicates that the small link connected from the origin makes the big difference in assigning volume on the network. But Tobin's model also has a better computational efficiency than the All-or-Nothing assignment method.

2.2.2.3 User Equilibrium Assignment(U-E)

The idea of user equilibrium is that for each O-D pair, the travel time on all used paths is less than or equal to the travel time that would be experienced by a simple vehicle on any unused path. In order to solve the problem of a congested network with the user equilibrium, five kinds of data have been given (37) :

1. A graph presentation of the urban transportation network.
2. The associated link performance functions.
3. An origin-destination matrix.
4. A shortest path algorithm
5. An algorithm for assigning vehicles to the paths between O-D.

The interaction between the routes chosen through all O-D pairs and the performance functions on all the network links determines the equilibrium flows and corresponding travel times throughout the network.

It is reasonable to be assumed that every motorist will try to minimize his or her own travel time where traveling from origin to destination. This does not mean that all vehicles between each origin and destination pair should be assigned to a single path. The travel time on each link varies with the flow. A stable condition is reached only when no traveler can improve his or her travel time by unilaterally changing routes. This is the characterization of the user equilibrium. These equilibrium conditions were built by Wardrop and are commonly referred to as the Wardrop conditions. The U-E also assumes that motorists have full information (they know the travel time on every possible route) and that they consistently make the correct decisions regarding route choice. Further, it assumes that all individuals are identical in their behavior.

2.2.2.3.1 Algorithm for User Equilibrium Assignment

In order to illustrate this assignment algorithm, three simple links between origin and destination are used. This algorithm will be discussed in detail later.

1. Compute the travel time on each link Sa(Va) that corresponds to the flow Va in the current solution;
2. Trace minimum path trees from each origin to all destinations by using the travel times from step 1;
3. Assign all trips from each origin to each destination to the minimum path (all-nothing assignment); call this link loading (Wa);
4. Combine the current solution (Va) and the new assignment (Wa) to obtain a new current solution (V'a) by using a value alpha selected through a one-dimensional search, so as to minimize the following objective function;

$$\text{Minimize} \quad Z - \sum \int_{0}^{V'_a} S_a(X)dx$$

5. If the solution has converged sufficiently, stop; otherwise return to step 1.

2.2.2.3.2 Comparison between Dial's model and U-E model

The U-E model assumed that users make consistently perfect decisions, this is not true, but it does not matter for heavily congested networks. Thus, the user equilibrium is good enough to be applied for heavily congested networks. On the other hand, motorists' inaccurate and / or distorted perception of link travel costs may play a more dominant role than congestion effects for lightly congested networks, therefore, Dial's model is useful in cases where congestion is not an important factor.

CHAPTER 3.0

MASSVAC Review

The MASS eVACuation (MASSVAC) model developed by A.G.Hobeika (15) is a computer model designed to simulate traffic flow under disaster conditions. The inputs to the model are area demographic characteristics, network geometry, link parameter, and risk factor. The model outputs include network clearance times, best evacuation routes by zone, optimal shelter locations, sites of possible traffic bottlenecks, and proper traffic management strategies to alleviate them.

3.1 MASSVAC Under Natural Disasters

The model has two levels of analysis, a macroscopic level and a microscopic level. The macroscopic level simulates the evacuation process on the highway network by looking at major road network arteries as a complete and integrated system. The model considers the shelter to be within the threatened community as well as outside it. Risk factors are determined for each route and consequently influence the traffic assignment on the routes. The model provides an estimation of the maximum network evacuation time under different disaster intensity levels, including severe traffic condition combinations.

At the microscopic level, the model deals only with a selected sub-network of the total network under consideration. Traffic assignment are carried on the links instead of the route. This microscopic model has been developed to determine the importance of certain traffic management strategies in solving the congestion at special sites (18).

3.1.1 Description of the Model

The MASSVAC model is composed of three interrelated modules as described below:

1. Community and disaster type characteristics module - which defines the threatened community type, the natural disaster characteristics and severity, and the hazard area boundaries and sectors.
2. Population Characteristics module - in which the spacial distribution of permanent/transient population and their demographic characteristics are identified, and then internally used to develop the trip generation.
3. Highway Network Evacuation Module - which employs highway network topology, public disaster response behavior, and traffic assignment algorithm to simulate traffic flow. It then yields the output statistics in terms of evacuation times, evacuation routes, and the location of traffic bottlenecks.

The model uses Dijkstra's algorithm to build the shortest path tree within the highway network. Dial's algorithm is then used to assign trips onto efficient paths. The combination of Dijkstra's and Dial's algorithms reduces the shortest path finding time and loads the traffic on the highway network with a probabilistic approach. An S-shape curve is used as the time distribution of the percent of evacuees leaving vulnerable areas. The Larporte regression linear model for mixed vehicles modified by Kalevela is used to determine the dissipation flow of the traffic on freeways and expressways (20).

3.1.2 Model Application

This MASSVAC model disaster has been applied to Virginia Beach City in order to determine the evacuation times under flood / hurricane situations. Different hurricane intensity levels and various scenarios were considered. The network evacuation times under each case were obtained and also the bottlenecks and major problem spots on the network were identified.

The following factors greatly affect the overall evacuation times :

1. Size of the population to be evacuated which in turn is dependent upon hurricane intensity and seasonal variation.
2. Location and number of shelters - whether they are located in areas with limited highway access or not.
3. Capacity of the roads being used as the evacuation paths - roads with low capacity increase the evacuation times.
4. Loading period - or -the time available for evacuating the people from the

threatened areas.

5. Specific traffic operational strategies used for alleviating the congested links and for reducing the travel time on the congested links such as the use of shoulders on freeways and expressways, one - way flow operation, and changing the signal to flashing operation on intersections with low volume on the side streets.

In general, the model proved to be sensitive to population size, highway characteristics, in terms of the capabilities of roads and availability of shelters in threatened areas, and specific traffic operational strategies. It provided reasonable and reliable estimates of evacuation times.

3.1.3 Heuristic Traffic Assignment Model - IEDSS

A heuristic traffic assignment method has been developed to simulate the traffic flow of a transportation network at a real-time speed. This new assignment method employs Dial's efficient-path concept to load trips. But trips has been apportioned to routes in terms of the available highway capacities, travel speeds, and travel times of the links forming those routes instead of using the assignment likelihood as a weight to load trips. The purpose of the assignment is to maximize the utilization of link capacity and to achieve an equilibrium assignment in terms of total network travel time. As a result of this algorithm, the efficiency of an assignment execution has been improved and a real-time traffic assignment model has been developed.

The Integrated Evacuation Decision Support System (IEDSS, 17) is a computer system which has the evacuation planning model and the evacuation operation model to treat evacuation problems. The IEDSS uses computer graphics to prepare input and interpret output. It helps a decision maker analyze the evacuation system, review evacuation plans, and issue an evacuation order at a proper time. Users of the IEDSS can work on evacuation problems in a friendly interactive visual environment.

3.1.4 Transportation Evacuation Decision Support System(TEDSS)

TEDSS is designed to help the user to

1. Prepare, analyze, and evaluate through plans before the arrival of disasters. This function is important for the areas under the shadow of potential disasters in particular.
2. Assign evacuation trips during the disaster threatening period. Working as a real-time problem solver is a significant advantage of this system when compared with other similar-function programs, to predict potential bottlenecks, and suggest possible solutions to those problems.
3. Search best paths for emergency vehicles, such as ambulances, police cars, fire engines, and special squads, to rush to the people in need of safety after the disaster. The task of re- building the harmed city is

currently proceeding.

4. Keep all data of the whole procedure so that the user may trace the works done in each stage.

All of these functions are performed with graphical display and interactive dialogues so that it is very user friendly.

TEDSS prepares the input data for all analysis programs so that there is no need for users to worry about the format of the data; TEDSS also runs the analysis module automatically and interprets the results immediately so the users do not have to get any technical knowledge of the operation of those models (22).

3.2 TEDSS Application to Nuclear Power Station Evacuation Planning

The concept of TEDSS under natural disasters has been applied to simulate evacuations around nuclear power plants. This evacuation problem is different from natural disasters by a viewpoint that the purpose of the evacuation is to escape the EPZ to safe places.

The Transportation Evacuation Decision Support System (TEDSS 3.0) has been newly developed for the evacuation plans for the Surry and the North Anna nuclear power stations in Virginia. This useful package for simulation helps the users in preparing a detailed evacuation master plan for different scenarios including such components as evacuation times, the efficient routes, traffic bottlenecks, and the location of evacuees. The system is also able to develop and evaluate Traffic Management Strategies such as signal operation, shoulder use, and one-way operation to improve evacuation situation by reducing the network clearance time and the number of bottlenecks. TEDSS 3.0 has colorful graphic display to make the model user friendly, flexible, quick to maintain, and easy to modify in case of the change of the scenarios. The 'Q-BASIC' language has been used for the TEDSS 3.0 package, while MASSVAC 3.0 has been written in 'FORTRAN' language.

3.2.1 Methodology of the Model

This is divided into two phases:

PHASE I - Highway data preparation and estimation of trip production for different evacuation scenarios from the socioeconomic and geometric data pertaining to the evacuation areas.

PHASE II - The trip production and digitized highway network data compiled in Phase I were used as input to MASSVAC - special purpose computer model, to estimate evacuation times and to evaluate highway network performance under evacuation.

3.2.2 Description of Simulation

TEDSS is an iterative, macroscopic, and operational evacuation model. The key processes in each iteration of evacuation analysis are trip production, trip distribution, trip assignment, determination of evacuation routes, determination of network clearance times, and identification of congested links and recording the clock time at which the links were over-capacitated. The evacuation time is calculated as:

Evacuation time = Clock time + Travel time on the longest path

where, clock time = simulation interval * iteration number

The largest value of this evacuation time computed during the simulation is regarded as Network Clearance Time for the network.

3.2.3 Characteristics in the MASSVAC

MASSVAC is a part of TEDSS. TEDSS is composed of INPUT process, SIMULATION process, and OUTPUT process. The role of MASSVAC is to simulate the model to obtain the outputs with respect to the given inputs. This model is outstanding in considering trip distribution and trip assignment. For Dial's assignment method, the model has an O-D pair in the trip distribution step. Geometric destination elimination techniques has been made to find feasible destinations for an origin. The purpose of the techniques is that the direction of all vehicles lead away from the power station. There are three similar methods for geometric destination elimination techniques which are the quadrant, the three quadrant, and the half-space methods. The other three ideas of destination selection has been introduced in the trip distribution process. Those methods are based on travel time.

In order to consider user's behavior, traffic assignment should be incorporated into trip distribution, because Dial's assignment cannot account for a user perception variance that depends on the length of the path to be travelled (18). Therefore, determination of destination and routes to destination is both distribution and assignment problem.

3.2.4 Model Application

The model has been applied to the Surry and North Anna nuclear power stations in Virginia. The evacuation times were intended to be obtained in terms of various scenarios. The worst case has been proven to be a quickly escalating disaster on a weekday during the peak hour. The other option considered is weather conditions which are normal and adverse. The Surry area is more applicable to the model than the North Anna area, because needs to be tested in an urban area. The result would explicitly represent the validation of the model, because there are more links and production from the origin in the Surry area. The Surry area also has a large population.

CHAPTER 4.0

Theoretical Aspects of the Model

4.1. Introduction

In this chapter, the developed model is explained in detail. A few algorithms and techniques form the core part of the program. The traffic assignment method, the shortest path algorithm, and the trip distribution techniques for the assignment are described here.

An earlier computer simulation model designed for the analysis and evaluation of the evacuation processes for nuclear power station accident has been modified and calibrated by including the user equilibrium traffic assignment method. Concepts and algorithms for the model have been borrowed from the previous model. However, the model has been enhanced by incorporating user equilibrium assignment principle, and some new algorithms.

The user equilibrium assignment principle has different assumptions from Dial's algorithm. By incorporating the user equilibrium algorithm with the model, it can be realized that which assignment method is more efficient and appropriate to solve the evacuation problem. Through the evacuation time, the number of congested link, and run time from the two assignment models, the advantages and disadvantages of the models in solving the evacuation problems will be discussed.

The input for the evacuation model are the network data and the trip production at each origin node. The network data include information on the beginning node , ending node, and link characteristics. The main results of the simulation are the network clearance time and identification of congested links. The comparison of evacuation time (equal to network clearance time) from this model and the old model are presented in chapter 6. The flow chart in Figure 4.1 depicts the implementation of the model.

4.2 Trip Distribution

Evacuation situation needs a regular Urban Transportation Planning System (UTPS) to establish the model. Trip distribution is the second step of the whole procedure. This procedure must be modified according to the assignment method chosen and the characteristics of the network studied. In earlier version of MASSVAC model, trip distribution models were developed in various point of view, which are travel time and the topology of the network. However, those techniques in the previous MASSVAC are not used for the user equilibrium.

Thus, the trip distribution has been developed only for the user equilibrium (U-E) assignment method in MASSVAC 4.0. The U-E traffic assignment method is not based on the paths between origin and destination, but the links on the network. All the destinations are connected to the terminal destination by dummy links which have infinite

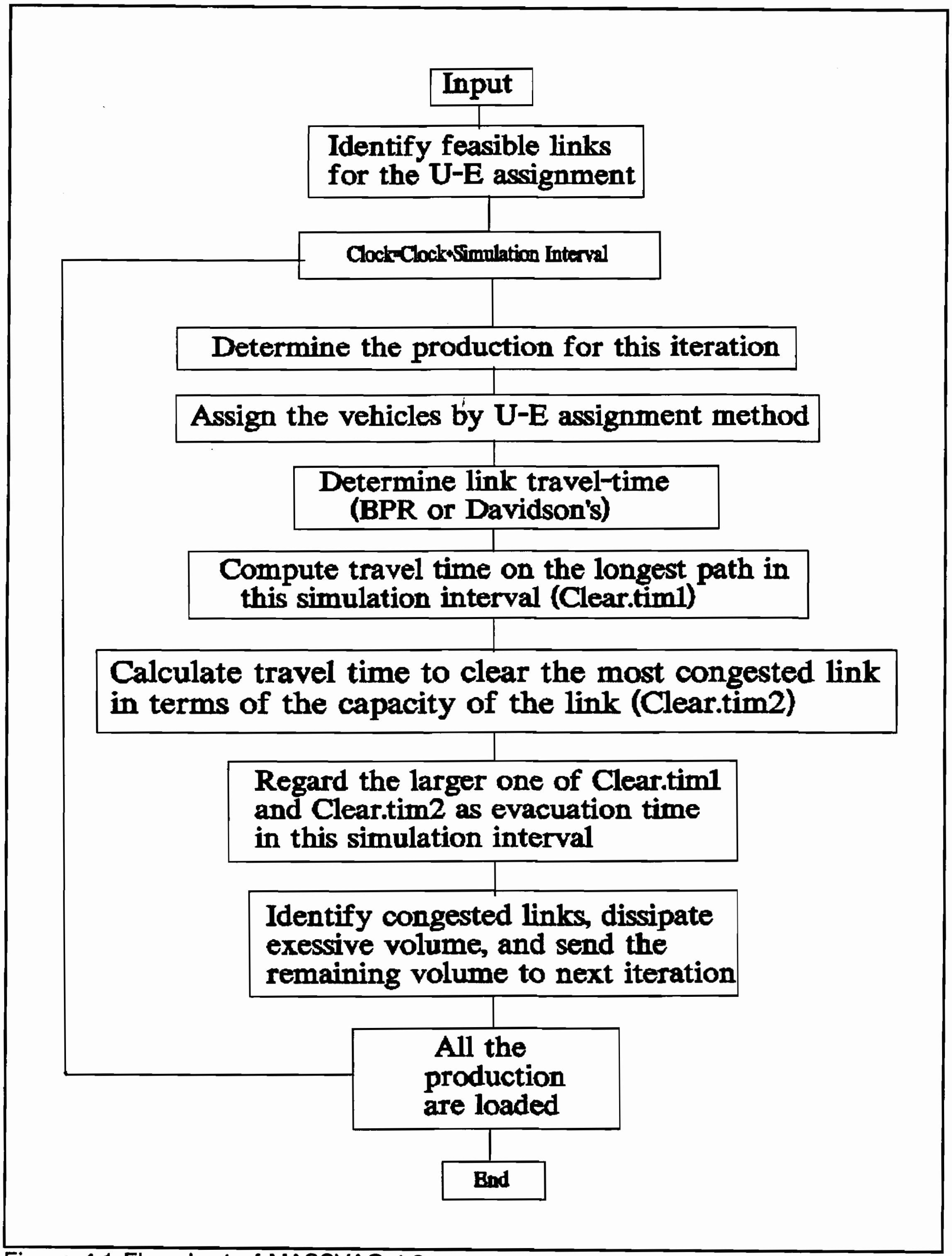

Figure 4.1 Flowchart of MASSVAC 4.0

capacities and zero travel times to traverse. Hence, it is not necessary to make an O-D pair in the distribution process, because all productions from each origin are supposed to travel toward the terminal destination. There is a restriction in travelling from origin to destination. If a nuclear accident takes place in the area, anybody would not be allowed to traverse parts of the network closer to the nuclear plant than where they started out from. It has been assumed that all vehicles in the network are supposed to travel toward the closest exit point just outside the emergency planning zones (EPZ). From here on, this basic concept will be considered applicable.

4.2.1 Trip Distribution for Dial's Assignment Model

Socioeconomic and highway data have been already established in the trip generation step before the trip distribution. In general, the trip distribution process determines the volume of the traffic between the origin and destination pair in a highway network, which determines where the produced volume will go and how they will be divided among the zones in the whole network.

The origins are nodes in the Emergency Planning Zones connected to the highway network with dummy links, and destinations are highway points lying just outside the periphery of the EPZ. The origins represent the centroids of the zones into which the area has been partitioned. The center of the nuclear power plant is fixed during the evacuation.

In Dial's model, feasible destinations for each origin in EPZs was identified using three logical geometric elimination techniques (20). The techniques limit the area to find out the feasible destinations for each origin. Thus, each origin would obtain several destinations to exit in the limited areas, but not all the destinations in the area. The goal of these geometric techniques is to eliminate the unfeasible destinations based on the orientation of the destinations with respect to the central point of the evacuation area. The idea of this geometric method was devised to overcome the drawback of the travel time impedance method, which can result in unrealistically long evacuation routes, over estimating Network Clearance Time much greater than the travel time in reality. In other words, the travel time impedance method distributes and assign trips to each destination without considering the distance from origin to destination. Of course, the main objective of the geometric elimination methods is to prevent the vehicles from going into the center point of the evacuation area.

The geometric methods have been conducted by using label-correcting shortest path algorithm. However, the destination chosen these geometric method do not reflect the actual travel times. Hence another selection process (based on travel time) has been added to the model for obtaining destinations based on closeness of the destinations from each origin. Even though it has some disadvantages, it has been included to give the user some options to take. The destination selection method must be repeated at the beginning of each iteration because the travel times on the links change with respect to the assigned volume in every iteration of the whole program. The simplest way for the destination selection method is the closest point exit technique which intends to find a path from each origin to destination. This may be also applicable for the all-or-nothing assignment method.

To avoid causing excess congestion in a specific link, other ways of modeling the user choice have also been built in addition to the closest exit point method. These are 'the three closest point method' and 'the 1.5 times method'. Due to many destinations chosen from the two other methods, the produced volume from each origin may be distributed into several routes between the origin and the destination. The general steps of the selection methods are:

1. For each origin, establish shortest path labels to all destinations in the network.
2. Choose the destination points by one of the available methods. (one, three, or more)
3. Apply the travel time impedance model to distribute the trips from the origin to the selected destinations. The travel time impedance method applied in MASSVAC distributes trips in inverse proportion of travel times (shortest path labels) in the particular time interval.

4.2.2. Trip Distribution for U-E Assignment

As described before, it is not necessary to make any O-D pairs because all destinations are supposed to aggregate at the terminal destination node. In other words, there are only one destination for all the origins on the entire network. For the first time, a model has been designed to use all links in the EPZ. But the assumption that a motorist does not want to drive towards the central point of the evacuation area has to be taken care of in the model, which means all links can not be utilized for the traffic assignment. Hence, the program must eliminate all the links directed towards the nuclear power plant.

This was initially attempted by a 'distance model'. By this model the distance between the central point of the area (site of accident) and the beginning node of a link (d1) was compared with the distance between the central point and ending node of the link (d2) in 'distance model (a)' of Figure 4.1. If the latter distance is longer than the former, the link will be used for the next procedure, else the link would be discarded. But in a situation as depicted by 'distance model (b)' of figure 4.1, d2 is greater than d1 even when the distance of the automobile from the central point is less than d1 at central point along the path traversed. To overcome this deficiency, a model based on the angle subtended at the beginning node by the link vector and the origin vector was considered as in 'theta model' of the Figure 4.1. This was called the ' θ model'. The dot product of the two vectors is given by

$$\vec{A} \bullet \vec{B} = |\vec{A}| * |\vec{B}| * \cos\theta$$

Thus the cosine of the angle θ is given by

$$\cos\theta = (\vec{A} \bullet \vec{B}) / (|\vec{A}| * |\vec{B}|)$$

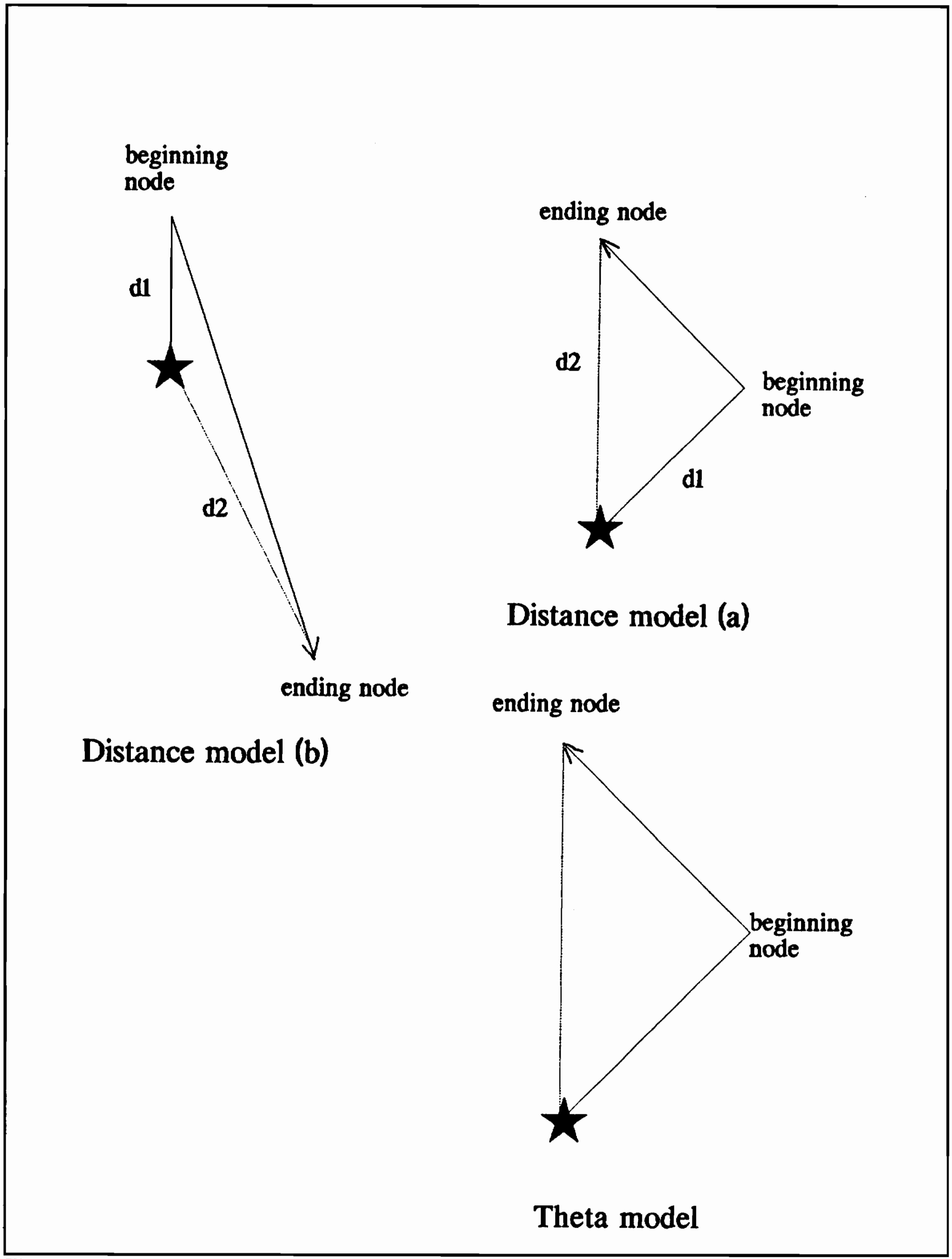

Figure 4.2 Distance model and Theta model

If θ is greater than or equal to 90 degrees, link A would be taken for the assignment. It is obvious that the links above $\theta = 90$ degrees will have the direction leading away from the center of the evacuation area. The angle between the two vectors can be calibrated appropriately by the user corresponding to the situation. In the area near the location of the reactor, the angle between the two vectors should be maintained at, at least $\theta = 45$, to satisfy the unique assumption for nuclear related accident. This option appears very reasonable except for the case in which there are no links emanating from a beginning node with $\theta > 45$, thus coming to a dead node. The number of links originating from each origin node has a big effect on the whole process. Some special cases of application of this θ model for specific cases have been discussed in chapter 6.

4.3 Shortest Path Algorithm

The shortest path algorithm is an essential step for conducting traffic assignment. The purpose of this algorithm is to find the shortest route(s) between origins and destinations.

This algorithm influences the computer run time of the program. Whenever the assignment process is executed, the shortest path algorithm must be recalled for the main step of the whole program. Usually, in almost all assignment processes, the algorithm consumes considerable computer time. The computer run time spent in the shortest path computation accounts for about 80 % of the total computer time required to obtain the solution (11). Therefore, it is recognized that the complete program running time is predominantly dependent on the role of the shortest path algorithm employed. Thus, an efficient shortest path algorithm will reduce the computer run time, as well as improve the efficiency of the assignment method.

Gallo and Pallottino (12) have classified the shortest path algorithms into a shortest - first search algorithm and a list - search algorithm depending on their input structure. The shortest - first search algorithm has been initiated by Dijkstra (6). Dijkstra's algorithm has been divided into two methods, which are the label-setting method and the label-correcting method. They assume that a real value label is related to each element, and that the element to be selected is the minimum label element. The algorithm is processed by adding a new element, removing the minimum value element, and correcting the label of an element. This algorithm is based on the lowest-first search. The list-search algorithm is executed by using the several types of lists which are used to implement the breath-first search strategy or the depth-first search strategy. Thus, this algorithm is easy to be applied to any assignment and has a relatively low storage requirement. It is also not influenced by the sign of the arc lengths.

Dijkstra's algorithm, used for the earlier version of MASSVAC model (20) concerning nuclear accidents, needs a sorting program to implement the shortest path algorithm. In order to avoid sorting, which is time consuming, the list-search algorithm has been chosen to use for the U-E model (13).

The objective of the shortest path algorithm in U-E model is to find the shortest route from origins to destination in the network during the assignment procedure. Of course, the algorithm could be used to get the most efficient evacuation time after the assignment step. Hillier and Liebermann (13) have defined that the procedure of the algorithm to start from the origin, identifying the shortest route to each of the nodes of the network in the ascending order of the shortest distance from the origin, and obtaining the solution of the problem when the destination node is reached. The procedure follows the following outlines:

Step 1: Input for nth iteration: Solved nodes (origin and the nodes along the shortest path) obtained from (n-1) iteration. The solved nodes and the origin are the nodes which build the shortest route from the origin. The others are unsolved nodes.

Step 2: Candidate for nth nearest node: One or more unsolved nodes that are connected directly to each of the solved nodes become a candidate.

Step 3: Calculation of nth nearest node: Total distance between the solved nodes and its candidates are computed by adding the shortest route distance from the origin to the solved nodes. The candidate with the shortest distance is the nth nearest node. Two or more nearest nodes supply other solved nodes for the next iteration. Total distance from the origin to the nth nearest node represent the shortest route by that iteration.

4.4 User Equilibrium Applying the Convex Combination Method

The convex combination method has been used to establish the user equilibrium program. The method includes a convex nonlinear objective function and a linear constraint set (37). The algorithm implements the all-or-nothing assignment method in terms of the time spent on the links. In other words, all the vehicles from the origin node are assigned on each link of the route that are obtained by using the shortest path algorithm. Then, the steps are repeated with a new parameter (α) in the iteration. The procedure of the algorithm is described in the following steps:

Step 1: Search for the shortest path from each origin to the terminal node, and assign the production from the origin, on all links of the path (X). The objective function in terms of X and the volume remaining from the previous iteration are calculated here. As described before, the value of the objective function (obj 1) is the cumulative addition of the area below the link performance curve for all the links in the network studied, not including the links that no the volume assigned. Set iteration N=1.

Step 2: Update the travel time on the links using a link performance function.

Step 3: Perform the all-or-nothing assignment method based on the updated time value, which means that the productions are assigned on each link of the path from each origin to the terminal node (Y).

Step 4: Find α in terms of X, Y, and the residual volume from the previous iteration of the whole program. The line search for the optimal move is performed with the bisection method which is supposed to be explained in the next chapter.

Step 5: Update the X value according to α, X, and Y.

$$X_a^{n+1} = X_a^n + \alpha * (Y_a^n - X_a^n)$$

for all the links

Step 6: Get a new objective function (obj 2) based on the new α

$$Obj\ 2 = \min \sum_a \int_0^{X_a^n + \alpha * (Y_a^n - X_a^n)} t_a(w)\, dw$$

where n= no. of iteration

a= no. of links

Step 7: Compare the two objective functions (obj1 and obj2) each from step 0 and step 5. If the criterion, |(obj1-obj2)/obj1| is greater than 0.01 (assumed value), replace obj 1 by obj 2, and then go to step 2, not step 1. If the criterion is satisfied with the assumed value, link volume becomes the addition of X value and the residual volume from the previous iteration. During the user equilibrium assignment process the residual volume is not involved in the procedure. The remaining volume is used only for getting the objective function.

4.5 Loading Rate

The loading rate on the network at each simulation interval is discussed in this section. The following relationship is used:

Ratio = 1 / (1 + exp [-z* (clock - half loading time)])

where z = the slope of the 's-shape' curve

The z parameter represents the response of public to disaster as shown in Figure 4.3. First, The 'steep curve (z=0.04)' shows the quick response resulting from late warning by the officials. The public would have little time available for evacuation in this first case. The next 'flat curve (z=0.022)' indicates the predominant response obtained from the states responses by individuals involved in actual evacuation. The 'lazy curve (z=0.01)' represents availability of more time for evacuation. The disaster in this shape is presumed to be forecasted a few hours before the accident happens. The z value can be calibrated according to the disaster type, and the z value will be affected by the amount of traffic volume in the network. If the traffic on the network is light, smoother and normal curve will be suitable for the evacuation process. The half loading times are assumed to be 2, 4, and 8 hours for steep, flat, and lazy curves respectively, which means that the loading periods are 4, 8, and 16 hours. These periods has been used to

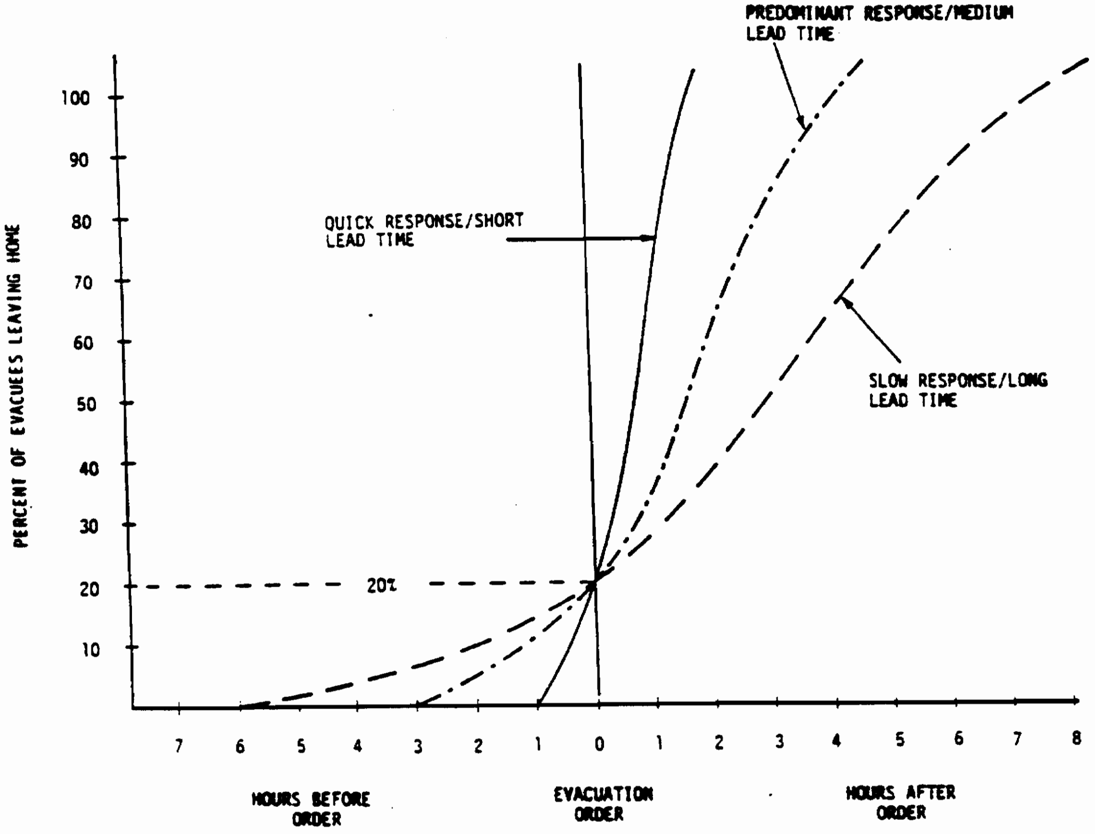

Figure 4.3 Evacuation Response Curves

MASSVAC evacuation model in the natural disaster. For Nuclear reactor related accidents, one hour has been used as the half loading time. The clock represents the cumulative simulation interval. For example, the clock time would be 60 minutes at fourth iteration. If the simulation interval is 15 minutes and the half loading time is 60 minutes, the simulation will be stopped in 8 iterations. Generally, the simulation interval ranges from 15 to 60 minutes depending on the total volume to be loaded on the network. The cumulative percentage of trips from any origin, to be loaded at each simulation interval can be easily calculated by dividing the cumulative volume loaded in the iteration by the total production from the origin. The percentage of trips at each interval is obtained by subtracting the cumulative percentage of the previous iteration from the present cumulative percentage (18).

The MASSVAC evacuation model adopts an the unique loading concept to avoid loading excessive volume on a link. If the link volume in the current iteration exceeds twice the link capacity and the link is directly connected from an origin or the link is only a segment of a path from the origin to the destination, the loading process for the origin will be stopped temporarily. New productions will not be added to the over-loaded link, if the remaining on the link is as much as two times link capacity. However, by this unique procedure, the simulation process may not terminate at the eighth iteration. The simulation will be continued for further iterations. The more number of iterations result in excessive run time, even though the actual evacuation time is not affected by the number of iterations. To overcome this drawback, and 85 % of the total production are loaded for all the origins, as for the above procedure, and the remaining 15 % will be loaded at one time. This will terminate the simulation process without excessive number of iterations.

4.6 Link performance functions

Travel times on each link is often revised during the simulation process. Travel time is influenced by traffic volume, link length, capacity, free flow travel time (travel time at zero flow), and link type. The travel time can be obtained from the link performance function. The link performance curve shows that the travel time sharply increases as the volume approaches link capacity. The capacity is defined as the maximum flow that can go through a transportation facility (37). For higher values of flow, reasonable travel time cannot be obtained since it is not possible to observe it. A heuristic method is employed to get the travel time for the link when flows are greater than the capacity.

4.6.1 Bureau of Public Roads function (BPR, 1)

The BPR function assumes that the travel time on each link is dependent upon the traffic volume, the capacity, and free flow travel time which can be expressed by the following formula.

$$T_Q = T_0 (1 + \alpha * (\frac{Q}{Q_{\max}})^{\beta})$$

where,

Tq = travel time at flow q

$T0$ = 'zero-flow' travel time

$Qmax$ = capacity

Q = traffic flow

α , β = parameters

α and β are model parameters $\alpha = 0.15$ and $\beta = 4.0$ are generally used.

This equation is used in many cases because the travel times are independent of the link types. The travel time is controlled only by the capacity of the link. However, this function may not be utilized if the volume to capacity ratio is greater than 4.

4.6.2 Davidson's model

Davidson (3) has developed a link performance function in terms of traffic volume and facility type. This model is asymptotic to a capacity flow based on queuing theory consideration, while BPR curves are not asymptotic to any capacity value (21). This model is given by

$$Tq = T0 * (1 -(1 - \tau)*(Q / Q\,max)) / (1 - (Q / Q\,max))$$

where Tq = travel time at traffic flow Q

T0 = zero - flow travel time

Q = traffic flow (vehicle/hour)

Q max = saturation flow (vehicle/hour)

τ = level-of-service parameter (LOS)

Data collected for travel time and volume from Toronto study were employed to find the equations for each link type. The link types are classified into five categories. The link volume and the link distance are the independent values to obtain travel time on the link. In addition to the five equations, the dummy links should be considered in calculation of evacuation time. These dummy links have infinite capacity and zero distance and zero travel time. The equations will be discussed in detail in the next chapter.

4.6.3 Empirical method

In this method, the above two models discussed are modified to incorporate rational lower and upper limits for travel time estimates. It is not possible to measure the real travel time beyond the capacity of the link. Thus, some empirical rules has been devised to find the travel time over the capacity scenario (20).

4.6.3.1 Upper Limit

If V/C (volume/capacity) is less than 1, select the minimum value of, 6 times free flow time, and the travel times obtained from the previous two equations.

If V/C is between 1 and 1.5, select the minimum value of, 8 times free flow time, and the travel times obtained from the previous two equations.

If V/C is greater than 1.5, select the minimum value of, 10 times free flow time, and the travel time obtained from the previous two equations.

4.6.3.2 Lower Limit

The travel time on a link is assumed to be greater than the free flow time. This is important since free flow speed is a user-controlled variable.

4.7 Evacuation Time

Evacuation time is the time required to clear all vehicles in the whole network. This evacuation time is updated in each iteration, and compared with the evacuation time of the previous iteration. The larger one will be taken as the evacuation time, expressed by the relationship in the equation below. After loading all the productions out of the origins or in the final iteration, the evacuation time is announced as the overall network clearance time. The evacuation time (clear.tim 1) in each simulation interval is calculated by,

'Clear.tim 1 = current clock time + travel time on the longest path'

The travel time on the longest path indicates that it is to choose the sum of the travel times consumed on its all member links along the longest path selected, out of the routes used for the traffic assignment. In the U-E traffic assignment this value would be considered in a different way. If a few routes are selected from an origin to the destination by the U-E traffic assignment, all the routes would have the same travel times. Thus, the term of the longest path could be replaced by the shortest path, because travel time on both the longest path and shortest path are the same.

The evacuation time is affected by the number of links on the network, the capacity of each link, and the total production from each origin. First, it is natural that if there exists many links in the network, the travel time will have a large value. However, a small number of links on the whole network might prevent the efficient processing of the traffic assignment step. Especially the number of the links directly connected from the origin is a very important factor influencing the evacuation time. If there are more links emanating from an origin, the production out of that origin can be distributed among these links to different path. This may result in less congestion in the network,and consequently reduce the evacuation time in each iteration. If only a single link connects the origin to the network, this can result in heavy congestion thereby preventing the loading in the next iteration. Second, by increase in the capacity of a link influences a reduction in the evacuation time. The travel time is not directly affected by the increase in the capacity. The increase effect a decrease in residual volume in end of each iteration. This means that there is not much volume remaining from the last iteration. The reduced amount of residual volume is expected to influence the total network clearance time. The capacity of a link can be calibrated by applying Transportation System

Management (TSM) measures, which will be discussed later. Thirdly, if a large production is supposed to be evacuated from a network with links with low capacity during a short period, the travel times (evacuation times) will be very large. When an evacuation problem is considered, the total production from the origin has to be reviewed carefully to avoid such a problem.

Another way to consider the evacuation time is devised in a different approach. After each iteration, it is assumed that the total time required to clear the whole network is replaced by the clearance time for the most congested link. If the volume on the most congested link is cleared in the simulation period, it is assumed that all the people in the EPZ are evacuated. For the implementation of this method, it is assumed that as many vehicles as the capacity of the link can be dissipated in the simulation interval. Until the remaining volume is completely cleared on the netowk, the iteration to dissipate the volume will be continued. After discharging all the volume from the most congested link, the travel time from the ending node of the most congested link to the terminal destination node will be added to the tentative evacuation time (number of iterations multiplied by simulation interval). This addition of travel time is developed to make the model more realistic. Thus, the overall evacuation time (clear.tim 2) for the remaining volume is calculated by

'clear.tim 2'= current clock time + time required to clear the volume on the most congested link + travel time between the ending node of the most congested link and the terminal destination node'

The above evacuation time (clear.tim 2) is compared to the evacuation time (clear.tim 1) obtained by the shortest path algorithm. The larger of the two is called the overall network clearance time for each iteration. After loading all the vehicles from the origin, the evacuation time is called the total network clearance time for the whole network.

4.8 Traffic Management Strategies

In order to control the traffic flow and direct vehicles from the origins to the destinations, operational strategies have been adopted in the earlier version of MASSVAC. These strategies were developed to control the congested links and the traffic bottlenecks in the network. Control measures have been classified as regular and special operational strategies (18). Regular control measures are related to the computer model and traffic control devices. Special control measures are controlled by the police and the personnel from the city government. Only the Regular operational strategies will be discussed here. The strategies are slightly modified for this research. They can be summarized as follows.

1. The destinations are assumed to have infinite capacity. Thus, a terminal destination is built and connected by dummy roads from each one of the real destinations. The terminal destination node also has infinite capacity. It is devised to enhance efficiency of the U-E assignment process. By building the dummy roads between destinations and the terminal destination, there is only one destination for each origin during the entire simulation. Besides, the model is designed to restrict the flow between two destinations. The travel from one

destination to another destination is worthless to evacuate people safely and efficiently. If a person arrives at a destination node, he / she does not have to proceed towards any other node except the terminal destination point.

2. To avoid the overloading of a specific link directly emanating from each origin, the capacity of the link must be increased. Thus, the direction of a link connected feeding into the origin is changed to one-way (away from the origin), because the link will not be used during the whole procedure. As a result of this change, a link from the origin will have twice as much as the original capacity. In order words, the idea is to change the direction of the unusable links to improve utility, thus two-way links become one-way links with doubled capacity. The same concept has been applied to the destination. The links emanating from the destination will not also be used during the simulation. Thus, these links can be added to the capacity of the oppositely directed links. Thus, these increased capacity links are expected to help reducing the number of congested links in the network.

3. If the link type is expressway or freeway, shoulder can be used for evacuation process. Thus, this option is set, the number of lanes on the link is increased by 1. These strategies will also help in reducing the evacuation time and improving the link performance.

CHAPTER 5.0

Technical Aspects of the Model (MASSVAC 4.0)

The source code of this new version of MASSVAC has been completely programmed using 'Q-BASIC' language, while FORTRAN was used for the earlier version of MASSVAC. The MASSVAC 4.0 is now written in the same language as TEDSS 3.0, which is the decision support system that includes MASSVAC evacuation model. Addition of MASSVAC 4.0 to TEDSS 3.0 will be an enhancement.

New algorithms and subroutines were necessary to enhance the efficiency of the program with respect to run time. Some other algorithms from the previous MASSVAC have also been modified to fit the user equilibrium assignment. These additions and modifications resulted in this new model whose subroutines are discussed in this section. Every subroutine is described in a verbal and algorithmic statement. The statement would assist to understand the role and the significance of each process. The structure of the new model and the relationship of subroutines are illustrated in Figure 5.1.

The most remarkable revision in MASSVAC 4.0 is that the assignment subroutine, which is called 'EQ.ANA,' has been introduced for the assignment step, instead of Dial's and all-or-nothing methods used in the previous MASSVAVC. A few additional subroutines have been added to execute the main traffic assignment algorithm. The U-E assignment is a convergent algorithm requiring a excessive computational effort. Thus, subroutine 'EQ.ANA' will be executed iteratively to obtain the optimized value. The objective of the U-E assignment method is to assign the trips from an origin to any destination node along equal travel time routes. The equilibrium procedure is designed to happen at the same time, not origin by origin. It indicates that the equilibrium state for an origin is not affected by another origin. After the equilibrium process, the entire network will be on the equilibrium state for each origin. A new shortest path algorithm, different from label correcting method used in the previous MASSVAC, is employed for the U-E assignment algorithm. Because the shortest path algorithm used in MASSVAC 4.0 does not require sorting, it takes less time to execute. The trip distribution subroutine in MASSVAC 3.0, which is called 'ODTAB', is a very important subroutine for the Dial's assignment algorithm. However, the O-D pair-making subroutine is not generated in MASSVAC 4.0. The trip distribution step is executed in subroutine 'INPUT', which reads data, instead of in the subroutine 'ODTAB'. When the travel time is going to be computed on the link, link performance functions are recalled to obtain the values. The BPR model and Davidson's model are included in the subroutine of link performance function ('LINK.TIME'). The results from those two models will be compared and discussed in chapter 6. The volume that can be dissipated per each interval are calculated considering the capacity of a link, jam capacity, and a few other equations with respect to each link type. The remaining volumes are stored for the next iteration to be regarded as link volume.

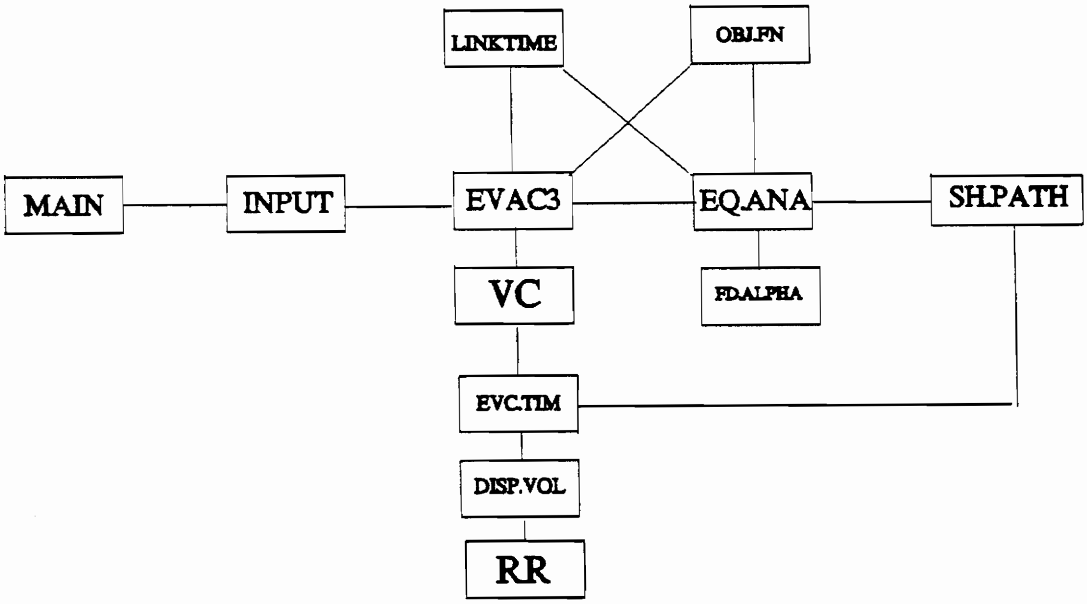

Figure 5.1 Organization of Subroutines in MASSVAC 4.0

5.1 Main program of MASSVAC 4.0

This is a major program in MASSVAC 4.0 which calls subroutine 'INPUT' and subroutine 'EVAC3'. The dimension of the variables which will be used in other several subroutines during the simulation are assigned here. The terminal destination node is given by 10000.

5.2 'INPUT' subroutine

The task of this subroutine is to gather input data and initialize program variables for the entire simulation.

1. Input: A loop begins to process by reading all the links in the network. This input subroutine comprises of eight sections. The various network data that are input during this step are:

   a. the largest origin node number ('n.org.end') and the largest destination node number ('n.des.end'). The nodes are assumed to be counted on destinations first, followed by the origin, and then the rest of the intersection nodes. Thus, destinations are numbered consecutively from 1 to 'ndes.end'. Origins addresses begin with 1 + 'n.des.end', until reaching 'n.org.end'. The total number of origins and destinations on the network can be easily obtained from the above description. For example, the total origins number is calculated by subtracting 'n.des.end' from 'n.org.end'. The total number of destination is given by 'n.des.end' itself.

b. simulation interval time and the half loading time.

c. link attributes - beginning node - the cartesian coordinates of the beginning node, ending node - the cartesian coordinates of the ending node, link length (mile), capacity per lane (vehicle/hour/lane), number of lanes, free-flow speed (miles/hour),link type (1 = isolated signalized, 2 = two-way stop sign, 3 = four stop sign, 4 = expressway, 5 = dummy), and the cartesian coordinates of central point. The links are numbered in the order in which they are read.

2. Link elimination :

a. Make the two vectors in terms of ending node, beginning node, central node. One vector starting from beginning node of a link to ending node of the link, the other vector from beginning node of a link to the central node.

b. build the dot product to check the validity of a link for the entire simulation. Compute the absolute value of two vectors.

c. The angle between two vectors is calculated as :

$$\cos\theta = \text{vec.pro} / \text{absol}$$

where vec.pro = dot product of two vectors absol = multiplication of the absolute values of two vectors

The θ value can be user defined. This value could be calibrated appropriate to the situation.

3. The link attributes have also been named in this subroutine for the next procedure:

a. beginning node = 'n.from(i)', ending node = 'n.to(i)'

b. link distance = 'ldist(i)', number of lane = 'n.lane(i)'

c. link distance / free-flow speed = 't.ff(i)'

d. capacity * number of lanes = 'capa(i)'

e. link type = 'ltype(i)'

f. 'nact' is the total number of links which will be used for the whole simulation. The distance of a link is assumed to be 0.00001 to prevent overflow for Davidson's model. If all the links in the EPZ are read, the loop is stopped at this point.

4. Generate dummy links from each destination to the terminal node (10000). In other words, each destination node is regarded as n.from(i) and the terminal node is n.from(i) for all the destinations. The other attributes of the newly-made dummy links are : t.ff(nact) = 0 ; capa(nact) = 9999 (infinity); ldist(nact) = 0; n.lane(nact) = 1.

5. compute jam density, jam capacity (18).

jam density = n.lane * (5280 / 18)

jam capacity = 9999. (for ldist(nact) = 0)

= (4/27) * jam density * free flow speed (for ldist(nact) > 0)

6. The flow from one destination to the other destination is restricted to travel by making the link distance infinity and by considering link capacity on zero. This is prevents its actual use. Thus, the vehicles, which arrive at the real destination node, are supposed to travel automatically towards the terminal destination (10000).

7. If a link is directed from a destination node or directed to an origin node, the links will not be used through the entire simulation. Thus, the capacity of the link is added to the oppositely directed roads. As a result of the addition, the opposite link, which is directed to the destination node from the origin node, has twice the capacity as the value before it was added. This step is to implement the transportation system management.

8. Input production (number of vehicles) from each origin in the EPZ.

5.3 *'EVAC3' subroutine*

This subroutine forms the main part of simulation in MASSVAC 4.0. It is proceeded by calling several subroutines. Each execution of this subroutine 'evac3' indicates an iteration of the whole program. The detailed functions of this subroutine are described below:

1. The number of iterations and the clock times are updated in the beginning part of the subroutine. The 'z' value in the loading rate equation is given by

   $$z = \log (49) / \text{half loading time}$$

   This z value is between the z value in the steep curve and the z value in the smooth curve. The net production per iteration is calculated according to the loading ratio and total production from the origin at this point.
2. Call 'eq.ana' subroutine to implement the user equilibrium traffic assignment algorithm. The volume coming from each origin is assigned the link based on the U-E algorithm.
3. Call 'link.time' or 'link.time2' subroutines to revise the travel time on each link in terms of the volume assigned to the link.
4. Call 'vc' subroutine to compute the travel time based on empirical method.
5. Call 'ev.time' subroutine to obtain the evacuation time in each iteration. The minimum value out of 'link.time' and 'vc' is regarded as the real travel time on the link for the simulation. The total travel times along a route are emerged from adding the travel time on each link through the path. Any path for a specific origin to the destination have the same travel time. Thus, the travel time along any path can be taken for obtaining evacuation time in the simulation interval. A maximum value among all the travel times along the path from an origin to the terminal

destination in the network is added to the clock time. Thus, the updated evacuation time is generated at this step, which is called as 'clear.tim1'.

6. Decide whether a link is congested or not before calling 'disp.vol' subroutine. If a link has twice the volume of the capacity of the link, the flag 'nden' is 2. Else if the volume is between the capacity and the doubled capacity, 'nden' is 1. Else 'nden' is 0. And then, call 'disp.vol' subroutine to compute the output which can be dissipated in each simulation interval. If the link volume exceeds the output, the residual volume is stored on the link for the next iteration to be considered as link volume.

7. Call 'rr' subroutine to compute the travel time separately for the remaining volume. Since this remaining volume did not go through the user equilibrium step, the volume should be considered for the evacuation time separately. Another evacuation time called 'clear.tim2' introduced by subroutine 'rr'. And then, the two values (clear.tim1 and clear.tim2) are compared to each other. The larger one will be regarded as the evacuation time in the current simulation interval. If the evacuation time in this current interval is smaller than the value obtained from the previous iteration, the evacuation time in the current iteration is replaced by the evacuation time from the previous iteration.

8. If the iteration number is less than 8 (or if all the vehicles are loaded), then go to step 1. Else go to the next step.

9. Take the maximum value among the evacuation times from each iteration as the network clearance time. However, if there are some remaining volumes after the 8th iteration, the volume must also be considered for the evacuation time

computation. To implement this, call 'rr' subroutine to find the evacuation time for the remaining volume. The evacuation time from 'rr' subroutine and the network clearance time are compared to select the larger one. The value from the comparison is the total network clearance time for the EPZ.

5.4 'EQ.ANA' subroutine

The U-E assignment algorithm is implemented by this subroutine. This traffic assignment method is based on (37). It is modified for the computer program :

1. If a link volume is congested, exceeding twice the capacity in the beginning part of this subroutine, the link cannot carry any volume in the current iteration.
2. If the only path from the origin in the EPZ is congested, then loading of trips from the origin will be stopped temporarily. The 'hold' variable is created to record the vehicles (production from origin) blocked in the current iteration, and the quantity is added to the next iteration. In case the production is blocked at a specific origin, there is no vehicles available for this subroutine. The link volume on the congested link are dissipated as much as the capacity of the congested link without equilibrium process. The detailed sequence of the steps in the algorithm are :

0) Call 'sh.path' subroutine to find the shortest path from each origin to the terminal

destination. Assign the production (X) from the origin on each link along the shortest path in terms of the free flow time. And obtain the objective function with respect to the production in current iteration and the residual volume from the previous iteration. On the other hand, the process to block the production from the origin is implemented here.

1) Call 'link.time' subroutine to update the travel time for the production and the residual volume. Based on the updated travel time, assign the production (Y) on the links through the shortest path algorithm.

2) Call 'fd.alpha' subroutine to obtain the α value in terms of X, Y, and the residual volume from the previous iteration. The objective function2 is computed while 'fd.alpha' subroutine is executing. And then, the volume 'X' are updated by using equation from the step 5 in the section 4.4. In order to check out whether the 'X' value is optimized or not, the ratio of objective function1 to objective function2 is computed. If the criterion is satisfied with the assumed value (0.1), the process is stopped. Else, go to step 1, while the objective function 1 is replaced by the objective function2.

5.5 'FD.ALPHA' subroutine

This subroutine finds the 'α' value for the U-E assignment algorithm. It follows the bisection method.

1. Set alf1 = 0, alf2 = 0.5, alf3 = 1.0, small = 0.0003. start to find the optimized α value with iteration number = 1.
2. Set iteration = iteration + 1.

   Make a internal loop to find 'sum1' and 'sum2'. For the sum1, alpha is assumed to be (al2 - small). For the sum2, alpha is (al2 + small). The sum1 value is the objective function based on the alpha, X, Y, and the residual volume. The sum2 value is also objective function based on (al2 + small).
3. If sum2 is greater than sum1, the flag 'if1' is recorded zero. Also, al3 is replaced by al2, which is half the sum of al1 and al2. If sum2 is less than sum1, the flag 'if1' is recorded 1, al1 is replaced by al2, and al2 is set as half the sum of al2 and al3.
4. If iteration number is 10, go to the next step. Else, go to step 2.
5. Finally, the alpha value is calculated in terms of the flag 'if1' in this step. If 'if1' is 0, the alpha is equal to the half sum of al2 and al3. If 'if1' is 1, the alpha value is the half the sum of al1 an al2. The objective function2 will be the sum of the addition of sum1 and sum2 from the last iteration.

5.6 'LINK.TIME' subroutine

This subroutine computes the link travel time by using the Davidson's link performance model. Some equations developed by the model are based on facility type and traffic volume. These equations are used to determine travel times on a link during the U-E assignment procedure and after the assignment procedure in each iteration. The links in the EPZ are classified into 6 categories, denoting link travel time by link.time, and link length by ldist, and link volume by l.vol. Before computing the link travel time, the unit of the link volume should be changed from vehicles to vehicle / hour to be consistent with the unit of the capacity. The equations and logic used for each link type are as follows (20):

1. Link type 0 (rural signalized):

   if volume is greater than 750 vehicles/hour/lane (vph/lane),

   link.time = (-30.58 + 0.0458 * l.vol(i)) * ldist(i)

   else,

   link.time = (2.25 + 0.00077 * l.vol(i)) * ldist(i)

2. Link type 1 (urban signalized):

   if volume is greater than 750 vph/lane,

   link.time = (-30.58 + 0.0458 * l.vol(i)) * ldist(i)

   else,

   link.time = (0.191 + 0.00077 * l.vol(i)) * ldist(i)

3. Link type 2 (two-way stop sign)

   if volume is greater than 900 vph/lane,

   link.time = (-23.9804 + .029321 * l.vol(i)) * ldist(i)

   else,

   link.time = (1.9036 + 0.000561 *l.vol(i)) * ldist(i)

4. Link type 3 (four-way stop sign)

   if volume is greater than 1070 vph/lane,

   link.time = (-22.8769 + .02354 * l.vol(i)) * ldist(i)

   else,

   link.time = (1.66355 + 0.000605 * l.vol(i)) * ldist(i)

5. Link type 4 (expressway or freeway)

   if volume is greater than 1600 vph/lane,

   link.time = (-18.1668 + 0.012290 * l.vol(i)) * ldist(i)

   else

   link.time = (0.9644 + 0.000333 * l.vol(i)) *ldist(i)

6. Link type 5 (dummy) are keep constant to the value at free - flow.

The unit of link volume should be returned to original unit (vehicle) to execute other procedure in the end of the subroutine.

5.7 'LINK.TIME2' subroutine

This subroutine is also used to compute link travel time based on the travel time vs. volume curves developed by BPR function. This equation includes free flow time, link capacity, and link volume as independent variables to determine the link travel time. This subroutine is built to compare the result from BPR function to the result from Davidson's function. The equation is as follows:

link.time2 = t.ff(i) * (1 + 0.15 * (l.vol / capa(i)) ^4)

where t.ff(i)=free flow time of a link i (minute)

l.vol(i) = link volume of a link i(vehicle / hour)

capa(i) = capacity of a link i (vehicle / hour)

5.8 'OBJ.FN' subroutine

The task of this subroutine is to find the objective function for all the links in the network. It is based on Davidson's link performance function. Thus, the objective function is determined by the link volume and the link distance.

1. Set w = xvol(i) + vol(i) + alpha * (yvol(i) - xvol(i))

   where xvol(i) = 'X' value from 'eq.ana' subroutine.

   yvol(i) = 'Y' value from 'eq.ana' subroutine.

   vol(i) = residual volume from the previous iteration.
2. The unit of 'w' is changed from vehicle to vehicle/hour.
3. a. Link type 0

   if volume is greater than 750 vph/lane,

```
   obj.fn = (-30.58 * w + (.0485 / 2) * w ^2) * ldist(i) / 60
   else
   obj.fn = (1.25 * w + (.00077 / 2) * w ^ 2) * ldist(i) / 60
b. Link type 1
   if volume is greater than 750 vph /lane,
   obj.fn = (-30.58 * w + (.0458 / 2) * w ^ 2) * ldist(i) / 60
   else
   obj.fn = (3.191 * w + (.000772 /2) * w ^ 2) * ldist(i) / 60
c. Link type 2
   if volume is greater than 900 vph/lane,
   obj.fn = (-23.9804 * w + (.029321 /2) *w ^ 2) * ldist(i)/60
   else
   obj.fn = (1.9036 *w + (.000561 / 2) * w ^2) * ldist(i) / 60
d. Link type 3
   if volume is greater than 1070 vph/lane,
   obj.fn = (-22.8769 * w + (.02354 /2 ) *w ^2) * ldist(i) /60
   else
   obj.fn = (1.66355 * w + (.000605 /2) *w ^2) * ldist(i) / 60
e. Link type 4
   if volume is greater than 1600 vph/lane,
   obj.fn = (-18.1668 * w + (.01229 /2) * w ^2) * ldist(i) /60
   else
   obj.fn = (.9644 * w +(.000444 /2) * w ^2) * ldist(i) / 60
```

5.9 'OBJ.FN2' subroutine

In this subroutine, objective function is computed for BPR link performance function.

1. Use the same 'w' as in the 'obj.fn' subroutine.
2. obj.fn2 = (t.ff(i) / 60) * (w +.15 * (w^5 / capa(i)^4 / 5))

where t.ff(i) = free flow time or zero flow time of a link i

capa(i) = capacity of a link i

5.10 'SH.PATH' subroutine

This subroutine implements the shortest path algorithm for the traffic assignment step. This subroutine is frequently called in the 'eq.ana' subroutine and 'evc.tim' subroutine. The shortest route from the origin to the terminal destination is determine through this subroutine. The steps involved in this algorithm are as follows:

1. It starts from an origin to find the shortest route to the destination. Call 'chk.sol' subroutine to check out whether a node has already been contemplated to be the candidate for a origin (or node). If any node has not been considered for being a candidate in the previous iteration, the node can be the candidate for the origin

(or a node). The travel time between the origin and the candidate nodes are determined. This value should be cumulative travel time from the origin to the node.

2. After obtaining the travel time of all candidates for the origin, these travel time values are compared to one another to get the minimum travel time. The node with the minimum value is regarded as a solved node which will be the starting node such as the origin in the next iteration.
3. If there exists only one solved node after step 2, attempt to execute step 2 with the origin and the solved node. Of course, the origin may lose the role of the solved node in the middle of the execution.
4. If a solved node reaches the terminal destination node, the iteration will be stopped.
5. The shortest path from an origin to the terminal destination is determined by tracing the links from the terminal destination node for each origin. The output includes the node number passed, the link number used, the travel time on each link, and the cumulative travel time along the shortest path.

5.11 'CHK.SOL' subroutine

This subroutine determines whether a node can be used as a candidate or not. If a node is the ending node ('to-node') of the link between the solved nodes, the node cannot be a candidate for a node.

5.12 'DISP.VOL' subroutine

After link assignment, this subroutine is called from 'evac3' subroutine to dissipate volume assigned on links according to the capacity or jam capacity of the link or some formula. The remaining volume on the congested links are calculated by subtracting the dissipated volume (output) from the link volume. If there is no over-capacitated, they are assumed to serve all vehicles assigned. This subroutine is described below (18).

1. If the link is an expressway (ltype=4), then follow the larporte regression equation modified by Kalevela (19) to compute the vehicles which the link can discharge in each simulation interval.
   a. If the capacity of a link is less than 9999, the 'speed' is computed by dividing link distance into link travel time. Else, the 'speed' is 9999.
   b. The unit of the link volume is changed temporarily from vehicles to vehicle per hour. And density of the link is given by

density = lk.vol(i) / (speed * n.lane(i))

where lk.vol(i) = link volume of a link i

   c. If the density value is greater than 99, the output is given by (19)

output(i) = capa(i) * sim.int / 60

Else, kalvel = (74.3 * den) - (0.75 * den * den) output(i) = kalvel * n.lane(i) *sim.int / 60

d. If the capacity of a link is 9999, then the whole volume assigned are supposed to be dissipated in the period (output = link volume).

2. If the link type is not freeway or dummy roads, the following discharge logic is used:

   a. The unit of link volume should be changed temporarily in the same way (vehicle (veh) → vehicles per hour(vph)).

   b. If link volume is less than the capacity of the link, the amount of the output is determined by comparison between the capacity per simulation interval and jam capacity per simulation interval. The minimum one of two values is selected as the output of the link in that interval.

   c. If link volume is greater than the capacity of the link, the output must be considered carefully. First, find the congested link which exceeds the capacity of the link. And then scan all links sharing the 'to - node' of the congested node.

   d. If no more than 2 links (including the congested link itself) are determined to share the 'to - node' of the congested link, the dissipated volume in the period is set to the assigned link volume. In other words, it is denoted that all the volumes on the link can be discharged during the simulation interval.

   e. However, if 3 or more links are aggregated at the 'to - node' of the congested link, a formula is employed to determine vehicle discharged per lane. The formula is:

Va = (V1 / (V1 + V2)) * (1800 / 60) * sim.int

Va refers to the dissipated volume per simulation interval at direction A on major road 1 ; V1 is the practical maximum value at main road 1, and V2 is the maximum volume at minor road 2.

f. The unit of the link volume is changed from vph to vehicle before exiting the subroutine.

3. If the links are dummy type (ltype=5), then the link is assumed to dissipate all the vehicles on the link.

5.13 'VC' subroutine

This subroutine is programmed for comparing the link travel time from Davidson's function or BPR function to the link travel time from empirical methods. The subroutine is used to calculate the rational evacuation time for each simulation interval (20).

1. If volume/capacity (v/c) ratio is less than 1, the minimum value among link.time and 6 * free flow travel time will be chosen as the travel time for computing the evacuation time.
2. If v/c ratio is between 1 and 1.5, the minimum value among link.time and 8 * free flow travel time is the travel time on the link.
3. If v/c ratio is greater than 1.5, link time is compared to 10 * free.flow travel time

5.14 'EVC.TIM' subroutine

This subroutine is to determine the evacuation time for each simulation interval. First of all, the travel times from each origin to destinations along the paths are determined using 'sh.path' subroutine. And then, the maximum value among each path travel time for the origin is chosen. The evacuation time is obtained by adding the clock time to the maximum value. This computation takes place at the end of assignment step. Usually, the evacuation time out of the last iteration is considered the evacuation time for the entire network.

5.15 'RR' subroutine

This subroutine is developed to consider the remaining volume for evacuation time. In the middle of the simulation, the amount of the volume might remain by subtracting the output of the link from link volume. But the evacuation time after the assignment process does not count on this remaining volume on the congested link. Thus, this subroutine takes charge of computing evacuation time for the remaining volume. It is assumed that as much volume as the capacity of a link can be dissipated in each simulation interval. For example, if the remaining volume of the most congested link is 700 vehicles per simulation interval, and the capacity is 400 vehicles per simulation interval, the first 400 vehicles are dissipated in the simulation interval. The remaining 300 vehicles are dissipated in the next simulation interval. If the simulation interval is 15 minutes, the evacuation time is going to be 30 minutes. The network evacuation time is obtained by adding this value to the clock time. In order to obtain the more realistic evacuation time, the travel time from the ending node of the most congested link to the destination node would be included in the evacuation time obtained before. In other words, the network clearance time in each simulation interval is computed by adding these three terms,namely the clock time, the time spent to clear the remaining volume, and the travel time from the ending node of the most congested link in the interval to the destination. It is presumed, that if the most congested link is cleared, all the vehicles are evacuated from the EPZ. This subroutine is called to compare with the evacuation time from the subroutine 'vc' every simulation interval. Of course, the larger of the evacuation times from the two subroutines is the final network clearance time in the clock time. The network clearance time obtained in the current iteration is compared to the value from the previous iteration. The larger value is considered the network clearance time by the current clock time. After the final iteration of the whole program, it will be obtained the network clearance time for the total production on the network.

CHAPTER 6.0

Model Application and Evaluation

6.1 Introduction

The MASSVAC 4.0 evacuation model was applied to evaluate comprehensively, evacuation scenarios for the 5-mile and 10-mile Emergency Planning Zones (EPZs) of the Surry nuclear power station in Virginia.

The information and the data for the Surry area are taken from the earlier version of MASSVAC (20). The Surry nuclear power station is located on the southern shore of the James river, approximately 50 miles south east of Richmond, Virginia. The nuclear power plant is located in a rural area. However, the 10-mile Emergency Planning Zone (EPZ) used in the evacuation planning includes urban areas, which are Williamsburg, and Newport News. Surry county, James city county, York county, and Wight county lie within the 10-mile EPZ. The population of these four counties are considered in 10-mile evacuation plans for the Surry power station. The EPZ are subdivided into 24 Protective Action Zones (PAZs), as in Figure 6.1. Thirteen of these zones are located the south of

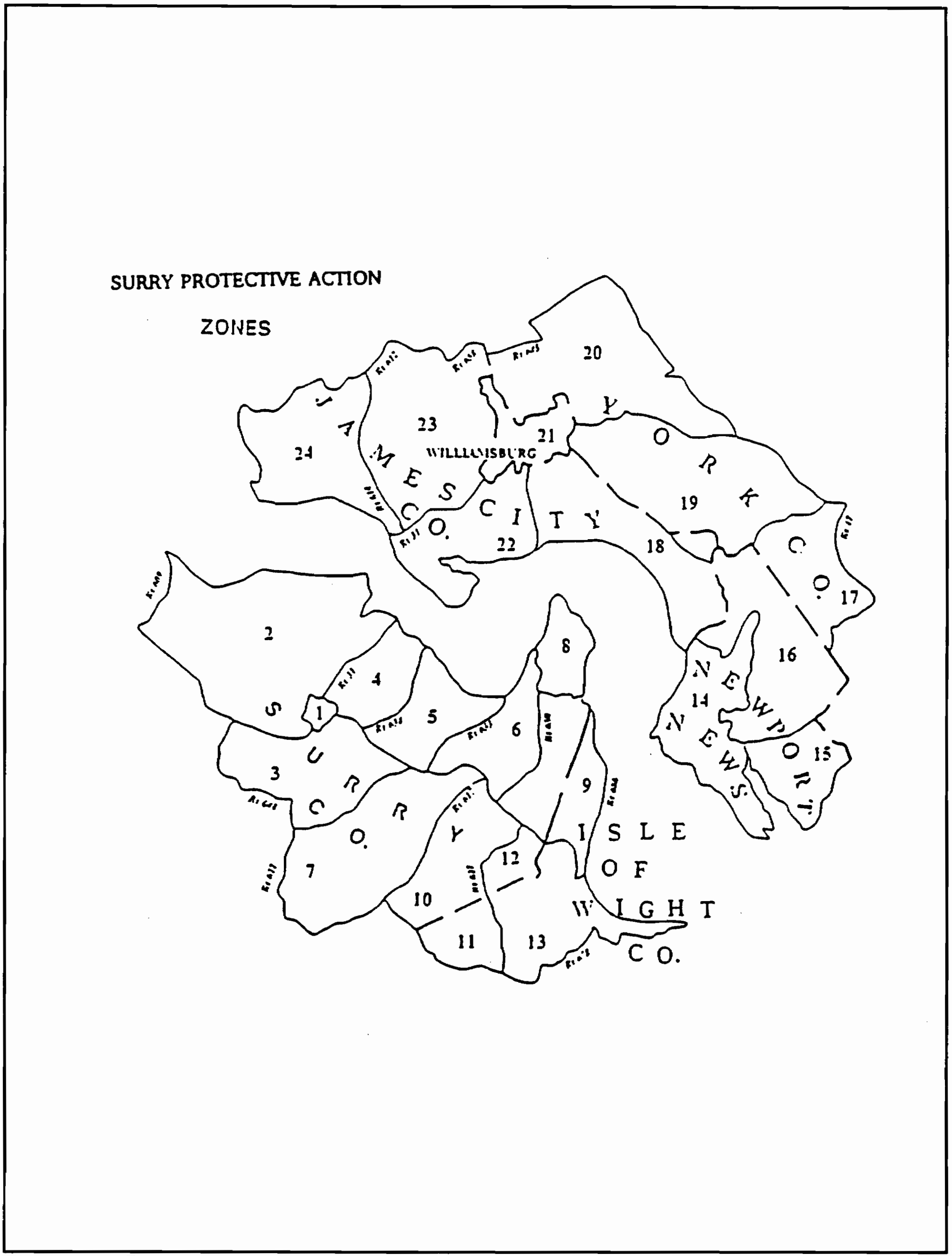

Figure 6.1 Protective Action Zones for Surry Power Station.

James river. The remaining zones lie north of the river. The population data are collected and allocated to each of these protective action zones. The MASSVAC 4.0 was applied to '5-mile' EPZ of the Surry nuclear power station, '10 mile region-north area', and '10 mile region-south area'. The worst case evacuation scenario is selected for the model. The combination of the worst case are as follows:

1. Weekday
2. Peak hour (i.e. summer season in Williamsburg area)
3. Quickly escalating disaster

Normal weather condition was used with the above conditions.

6.2 Calibration of MASSVAC 4.0

6.2.1 Simulation Interval and Half Loading Time

The simulation interval represents the time-period of the evacuation process, and determines the accuracy of the network performance. It is desirable to load the vehicles on the network at small time intervals. However, the simulation interval should be considered along with the half loading time. These values must be decided after reviewing the information of the study area. The values of two factors can be calibrated according to the situations. Fifteen and sixty minutes, respectively, are used for all the cases as the simulation interval and the half loading time in this research. The relationship between the two factors is:

$$\text{Number of iteration} = \frac{\text{half loading time}}{\text{simulation interval}} * 2$$

The half loading time is the time by which 50 % of the trip production is loaded on to the network. The loading procedure is independent of the network service in case of evacuation around nuclear power station, because all the people attempt to escape the vulnerable area as soon as possible. The logit curve formula was employed for the loading process in each iteration.

6.2.2 Elimination of Links

The ’θ model’ (Chapter 4) was used for the whole evacuation process in this research. In the application to ’5-mile region’ centered at the plant, the angle between the two vectors is maintained at ’$\theta = 45$’ to satisfy the unique assumption for the nuclear related accident. The θ value was suitable for the 5-mile area around the Surry power plant. As a result of applying the ’ θ model’ to the ’5-mile region’, 25 links were eliminated out of a total of 159 links (including dummy roads for the origin). The result indicates that most of the links on the network were used for the evacuation plan. Of course, the total number of links does not include the dummy links generated for the terminal destination. The θ value have to be calibrated according to the area studied.

In areas much farther from the center of the EPZs, all the links may be employed for the U-E assignment due to comparatively reduced risk in the area. The above concept was applied to the 10-mile evacuation plan. All the links in the region between 5 mile and 10 mile radii surrounding the center of the evacuation power station were utilized for the evacuation procedure. Of course, the 'θ model' with '$\theta = 45$' was applied to the area inside 5 mile border. Four hundred and twenty six links out of 437 links were used for the 10-mile north evacuation plan.

As the number of links are increased, a less congestion can be expected on the links. The reason is that more links would share the volume from each origin. It is one of the advantages in the user equilibrium assignment method.

6.2.3 Miscellaneous Features

The stopping criterion used in the U-E traffic assignment algorithm is based on the comparison of the two objective functions (obj.fn1 and obj.fn2 in chapter 4 and 5). If the ratio of the two objective functions is less than 0.1, it is assumed that all the links on the entire network are at equilibrium state. As pointed out by Sheffi (37), there is a difficulty in obtaining the optimal value for the U-E traffic assignment. As the value of the objective function is reduced to a sufficiently small value, the values seems to follow the 'zig-zag' shape, changing by a little amount around the exact optimized value. Then, if there is no truncation point, the program may be iterate forever. Therefore, a criterion needs to be established for terminating the algorithm.

6.3 Comparison of the Model (MASSVAC 4.0) with MASSVAC 3.0

The model using user equilibrium assignment algorithm is compared with the model using Dial's algorithm on several categories. The results of both models applied to several sample areas are investigated and discussed in detail. The advantages and the disadvantages of the two traffic assignment methods in the evacuation situation are also described in the following section.

The models were applied to the three different sample areas, which are '5-mile region' around the Surry nuclear power station, 10-mile region south of the James river, and 10-mile region- north of the James river. The '5-mile region' has 144 links and 13607 vehicles to be evacuated. The '10-mile region-south area' is composed of 182 links and 3966 vehicles. On the other hand, there exists much larger number of links and vehicles in the '10-mile region-north area' of the James river (420 links, 65600 vehicles).

The total clearance time (evacuation time) through the whole procedure, the number of congested links, and computer run times for the three areas with and without Transportation System Management(TSM) strategies are shown in table 6.1. For the '5-mile region', the evacuation times due to both traffic assignment models are almost the same for non-TSM case. The evacuation times in the '10-mile region-north area' do not show significant difference between the two models for non-TSM case. However, in the '10-mile region-south area' for non-TSM case, the vehicles are cleared out of the EPZ (Evacuation Planning Zones) faster in the U-E model than in the Dial's model. The reason is that more links were utilized in the U-E model for evacuating the vehicles from the evacuation areas. While 140 out of 182 links in the '10- mile south region area' were used for the whole simulation process in the U-E model, only 129 links were used in the Dial's model. The user equilibrium algorithm implements efficiently the role of the traffic assignment for evaluating the evacuation problems in the '10-mile region-south area'. But the evacuation time in Dial's model can be improved using different trip distribution options. The geometric destination elimination technique is used as a trip distribution method for the comparison with the U-E model. In order to improve the results of the two models, several TSM options (the operation of two way to one way, use of shoulder, flashing operation) were applied to each sample area. The clearance times are reduced considerably in the two assignment models. The increase in the link capacity by applying Transportation System Management (TSM) strategies for the '5-mile region' and the '10-mile north-region area' results in the improvement of the evacuation time and the reduction in the number of congested links in U-E model rather than in Dial's model. While the destination nodes to be considered for an origin are limited by trip distribution method in the Dial's model, all the destination nodes can be candidates for the destination for an origin in the U-E model. Therefore, if the vehicles go through the link emanating from the dummy road connected to the origin, then there are many links to choose from the network for evacuation route in the U-E model, because the vehicles are distributed widely. This is the reason why the U-E model is more influenced by TSM actions than Dial's model in determining the evacuation time. The travel times on all the paths between the origin and the destination in the Dial's model are various. Thus, the evacuation time, which is travel time on the longest path among all the paths, can be wrongly estimated. Of course, destination selection is restricted by 'θ model. The '10- mile region-south area' is not affected by TSM actions. Considering the evacuation times from the three sample areas, the number of vehicles in the network is the most influencing variable.

Next, the number of congested links is investigated for the two models. The table 6.1 shows that the number of congested links is reduced by applying TSM strategies to the two assignment models in the '5-mile region'. There are more congested links in Dial's model than in U-E model. This indicates that more links (64 out of 144 links) are utilized for the whole process in the Dial's model than in the U-E model, owing to the structure of the network, which most of the critical links are uni-directional. As a matter of fact, it is not necessary to use many links in the small area. Of course, the number of vehicles on the network should be considered carefully for evaluating the evacuation problem. The usage of many links result in over-estimated evacuation time in small area. Dial's algorithm shows the kind of the drawback in '5 mile region' application. The user equilibrium assignment algorithm seems to perform like All-or-Nothing assignment algorithm because the links are used in a small amount (32 out of 144 links). Thus, if there are many links in a small network, the U-E algorithm with TSM will implement efficiently the entire process. In '10-mile region-south area', there is no congested volume for the U-E model, which means that all the vehicles from the origin in each iteration are loaded without any remaining volume. Since the Dial's model used less number of links (129 links) in the '10-mile- region-south area' than the U-E model (140 links), Dial's model has few congested links. Like this '10-mile region-south area' case, if the number of links is comparatively small in the large network, the usage of links for the simulations are critical to improve the evacuation time. As the model uses more links, the evacuation time will be decreased in the '10-mile region south area' case. Generally, it may be announced that U-E algorithm for the evacuation implements better than Dial's algorithm in a point-of-view of the number of the congested links. On the other hand, computer run time in Dial's model increases in terms of the total number of the links on the network. The simulation time grows with sharp slope in the U-E model, because the U-E model has more iterations for finding the shortest path in the network. However, the run time is independent of the number of vehicles on the network. Even if an area has relatively smaller number of vehicles to be evacuated in the network with large number of links, the run time might be larger than expected. For example, the '5-mile region' has more vehicles (13607) in the network with fewer links (144) than the '10-mile region-south area' (3966 vehicles and 182 links). However, the run time in the '10-mile region-south area' is longer than that for in the '5-mile region'. The '386 DX' computer (25 MHz of clock speed) was used for running the model.

Table 6.2 shows the evacuation times in each iteration for different sample areas. The simulation in '10-mile region-south area' stopped after 8 iterations, which means that there is no residual volume in each iteration. The evacuation time increases with number of iterations. However, the '5-mile region' and '10-mile region-north area' show different trends. Since there are large number of vehicles to be evacuated in a short period, some volume remains after the assignment step in a certain iteration. The other reason for the remaining volume is that if the link directly emanating from the origin carries volume exceeding twice the capacity of the link, the loading is temporarily stopped temporarily in the next iteration. The fourth and fifth iterations in Dial's model indicate that, the volume from the origin, which affects the most on evacuation time, is stopped loading at the iteration. The phenomenon happens again at sixth and seventh iteration. The simulation process was stopped at ninth iteration for the '5-mile region', at eleventh iteration for the '10-mile region-north area'. The reason is that, as the vehicles from all the origins are loaded above 85 % of the total production, the remaining 15 % of the total production are loaded into the network at one time. That one-time loading can produce excessive volume from a specific origin. Table 6.3 is developed to compare the evacuation times between Davidson's and BPR link performance functions in the U-E model. The evacuation time using BPR function produced slightly faster evacuation times. Transportation System Management (TSM) options were applied to the U-E and Dial's models, as shown in table 6.4, to compare with the evacuation times in table 6.2. The evacuation times were considerably decreased by applying TSM in the '5 mile-region' and '10 mile region-north area' as indicated in table 6.2 and table 6.4. The changing trend of evacuation times in table 6.4 according to the number of iteration shows the same one as in table 6.2. The evacuation times for the two time functions (BPR and Davidson's) are compared in table 6.5. This table shows that BPR link performance function performs better than Davidson's function in the two models with TSM options. Tables 6.6 and table 6.7 represent the number of congested links in each iteration. Table 6.6 indicates the number of the congested links corresponding to the table 6.2. Since the large number of the vehicles are loaded at the fourth and fifth iterations (about 22 % in each), these iterations show the largest number of congested links. As expected, there is no congested link in the '10-mile region-south area'. The number of the congested links is reduced greatly including TSM actions into the model in the '5-mile region', as shown in table 6.7. In the '10-mile region-north area', the number of the congested links is not reduced much by applying TSM strategies to both models (Dial's and U-E model). This may be because too many vehicles are to be evacuated in a short period of time.

Table 6.1 Results of the Model using Davidson's Link Performance Function.

		5 - MILE		10 - MILE SOUTH		10 - MILE NORTH	
		U - E	DIAL'S	U - E	DIAL'S	U - E	DIAL'S
EVAC. TIME (MIN.)	NON-TMS	230.9	231.7	141.5	172.1	518.3	503.5
	TMS	152.8	172.2	141.5	172.1	363.9	431.0
NO. OF CONGESTED LINKS	NON-TMS	32	57	0	4	1099	1073
	TMS	7	13	0	4	987	975
RUN TIME	NON-TMS	1.5 MIN.	2.5 MIN.	7 MIN.	10 MIN.	2 HRS. AND 45 MIN.	20 MIN.

Table 6.2 Comparison of the Evacuation Time Between Dial's model and U-E model using Davidson's Function.

Iteration number	5 - MILE		10 - MILE SOUTH		10 - MILE NORTH	
	DIAL'S	U-E	DIAL'S	U-E	DIAL'S	U-E
1	46.8	27.8	67.7	36.8	155.1	93.9
2	71.8	47.9	82.7	52.2	187.5	103.1
3	97.1	77.1	98.3	68.7	296.9	174.4
4	100.3	88.2	115.8	85.4	296.9	287.6
5	115.3	172.5	134.1	100.4	296.9	407.6
6	173.0	172.8	145.2	113.6	344.9	437.5
7	173.0	172.8	157.3	127.3	344.9	445.6
8	173.0	172.8	172.1	141.5	347.7	445.6
9	231.7	230.9			349.5	478.4
10					349.5	478.4
11					503.5	518.3

Table 6.3 Comparison of the Evacuation Time Between Davidson's Function and BPR Function for U-E mdoel.

Itera-tion number	5 - MILE		10 - MILE SOUTH		10 - MILE NORTH	
	DAVID.	BPR	DAVID.	BPR	DAVID.	BPR
1	27.8	23.1	36.8	28.2	93.9	45.7
2	47.2	30.6	52.2	43.2	103.1	100.8
3	77.2	77.1	68.7	58.5	174.4	160.3
4	88.3	106.4	85.4	91.3	287.6	274.5
5	172.7	172.8	100.4	107.7	287.6	375.3
6	172.7	172.8	113.6	109.4	437.5	390.3
7	172.7	172.8	127.3	123.6	445.6	390.3
8	172.7	172.8	141.5	133.2	478.3	418.4
9	230.9	226.7			478.3	418.4
10					478.4	430.4
11					518.3	509.7

Table 6.4 Comparison of the Evacuation Time Between Dial's model and U-E model using Davidson's Function and applying TSM.

Iteration number	5 - MILE		10 - MILE NORTH	
	DIAL'S	U-E	DIAL'S	U-E
1	42.9	27.8	138.9	69.9
2	58.0	42.9	192.5	69.9
3	73.6	59.9	273.5	111.1
4	89.1	93.5	273.5	183.9
5	104.1	95.8	308.7	183.9
6	118.4	121.1	308.7	303.9
7	132.7	121.1	308.7	303.9
8	147.5	135.0	308.7	303.9
9	172.2	152.8	331.6	303.9
10			431.0	363.9

Table 6.5 Comparison of the Evacuation Time Between Davidson's Function and BPR Function for U-E Model Applying TSM.

Iteration number	5 - MILE		10 - MILE NORTH	
	DAVIDSON	B.P.R.	DAVIDSON	B.P.R.
1	27.8	23.1	69.9	47.9
2	42.9	38.1	69.9	78.4
3	59.9	60.8	111.1	157.6
4	93.5	90.0	183.9	157.6
5	95.8	120.0	183.9	201.1
6	121.1	120.0	303.9	205.2
7	121.1	135.0	303.9	273.7
8	135.0	135.0	303.9	273.7
9	152.8	139.8	303.9	273.7
10			363.9	356.8

Table 6.6 Comparison of Number of Congested Link Between Dial's Model and U-E model Using Davidson's Function.

Itera-tion number	5 - MILE		10 - MILE SOUTH		10 - MILE NORTH	
	DIAL'S	U-E	DIAL'S	U-E	DIAL'S	U-E
1	3	0	0	0	47	10
2	4	2	0	0	63	30
3	6	4	0	0	103	77
4	5	6	2	0	115	174
5	4	6	2	0	77	189
6	13	5	0	0	163	173
7	8	2	0	0	136	137
8	4	1	0	0	91	118
9	4	3			114	98
10					94	56
11					70	37

Table 6.7 Comparison of Number of Congested Link Between Dial's Model and U-E Model using Davidson's Function and applying TSM.

Iteration number	5 - MILE		10 - MILE NORTH	
	DIAL'S	U-E	DIAL'S	U-E
1	0	0	40	13
2	0	0	69	34
3	2	1	100	98
4	2	2	98	167
5	2	1	123	173
6	2	1	127	166
7	2	1	117	146
8	2	1	83	108
9	1	0	106	43
10			112	39

CHAPTER 7.0

Conclusions

The user equilibrium traffic assignment has been applied to MASSVAC evacuation model in this research. The new MASSVAC incorporated with the user equilibrium was implemented efficiently for evaluating the evacuation performance, as indicated by the tables 6.1 through 6.7. While the policies, which are trip distribution method, traffic assignment method, and Transportation System Management (TSM) strategies, are fixed in OPTIMIZATION process, the policies in SIMULATION process can be calibrated according to the situation and compared to each other. Thus, the new MASSVAC simulation model (MASSVAC 4.0) was compared with the earlier version of MASSVAC in terms of various scenarios.

The evacuation performance is predominantly dependent upon the production from the origin. Presence of large number of vehicles on the network creates congestion in more number of links, thus increases the evacuation time. However, the availability of links on the entire network is also a very important factor in MASSVAC 4.0. For areas studied, the volume from an origin was distributed effectively onto many branches in the user equilibrium assignment. The sharing of the volume by the links reduced the travel times for the whole procedure. But if the number of links is fewer such as in a rural area, the user equilibrium assignment performs like All - or - Nothing assignment. This is due to unavailability of many links for distribution of vehicles in a rural network. Dial's model used more numbers of links than the user equilibrium model in '5-mile region', which is a rural network. However, since the vehicles utilized unnecessarily more number of links in the Dial's model, the evacuation times were over-estimated.

In order to improve the evacuation performance, Transportation System Management (TSM) strategies were included into the model. These strategies includes one way operation of roads, shoulder-use and the signal-operation. The results of '5-mile region' and '10-mile north-region area' were improved by applying TSM options. The user equilibrium case shows better improvement in evacuation time and reduced number of congested links. On the other hand, the run time increases depending on the number of links in the whole network. The run time for the U-E model in '10 mile-north-region area' is high compared to Dial's model. However, the run time can be remarkably improved by applying to the better computer.

7.1 Recommendation for Further Study

Future improvement to the model can be made in technical areas. The earlier version of MASSVAC, which is written in 'FORTRAN' language, can be rewritten in the same language as MASSVAC 4.0. In addition, these simulation models need to be incorporated within Transportation Evacuation Decision Support System (TEDSS) in a single program, having the capability of displaying the results of each iteration of simulation graphically during real-time operation.

Another possible improvement is on efficiency of the model. The user equilibrium assignment process step is the most-time consuming part in MASSVAC 4.0 is the user equilibrium assignment process. The user equilibrium assignment is a convergent algorithm requiring considerable execution time for a large network. The main frame computer can be used for running the model for large networks. However, the shortest path algorithm can be implemented more efficiently to improve the execution time of the model. It is difficult to estimate the number of vehicles exactly held up within the network during a certain simulation interval, due to the macroscopic nature of the model. It is also hard to actually determine how many vehicles are cleared from the EPZ at the simulation interval, even though the loading volume are computed easily. In the case of the equilibrium assignment, it is difficult to identify the routes used by the vehicles being evacuated. To overcome these drawbacks, a dynamic traffic assignment method can be applied for evaluating the evacuation performance. Since the routes can be traced by the dynamic assignment, the used routes can be recorded to control the evacuation procedure in the simulation interval.

BIBLIOGRAPHY

1. Bureau of Public Roads, "Traffic Assignment Manual," Office of Planning, Urban Planning Division, June 1964.
2. Daganzo, C.F. and Sheffi, Y., "On Stochastic models of traffic assignment.", Transportation Science, 11: 253-274, 1977.
3. Davidson, K.B., "A Flow Traveltime Relationship for Use in Transport Planning, Proceedings, Australian Road Research Board, 3, 1966.
4. Dial, R.B., "A probabilistic multipath traffic assignment model which obviates path enumeration.", Transportation Research, 5: 83-111, 1971.
5. Dickey, John W. et.al., "Metropolitan transportation planning.", McGraw-Hill, 1983.
6. Dijkstra, E., " A note on two problems in connection with Graphs.", Numerische Mathematik 1, 269-271, 1959.
7. Eiger, A., Niedowski, R, Erickson, D., "Large scale Traffic System Simulation : An Application of the TRAFLO.", ITE Journal, July, 1983.
8. Federal Highway Administration, "Urban Transportation Planning : General Information and Introduction to System 360," U.S Department of Transportation, 1972.
9. Federal Highway Administration, "Traffic assignment," III-15, U.S. Department of Transportation, Aug., 1973.
10. Florian, M. and Fox, B., "On the Probabilistic origin of Dial's multipath traffic assignment model.", Transportation Research, 10 : 339-341, 1975.

11. Florian, M., "An introduction to Network Models used in Transportation Planning.", Transportation Planning Models, North-Hollard, Amsterdam, 1984.

12. Gallo, G. and Pallottino, S., " Shortest Path Methods in Transportation Models.", Transportation Planning Models, North-Hollard, Amsterdam, 1984.

13. Hillier, F. S. and Lieberman, G. J., "Introduction to Operation Research.", Holden-Day, Inc., Oakland, CA, 1986.

14. Hobeika, A. G. et al., "Population and Evacuation Study for Surry Power Station and North Anna Power Station.", Final Report, University Center for Transportation Research, Virginia Polytechnic Institute and State University, Nov. 1984.

15. Hobeika, A.G. and Jemei, B, "MASSVAC : A Model for Calculating Evacuation Times Under Natural Disaster,", Proceedings of the Conference on Computer Simulation in Emergency Planning, Society of Computer Simulaiton, Volume 15, No. 1, La jolla, California, Jan. 1985.

16. Hutchinson, B.G., "Principles of Urban Transportation Systems Planning." McGraw-Hill Book company, N.Y. 1974.

17. Hwang, K., "Applying Heuristic Traffic Assignment in Natural Disaster Evacuation - A Decision Support System.", PH.D Dissertation, VPI&SU, 1986.

18. Jamei, Bahram, "Transportation Actions to Reduce Highway Evacuation Times under Natural Disasters.", PH.D Dissertation submitted to Graduate school of VPI&SU, Nov., 1984.

19 Kalevala, A.F. Sylvester, "Investigation of the effect of change in vehicular characteristics on highway capacity and the level of service," M.S Thesis, VPI&SU,

1984.

20. Kari, U.S., "Emergency Evacuation around nuclear power station - a system approach." M.S Thesis, VPI&SU, 1989.

21. Khisty, Jotin C., "Transportation Engineering : An Introduction.", Prentice Hall, 1990.

22. Lee, Han, "A Decision Support System for Mass Evacuation and Emergency Management." M.S. Thesis, VPI&SU, 1986.

23. Lewis, Stephen M., "A comparative Assessment of two Transportation Evacuation Models.", M.E. project Report, VPI&SU, 1987.

24. Mclean M.A. et al., "CLEAR : a model for calculation of evacuation time Computer Simulation in Emergency Planning.", San Diego, Simulation Series, Volume 11, Number 2, Jan., 1983.

25. Morris, Richard Jere, "A Comparative Analysis of Trip Distribution and Traffic Assignment Models for Transportation Planning in developing Regions.", 52-172, Stanford University, DOT/UMTA University Research, Dec., 1973.

26. Mileti, Dennis S., Drabak, Thomas E., Haas, Eugene J., "Human Systems in Extreme Environments : a sociological perspective.", Institute of Behavioral Science, The University of Colorado, 1975.

27. New York Times, June 16, 1991.

28. Nuclear Energy Agency, "The Radiological Impact of the Chernorbyl Accident in OECD countries." 1987.

29. Nuclear Management and Resources council," Graded Response : The preferred Evacuation Strategy for nuclear power plants.", Feb., 1989.

30. Perry, Ronald W., Lindell, MIchael K., Greene, Marjorie R., "Evacuation Planning in Emergency Management," pp. 1-9, Battelle Human Affairs Research Centers, Lexington Books, D.C. Heath and Company, 1981.

31. Plosila, Walter H. et. al., "The socio-economic impacts of the three mile island accident." final report, 1980.

32. PRC Voorhees, "Evacuation Planning Package.", Mclean, Virginia, 1982.

33. Quarantelli, E. L., Editor, "Disaster Behavior and problems : Finding and Implications form the Research Literature.", Miscellaneous Report No. 27, Disaster Research Center, The Ohio State University, 1980.

34. Roanoke Times & World News, April 15, 1991.

35. Robillard, P., "Calibration of Dial's assignment method." Transportation Science, 8 : 117-125, 1973.

36. Schneider, M., "Probability maximization in networks.", Proc. of the Inter. Conf. Transportation Research. 748-755, 1973.

37. Sheffi, Yosef, "Urban Transportation Networks.", Prentice-Hall, 1985

38. Sheffi, Yosef, Mahmmassani, H., and Powell, Warren B., "A Transportation Network Evacuation Model." Center for Transportation Studies, MIT, June, 1980.

39. Thiel, C. C. Jr., "Competing against Time.", Report to Governor George Deukmejian, May, 1990.

40. Time magazine, Nov. 25, 46-58, 1985.

41. Tobin, R., "An extension of Dial's algorithm utilizing a model of tripmakers' perceptions.", Transportation Research 11 : 337- 342, 1977.

VITA

Changkyun Kim was born on January 5, 1963 in Seoul, Korea where he had lived before coming to the United States for studying in August, 1986. He entered the Sungkyunkwan University in 1981 in Civil Engineering. After attending 2 years, he joined the korean army for two years and three months, which is mandatory for Korean men. After his military duty, he had prepared for studying in the United States. At that time, he married to Aejin Lee on July 2, 1986 in Seoul, Korea. And then, he came to the United States in August 1986 to pursue a Bachelor of Science in Civil Engineering at Polytechnic University in New York. After obtaining the B.S. degree in May, 1989, he entered Virginia Polytechnic Institute and State University (VPI & SU) to pursue a Master's degree in Civil Engineering. On the completion of his degree, he plans to study continuously for pursuing the Ph.D degree at VPI & SU.