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A MICROCOMPUTER BASED TRAFFIC EVACUATION MODELING SYSTEM FOR EMERGENCY PLANNING APPLICATIONS

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A MICROCOMPUTER BASED TRAFFIC EVACUATION MODELING SYSTEM FOR EMERGENCY PLANNING APPLICATION

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ABSTRACT

Vehicular evacuation is one of the major and often preferred protective action options available for emergency management in a real or anticipated disaster. Computer simulation models of evacuation traffic flow are used to estimate the time required for the affected populations to evacuate to safer areas, to evaluate effectiveness of vehicular evacuations as a protective action option, and to develop comprehensive evacuation plans when required. Following a review of the past efforts to simulate traffic flow during emergency evacuations, an overview of the key features in Version 2.0 of the Oak Ridge Evacuation Modeling System (OREMS) are presented in this paper. OREMS is a microcomputer-based model developed to simulate traffic flow during regional emergency evacuations. OREMS integrates a state-of-the-art dynamic traffic flow and simulation model with advanced data editing and output display programs operating under a MS-Windows environment.

INTRODUCTION

The U.S. Army stockpiles unitary chemical weapons, both as bulk chemicals and as munitions, at eight major sites in the United States. The continued storage and disposal of the chemical stockpile has the potential for accidental releases of toxic gases that could escape the installation boundaries and pose a threat to the civilian population in the vicinity. The U.S. Army, in conjunction with the Federal Emergency Management Agency (FEMA) and other federal agencies, is committed to implementing an emergency preparedness program that will significantly reduce the adverse effects of accidental releases from the chemical stockpile (Carnes *et al.* 1989).

Evacuation is a preferred protective action option available for emergency management in times of threat to the general public in all types of hazard, when enough time exists for successful implementation. For the Chemical Stockpile Emergency Preparedness Program (CSEPP), evacuation by itself or in conjunction with other protective actions (e.g., respiratory protection) is being considered as a viable option to reduce the risk of adverse health effects from accidents involving the chemical agent stockpile.

As part of a broad effort to provide technical assistance to FEMA and the U. S. ARMY for the CSEPP program, Oak Ridge National Laboratory (ORNL) has been developing a microcomputer-based software for analysis, evaluation, and development of evacuation plans for the eight CSEPP sites. This package is referred to as the Oak Ridge Evacuation Modeling System (OREMS). Following a review of the past efforts on evacuation traffic flow modeling, this paper describes the key features of the soon to be released Version 2.0 of OREMS.

EVACUATION MODELING: PREVIOUS EFFORTS

The use of traffic flow models in evacuation planning is a widely accepted practice in the United States and is also becoming popular in other first and second world countries. These analytical or simulation models are used to estimate the time required for the affected populations to evacuate to safer areas and to evaluate the effectiveness of vehicular evacuations as a protective action option. These analyses are an integral part of evacuation planning in many situations and are often performed to meet certain regulatory requirements (e.g. relicensing of nuclear power plants).

A range of approaches have been used in developing evacuation traffic flow models. Basically, the modeling involves estimating the number of vehicles that will evacuate from different zones of the affected area during the response period (the demand), estimating the evacuation routes, and comparing the traffic demand with the highway network capacity. One of the simplest approaches is an aggregation procedure which estimates the number of evacuating vehicles (load) from a given region or zone, assigns the vehicle load to routes, and estimates the evacuation time by dividing the number of vehicles by estimated roadway capacity (see for example, Stone 1983). Such analyses can produce meaningful results, when populations are small and the roadway systems are not complex. However, for large population evacuations on a regional basis, simplified analyses such as these are neither feasible nor meaningful (Urbanik and Jamison 1992).

On the other extreme are the very sophisticated computer models and traffic modeling approaches that were developed in the early 1980's. One of the early efforts was the CLEAR (for Calculates Logical Evacuation and Response) model developed for the Nuclear Regulatory

Commission (NRC). CLEAR simulates vehicle departure and movement on a roadway network, given the most likely subset of evacuation routes (McLean *et al.* 1983). The CLEAR model makes several simplifying assumptions, including modeling of individual vehicles only on the primary road network. More detailed and realistic simulation models for evacuation traffic flow are the I-DYNEV, NETVAC1, EVACD, and MASSVAC computer programs (Southworth 1991). Most of these models incorporate mobilization time, destination selection, and route choice behavior in the simulation procedure and each produces an estimate of the evacuation time (time to clear the area), as well as, traffic performance in the represented network.

I-DYNEV (for Interactive Dynamic Network Evacuation model) is perhaps the most sophisticated and most used evacuation planning model. I-DYNEV was developed by KLD Associates, as part of FEMA's Integrated Emergency Management Information System (IEMIS), for application to nuclear power plant emergencies (Jaske 1986). I-DYNEV combines a static, equilibrium traffic assignment model with a macroscopic simulation model, both of which were adopted from the TRAFLO family of simulation models developed for the Federal Highway Administration (Lieberman *et al.* 1983). A trip distribution model was later integrated with the traffic assignment model (Lieberman 1987). I-DYNEV has been used to estimate evacuation times and develop evacuation plans for several nuclear power plants licensees and other natural and technological hazards (Urbanik *et al.* 1988).

Despite the progress made since the early 1980's, however, a great deal of additional research and development needs to be done before the existing evacuation traffic models can be used very effectively for the analysis, evaluation, and development of evacuation time estimates, routing strategies, and overall evacuation plans. The ability to realistically replicate a likely evacuation event and provide useful analysis tools poses many technical challenges. The lack of proper data and models, complexities in models, interaction among models, transportation considerations for all affected populations, the need to analyze a multitude of scenarios, large databases, and various other considerations make the task extremely complicated and difficult.

A major problem with these models has been the lack of realistic representation of driver behavior with respect to departure delays, destination selection, and route selection. In addition, the existing models lack user-friendly interfaces for data entry and manipulation, output analyses, and database management. The user interface for even the sophisticated models, such as I-DYNEV, are primitive by today's standards in microcomputer-based software. The task of creating a data file, developing evacuation scenarios, explaining the modeling concepts to emergency planners, and interpreting the output data remains a tedious and difficult task (Rathi *et al.* 1993).

Another major deficiency of the research in this area is the lack of comparative studies and model validation. While the I-DYNEV model has been used in numerous applications, very little is known about the model logic and the accuracy of its results. Aside from a small benchmark study, conducted for Pacific Northwest Laboratory by the Texas Transportation Institute (Urbanik *et al.* 1988), very little information exists in the open literature about the validation and "realism" of the model.

Finally, considerable work must still be done before "real time" decision support systems can be developed. The evacuation traffic simulation models are currently being embedded within emergency management information systems, such as FEMIS. However, much work must still be done before these models can truly be used in an "on -line" fashion for management of emergencies in real-time.

THE OAK RIDGE EVACUATION MODELING SYSTEM (OREMS)

In response to the various difficulties encountered with the I-DYNEV model during preliminary evacuation studies associated with the CSEPP program (Rathi *et al.* 1993) and to develop a non-proprietary evacuation model for use by various state and local emergency management planning offices, FEMA and the U.S. Army are sponsoring the development of a microcomputer-based evacuation modeling system at ORNL. This system is popularly known as OREMS (for Oak Ridge Evacuation Modeling System).

OREMS is an integrated software system which performs three operations: input data file and management, simulation analysis, and output displays. The following section provides a brief description of the major features of OREMS.

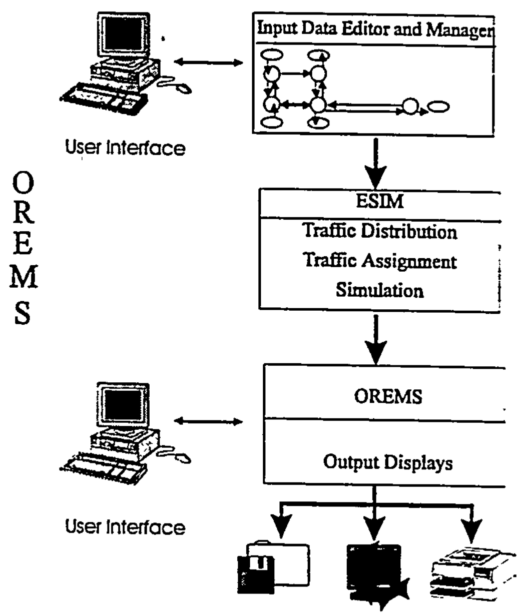

Figure 1. OREMS Structure from the User's Guide

ESIM Model

ESIM (for Evacuation SIMulations) is the analytical core of OREMS. ESIM is a rather complex FORTRAN-based program that simulates the traffic conditions over a transportation network as an evacuation progresses. The ESIM model combines a trip distribution and traffic assignment model with a detailed traffic flow simulation model. Through traffic distribution and assignment, ESIM determines the destinations selected by evacuees and the routes taken to reach the selected destinations. It also performs a detailed simulation of traffic operations on the evacuation network, given these projected flows and routes under prevailing roadway and traffic conditions. This simulation allows the analyst to estimate service rates in the evacuation network by location and by time; identify performance characteristics of traffic; identify bottlenecks; and estimate evacuation times across various categories (link, sector, or region specific estimates by time). The algorithms used in ESIM's traffic assignment and simulation models are based on techniques that have resulted from years of research sponsored by the Federal Highway Administration. The three submodels of the ESIM model are described next.

ESIM's Simulation Model - ESIM's simulation model is an adaptation of the NETFLO II and FREFLO models of the TRAFLO family of macroscopic simulation models (FHWA 1991). The term macroscopic means that the model simulates the flow of traffic in some aggregate fashion rather than the movement of individual vehicles in a microscopic fashion. The vehicular movements on surface streets are modeled using the NETFLO II logic and that on the freeway sections are based on the FREFLO logic.

The traffic stream in the NETFLO II model is represented in the form of movement-specific statistical histograms. The length of time during which a simulation is performed is split up into a series of Time Periods (TP) with each TP being further subdivided into a series of Time Intervals (TI). Traffic congestion and spillbacks are treated explicitly in the simulation model. Vehicles can move on to the receiving link only if there is space available to accommodate the vehicles that want to enter that link. In this way queues develop. The effects of traffic control measures (i.e., signals, STOP and YIELD signs) are also simulated at every intersection.

In FREFLO, the traffic is represented as aggregate measures such as the flow rate, space mean speed, and density. The freeway itself is modeled as a set of segments each with its own attributes representing the aggregate measures of traffic flow. Traffic flow is assumed to be homogeneous within a section. The model logic primarily consists of a pair of dynamic equations expressing the conversation of vehicles and the dynamics of speed behavior. The model accommodates freeway-to-freeway connectors involving merge/diverge points and on/off-ramp flows.

ESIM's Trip Distribution Model - The destination selection models are commonly referred to as the trip distribution models by transportation planners/analysts. Simply stated, trip distribution is the process by which the origin and destination ends of a trip are defined. In the case of evacuation modeling, the origins of trips are determined based on the location of the populations (in various categories) at the time of the emergency. The destinations selected by evacuees are modelled in one of the three ways:

1) evacuees will exit via pre-specified destinations based on an established evacuation plan;
2) evacuees will exit the 'at-risk area' by heading for the nearest destination in terms of distance or time; and
3) evacuees will exit via the closest destination in terms of time or distance, on the basis of traffic conditions at their time of departure.

ESIM allows the user to specify the destinations associated with each traffic origin. As an option, the model performs a trip distribution to determine the destinations for an origin. The destination selection (trip distribution) is based on a hybrid of the three modeling options described above.

ESIM's Traffic Assignment Model - Route selection models are used to approximate the path selected by evacuees (i.e., evacuation routes). The process of assigning paths to the traffic flow is referred to as traffic assignment in transportation planning. The basic methodology in traditional traffic assignment is to determine a logical path between an origin and a destination under given traffic conditions, based on system or user optimal travel behavior.

ESIM's traffic assignment model is an equilibrium assignment model which attempts to find a user optimal solution. The term equilibrium is characterized by Wardrop's famous first principle (Wardrop 1952) which states that "the journey times on all routes actually used are equal, and less than those which would be experienced by a single vehicle on any unused route." For this user-optimal assignment principle, an equivalent minimization problem can be formulated. The solution to this problem, thus, produces the traffic pattern which satisfies Wardrop's first principle. The traffic assignment model of ESIM and TRAF is an elaboration of the equilibrium traffic assignment model, TRAFFIC, developed by Nguyen (Nguyen 1975).

TRAFFIC is still one of the best traffic assignment models. One of the key inputs to traffic assignment models is the estimate of the capacity of highway segments. Most, if not all, other traffic assignment models employ constant, estimated values of link capacities. It is well known that link capacity is a function of many factors including the unknown turn volumes on all approaches serviced by an intersection. A very comprehensive capacity estimation model has been included in the TRAF and thus ESIM models. This model produces, through iterations, accurate estimates of service rates (capacities) for each link of the highway network by taking into account the assigned volumes and type of traffic control at each intersection. The solution procedure used in the capacity model is rapid, accurate, and unconditionally convergent.

Input Data Manager

Simulation models by their very nature are data intensive and ESIM is no exception. The physical highway environment, which must be specified as input data to use the ESIM model, includes the network geometry, traffic inflow, turn percentages, and traffic control. The user is required to enter detailed information on these items (e.g., lane channelization, signal control data), much of which also varies by time. In addition, several other input parameters must be specified for run control or to change the default values embedded in the models. The smallest ESIM input data file representing an isolated intersection consists of over 50 lines of 80-column data. The large data files, on the other hand, can consist of hundreds of lines of data. Also, the data structure is such that one must adhere to very strict formats while utilizing many numeric codes. Preparing the data files needed to run ESIM for even small networks can be a very tedious and time consuming activity.

OREMS is a graphical user interface (GUI) which was developed to greatly simplify the task of creating the data base (or data files) necessary to use the ESIM simulation model. This GUI allows the user to create an input data file from scratch or modify an existing data file. It has been designed to simplify the task of data entry, so that the user does not have to understand and remember the "record types" and countless numeric codes associated with each record type used in the ESIM data files. In addition, OREMS' s GUI performs comprehensive and intelligent error checking to insure the accuracy and consistency of the data. Due to its total graphical mode of data entry and manipulation, OREMS provides superior functionality and performance relative to other programs and utilities developed for the same purpose. OREMS's GUI for input has over 100 functions which allow the user to create/edit data files very efficiently. These functions handle file management, user interaction, display, data entry/manipulation, network sizing, printing, and various other options available with the program. The user can create or edit a data file without lifting a finger from the mouse (Rathi *et al.* 1993).

Output Display Program

OREMS's GUI also displays the input data to and the results produced by the ESIM evacuation simulation model. The data produced by the ESIM simulation model allows the user to analyze traffic conditions during a regional population evacuation. The model produces data on a variety of measures of effectiveness at user-specified time intervals. The statistics are provided for individual links, as well as, for the entire network in a summary format. These data are provided for each link and are also aggregated over the entire network.

Because of the detail of the output data, one could expend considerable time and energy trying to properly interpret the model output to derive statistics of interest from the output files created by ESIM. Typically these output files are several hundred pages of computer printout. The output is in the form of statistics which are hard to visualize even for the most competent and experienced users. Furthermore, the output shows a few obvious statistics on the traffic conditions and the progress of evacuation for the entire area; it requires considerable additional computation to obtain sector- or area-specific statistics or information on bottlenecks in the transportation network.

The post-processor component of OREMS has been designed not only as a utility for analyzing the simulation output, but also to assist the user with evacuation planning. This GUI includes a graphical representation of the simulated traffic conditions for a scenario and displays the "hot spots" in the network, area-specific statistics, and other useful information with a few clicks of the mouse.

Capabilities of OREMS

OREMS is designed to allow the user to perform comprehensive evacuation planning studies; including estimates of evacuation times, development of traffic management and control strategies, identification of evacuation routes, identification of traffic control points, and other elements of an evacuation plan. OREMS can be used to estimate evacuation time and to develop evacuation plans for different events or scenarios (e.g., good vs. bad weather conditions, day vs. nighttime evacuations) for user-defined spatial boundaries. OREMS allows the user to experiment with alternate routes, destinations, traffic control and management, and evacuee response rates. For a given situation, OREMS can help the planner identify the evacuation or clearance times, traffic operational characteristics (e.g., average speed), bottlenecks, and other information necessary to develop effective evacuation plans.

All of the above information can be obtained for a given section of highway, an area within the network, a sector/ring, or at any other level of spatial aggregation. Detailed information on the traffic's operational characteristics can also be obtained at user-specified time intervals between the beginning and end ("clearing") of an evacuation.

APPLICATION OF OREMS IN EVACUATION STUDIES

The first step in evacuation planning and analysis, of course, is the delineation of the emergency planning zones. A three-zone concept for the application of evacuation and other protective action strategies is commonly utilized in the planning process. These zones are: Immediate Response Zone (IRZ), which is the area closest to the point source of the potential disaster, where prompt and effective response is most critical; the Protective Action Zone (PAZ) is an area which is slightly farther away, but still under a potential threat depending upon the type of accident and weather condition; and the Precautionary Zone (PZ) is the outermost boundary beyond which no adverse effect can be expected as a result of the disaster and therefore does not require any significant pre-event planning. For a given area, the specific zonal boundaries are determined on the basis of political, human, and topological factors, with spatial and temporal distribution of the hazard as the most important consideration.

Having determined the IRZ, PAZ, and PZ boundaries, an accurate and reasonably detailed representation of the highway network within these zones is needed to estimate evacuation times and to develop evacuation plans using OREMS. In addition, the following information is required:

a) estimate of traffic demand (number of evacuees and vehicles by location);
b) trip generation time (timing of people's response to the perceived emergency by location);
c) destination and route selection by evacuees; and
d) capacity of the highway network.

Capacity is defined as the maximum number of vehicles that can pass on a given section of highway, in one direction, during a given time period under prevailing roadway and traffic conditions.

Using the information in items (a) and (b) as input to a reasonably detailed description of the highway infrastructure, OREMS can be used to generate the information required in items (c) and (d). The traffic assignment/distribution model of ESIM determines the destination selected by evacuees and the route taken to reach the selected destinations. The simulation model component of ESIM performs a detailed simulation of traffic operations on the evacuation network, given these projected flows and routes under prevailing roadway and traffic conditions. This simulation allows the analyst to estimate service rates in the evacuation network by location and by time, identify performance characteristics of traffic, bottlenecks, and estimate evacuation times across various categories (link-, area- or network-specific estimates by time). The user can specify the origin-destination flows rather than using the traffic distribution model. Typically, the OREMS model has to be used in an iterative manner to obtain the best estimate of evacuation time. Iterations are required not only when experimenting with alternate control strategies, but also to accommodate some limitations of the traffic model.

HARDWARE AND SOFTWARE REQUIREMENTS

The first release of OREMS works for IBM compatible microcomputers under the DOS 5.0 or later versions of the operating system. The upcoming Version 2.0 of OREMS is being developed to work under the MSWindows operating systems on IBM compatible microcomputer with an 80386 or higher preprocessor. The memory requirement is at least 8 MB of RAM. The programs and data for OREMS will need 20 MB of hard disk space to run efficiently.

AVAILABILITY AND WORK IN PROGRESS

OREMS is being developed by the Center for Transportation Analysis in the Energy Division of the Oak Ridge National Laboratory through funding from the Federal Emergency Management Agency (FEMA) and the US Department of the Army, under the Chemical Stockpile Emergency Management Program (CSEPP). Version 1.0 of the OREMS has been distributed to over 30 users since March 1994. Version 2.0 (Beta) is expected to be made available to interested users by spring/summer 1995.

In its current form, OREMS is more user-friendly than I-DYNEV and also a better traffic model. However, much work still has to be done to make it a realistic traffic simulation model, to make the software more user-friendly and versatile, to integrate the model with other analysis tools, such as a plume dispersion model, and to improve its computational efficiency.

Work is now in progress to:

- test and debug OREMS;
- improve user interfaces;
- experiment with microscopic simulation models;
- integrate traffic simulation, assignment and distribution models; and
- integrate the model with other planning models and PADRE;

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