Post-Disaster Dynamic Routing of Emergency Vehicles

DEVELOPMENT OF EMERGENCY RESPONSE MODEL FOR ORLANDO INTERNATIONAL AIRPORT

By

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EXECUTIVE SUMMARY

With the advances in traffic simulation during the last decade, it is now possible to model many traffic problems, such as signal control optimization, testing of Intelligent Transportation System technologies, and emergency management. These problems are difficult to solve using the traditional tools, which are based on analytical methods. The September 11th disaster has raised the consciousness of transportation professionals, for better emergency response. Advances in the traffic simulation technology can be used to model and test the disaster management strategies. This is not only a cost effective way to prepare for an emergency, but it is also possible to test the various available scenarios which can not be tested in the field.

This thesis presents the use of a microscopic traffic simulation model to evaluate the emergency vehicle routing strategies in case of an emergency. A detailed framework outlining the model building and calibration of the model using microscopic traffic simulation model PARAMICS is provided.

The network around the Orlando International Airport is coded into PARAMICS with 50 signalized intersections, 7 fire stations and 66 zones. The study assessed the routes to be taken, from the fire stations to the airport for quick response, in case of an emergency at the airport.

Roadway network and travel demand data are the two main inputs required for building the model. Roadway network data consists of geometric layout of the network, number of lanes, and intersection description including the turning bays, signal timings, phasing sequence, etc. The travel demand data includes the vehicle counts in each link of the network. Since the vehicle counts data are not directly used by the PARAMICS model, travel demand model was needed to estimate the demand from one zone to

another within the network. To address this, two approaches were used for estimating the origin-destination matrix between the zones; Gravity model and a heuristic approach.

The road network was calibrated and validated for the peak hour, by comparing the simulated link counts with that of the actual link counts at different locations in the network. Then the network was simulated under peak hour, off peak hour, and free flow conditions. The time taken by the vehicles from the fire stations' zones to the airport was collected. These were used as measures of effectiveness and to determine which fire station is to respond first and the time needed for dispatch. Different scenarios were considered with incidents on the links that are used by the fire stations under normal conditions. Alternative routes under incident conditions were determined, and the sequence in which the fire stations are to route their vehicles for faster emergency response were proposed.

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CHAPTER 1
INTRODUCTION

Overview

Traffic simulation is a powerful tool for assessing the benefits and impacts of transportation projects. Simulation is less expensive and safer than on-line tests. Moreover, simulation not only provides transportation engineers with the ability to test the feasibility and performance of a system before it is implemented, it can also be used to optimize the proposed system.

Simulation tools are becoming more attractive in studying traffic issues. With the advances in computers and simulation techniques, it is now possible to model any transportation network and simulate traffic flow on these roads in a very realistic fashion. This enables traffic engineers and planners to investigate the effect of hypothetical changes in the network geometry and traffic control strategies on traffic performance. Also, it enables the evaluation of several scenarios such as building a new highway, addition of new lanes, testing the Variable Message Sign (VMS) and other Intelligent Transportation Systems (ITS) applications, etc.

September 11th disaster has raised the consciousness of transportation industry about the need for better crisis management, disaster planning, and better response in case of an emergency. The present goal of transportation system is not only moving the people and goods safely and efficiently, but also to be well prepared and protected against the attacks, and respond rapidly and effectively to natural and human caused threats and disasters and restore normalcy quickly and efficiently.

Advances in the traffic simulation technology can be used to model and test the disaster management strategies. This is not only a cost effective way of preparing for the emergency, but it is also possible to test the various available alternatives which can not be tested in the field. The traffic simulation may be used to conduct a more security oriented transportation planning and to study the interactions among the various sectors, which are essential for effective disaster management.

Report Objective

The main objective of this study is to use the micro-simulation capabilities of traffic simulation and to develop a methodology for modeling of transportation networks in order to determine the fastest and most effective routing strategy of emergency vehicles to Orlando International Airport (OIA) in case of disaster.

The study area consists of the roadway network in the vicinity of OIA. This roadway network extends from Orange Blossom Trail in the east to State Road 417 (SR 417), in the west, covering a stretch of 11.5 miles, and from Hoffner Avenue and Oakridge Avenue in the north to SR 417 in the South covering a stretch of 9 miles. All the major roads, Beeline Expressway (SR 528), Sand Lake Rd, Land street, Tradeport Drive, Orange Avenue, Boggy Creek Rd, Wetherbee Rd, Semoran Blvd , Goldenrod Rd, and Narcoossee Rd are considered. The resulting network consists of 66 zones with 50 signalized intersections and covering an area of around 100 sq miles. Seven fire stations lie in the study area, so these are considered as zones for routing the emergency vehicles to the airport. Approximately 42,000 vehicles enter and leave the study area during the peak hour. The aerial extent of the study area, the routes covered, and the fire stations included in the study are highlighted in Figure 1-1.

The simulation model developed for this purpose is used to determine:

- Locations from which the emergency response services should be dispatched.
- Number of vehicles to be dispatched from each location.
- The routes that should be chosen so that the fastest response time to the OIA is achieved.
- Account for the changes in dispatch pattern in case of an incident on particular routes.

The different routes are tested under peak period, off-peak period and incident conditions and the best routes based on minimizing travel time are selected.

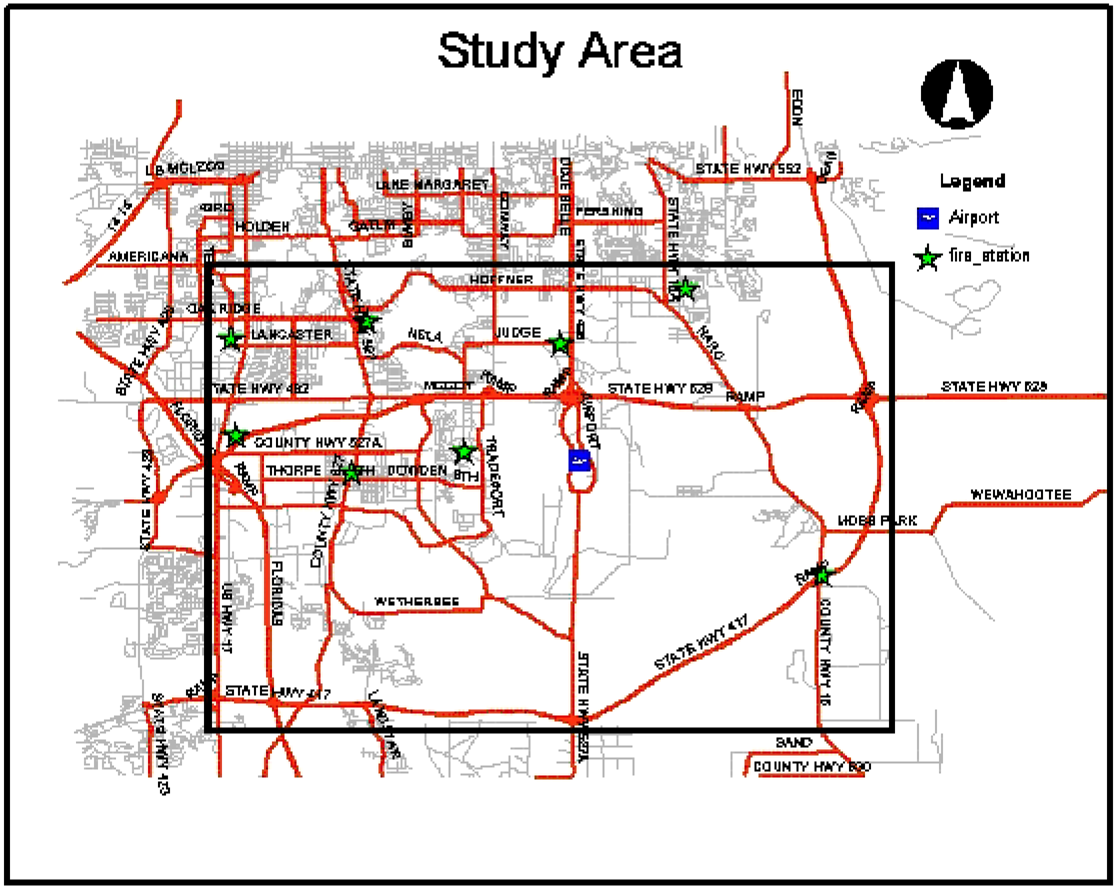

Figure 1-1: Study Area

Report Contributions

This report presents an approach for using traffic simulation for emergency deployment modeling. Results from the report provide the OIA authority a detailed picture of how and from where to deploy the emergency vehicles in case of disaster at OIA. The study also provides the alternative routes to be taken in case of the incident and road blockage scenarios.

Report Layout

The following chapters will present a literature review, outline of the approach, demand estimation and model validation, results and scenarios, and future scope.

The literature review provides insights into current traffic simulation models from the current literature. This chapter discuses the process of microscopic simulation modeling and the options available for the present day modelers. Much of the focus is on PARAMICS micro-simulation model, the technicalities involved with this model, and review of the studies conducted using PARAMICS.

Following the literature review, a thorough discussion of the model development approach is discussed. The chapter touches on data collection, details of model building, and preparation for calibration and validation of the model and explains the detailed procedure employed in calibration and validation.

Next, a chapter is devoted to the Origin and Destination Matrix (OD Matrix) estimation, which is a crucial part of model development in PARAMICS. Since PARAMICS uses zones for production and attraction, an external OD should be supplied.

In this chapter two methods of OD estimation are discussed: (1) the traditional gravity model, and (2) node balancing method.

Following the OD matrix estimation chapter, a complete discussion of how the model is calibrated and validated is presented. This chapter deals with determining the number of simulation runs required, and the selection of seed values for initiating the simulation.

The final chapter provides the findings from the study conducted in terms of the shortest routes for deploying the emergency vehicles from different fire stations. Different scenarios under incident and road closure conditions are modeled. The conclusions and future scope of this study are highlighted at the end.

CHAPTER 2
LITERATURE REVIEW

Traffic Simulation

What is Simulation?

Simulation involves imitation of a real world system through mathematical and logical representations of the interaction between the entities present in the system. May (1) defines simulation as "numeric technique for conducting experiments on a digital computer, which may include stochastic characteristics, be microscopic or macroscopic in nature, and involve mathematical models that describe the behavior of the transportation system over extended periods of real time." Traffic simulation is a powerful tool to assess the benefits and impacts of transportation projects. Simulation is cheaper and safer than the field tests; it provides the transportation engineers not only with the ability to test the feasibility and performance of the system, but also to optimize the proposed system.

Computer advances made traffic simulation much easier, powerful, and more comprehensive, which led to the increased use of traffic simulation models. One of the strengths of modern simulation models is that they are based on the random movements of each vehicle. This discrete modeling provides the opportunity to view the animated vehicles on a graphical representation of the network.

Why Simulation?

Traffic simulation can be applied in following situations:

- Other easier means of treatments like the mathematical and logical modeling are infeasible or more complicated to represent the system in detail
- In order to view the animation of the vehicles, their behavior in a given system and understand the characteristics of the system in minute detail
- To model congestion over long time periods
- When underlying mathematical models are of suspect and produce an unrealistic quasi equilibrium.

Choosing a simulation model

The simulation model chosen should be appropriate for the intended application. Usually, this choice is a tradeoff between the accuracy and precision of the model and the development costs, data needs, and time required to execute the simulation.

Traffic simulation models are mainly classified based on the details that the model represents in a given system (2). They are classified into Microscopic (high fidelity), Mesoscopic (mixed fidelity), and Macroscopic (low fidelity).

Microscopic models consider the traffic characteristics of each vehicle and simulate vehicle to vehicle interaction. These models give the continuous profiles of the vehicle locations and their speed with time. They also represent the real world more realistically. These types of models incorporate queuing analysis, shockwave analysis, and other analytical techniques. Due to considerations of the minute characteristics of every vehicle, these models are difficult to build and require more computational effort and cost more. Calibration of these models requires greater number of parameters to be taken into account and require extensive inputs.

Macroscopic models are characterized by the continuum fluid representation of the traffic flow. They consider the aggregate characteristics of the traffic like flow, density, and average speed. These models represent the real world in a less detailed manner, but they are computationally faster than their counterparts and require fewer inputs.

Third category, Mesoscopic models inherit the characteristics of both the microscopic and macroscopic models. In these models platoon or a group of vehicles are simulated, and usually the results from the microscopic models are aggregated for use in these models.

The other classifications of the models are based on the type of the facilities. They analyze locations such as intersections, freeways, arterials, toll plazas, etc. Models can also be classified based on the uncertainty they represent, namely stochastic and deterministic. Stochastic models include the uncertainty aspect in the form of probability distributions, while deterministic models do not include any randomness. All the interactions in the system are defined by the exact mathematical/logical/statistical relationships.

Evaluation of the Simulation models

Boxill and Yu (3) conducted a two-step evaluation study of simulation models: initial screening and in-depth evaluation. Criteria for initial screening were developed in order to eliminate models with no potential for use with ITS applications. In-depth evaluation attempts to identify more specific features and limitations of models selected from the initial screening process. Nine models were assessed in terms of ITS features modeled. These models were AIMSUN 2, CONTRAM, CORFLO, CORSIM, FLEXYT II, HUTSIM, INTEGRATION, PARAMICS, and VISSIM. It was found that PARAMICS is the leading model for real time simulation of hundreds of vehicles. It also appears to be a comprehensive visualization system and provides intelligent route guidance capabilities. Table 2-1 summarizes the in-depth evaluation. Table 2-2 is the summary of application areas of selected models.

Table 2-1: Summary of Models Based on In-Depth Criteria (Boxill and Yu, 2000)

	AIMSUN 2	CONTRAM	CORFLO	CORSIM	FLEXYT II	HUTSIM	INTEGRATION	PARAMICS	VISSIM
ITS Features Modeled									
Traffic devices	X						X	X	
Traffic device functions	X						X	X	
Traffic calming					X	X	X	X	X
Driver behavior	X			X	X		X	X	
Vehicle interaction	X			X	X		X	X	
Congestion pricing						X		X	
Incident	X		X	X	X	X	X	X	X
Queue spillback	X			X	X	X	X	X	X
Ramp metering	X			X	X	X	X	X	X
Coordinated traffic signals	X	X	X	X	X	X	X	X	X
Adaptive traffic signals	X	X	X	X	X	X	X	X	X
Interface w/other ITS algorithms	X								
Network conditions		X				X		X	
Network flow pattern predictions					X	X	X	X	X
Route guidance									
Integrated simulation	X	X		X	X	X	X	X	X
Other Properties									
Runs on a PC	X	X		X	X	X	X	X	X
Graphical Network Builder	X	X			X	X			X
Graphical Presentation of Results	X	X		X	X	X	X	X	X
Well Documented	X	X	X	X	X	X	X	X	X

Table 2-2: Summary of Application Areas of Selected Models (Boxill and Yu, 2000)

AIMSUN 2	**Traffic control systems** **Route guidance, VMS** **Evaluation of roadway design alternatives**
CONTRAM	***Time varying traffic demands*** **Prediction of variation of time through time of the resulting routes, queues, and delays** **Design of urban traffic management options**
CORSIM	**Assessment of advanced traffic control scenarios** • Adaptive traffic signal control on arterials • Traffic responsive ramp metering without diversion
FLEXYTT II	**Effects of control strategies of comparison of different strategies of control**
HUTSIM	**Evaluation and testing of signal control strategies and different traffic arrangements** **Development of new control systems** **Evaluation of ITS applications**
INTEGRATION	**Corridor improvement strategies (HOV)** **Assessment of real time route guidance and information benefits**
PARAMICS	**Simulation of** • Impact of traffic signals • Ramp meters • Loop detectors linked to variable speed signs • VMS and CMS signing strategies • In-vehicle network state display devices • In-vehicle route guidance
VISSIM	**Transit signal priority studies** **Intersection/Interchange design and operations**

Shaw and Nam (4) used three popular simulation tools (CORSIM, PARAMICS and VISSIM) for a detailed examination of the safety and operational performance of the Metropolitan Milwaukee freeway system. The main purpose of the project was to identify locations with performance problems and to develop the strategies for improving, through traffic control devices, and the changes in geometry. In meeting the project's requirements, both PARAMICS 3.0 and VISSIM 3.51 offered significant advantages compared to CORSIM 4.2. PARAMICS 3.0 appeared to be the most suitable package after careful evaluation of the state-of-the-art micro simulation software. PARAMICS was chosen for the final project. The results are summarized in Table 2-3.

Choa et al. (5) conducted a study on a typical freeway interchange using PARAMICS, CORSIM, and VISSIM. Their results and evaluations with these pieces of software are summarized as follows:

- CORSIM provided the shortest set-up time. Both PARAMICS and VISSIM required about an additional day for model refinement.

- Both CORSIM and PARAMICS use link-based routing, which can result in inaccurate lane utilization for closely spaced intersections. The path-based routing in VISSIM eliminates this problem.

- Both PARAMICS and VISSIM provide three-dimensional animation, although VISSIM has more options for enhancing the visual setting. The CORSIM's two-dimensional animation is more simplistic.

- No software provides average control delay for each turn movement although CORSIM does provide average control delay for each approach. All models report total delay by link.

- CORSIM has an artificial barrier between arterial and freeway networks that can cause inaccuracies such as the "metering" of traffic on high-volume on-ramps or "backups" of traffic on high-volume off-ramps.

- Overall, PARAMICS and VISSIM generated simulation results that better matched field observed conditions, traffic engineering principles, and expectation.

Table 2-3: Summary of Final Evaluation Results (John Shaw and Nam, 2001)

	EVALUATION CRITERIA	**CORSIM**	**PARAMICS**	**VISSIM**
A. Model Capability				
1	Network Size Limit	X	XXX	XXX
2	Network Representation	X	XXX	XXX
3	Traffic Flow Composition	XXX	XXX	XXX
4	Detail of Output	XX	XXX	XX
5	Network Merge	X	XXX	X
6	3-D Modeling	X	XXX	XX
7	Traffic Composition	X	XXX	XXX
8	Animation	XX	XXX	XX
B. Ease of Use				
9	Input Data Requirements	XXX	X	XX
10	Network Coding/Editing	X	XXX	XX
11	Input/Output Review	X	XXX	XX
C. FSOA Application Requirements				
12	VISTA (GIS) Interface	XXX	XXX	XX
13	Economic Analysis Interface	XX	XXX	X
14	Incident Management Analysis	X	XXX	XX
15	Actuated Signal Control Devices	X	XX	XXX
16	User Defined Traffic Control & API	X	XXX	XXX
17	Public Transportation	X	XX	XXX
D. Other				
18	Calibration Results	XX	XXX	XX
19	Program Integrity	X	XXX	XXX
20	Technical Support	X	XX	XXX
21	Documentation	X	XX	X
22	Record of Large-Scale Freeway Applicatio	X	XXX	XX
23	Software Cost per Copy	XXX	X	X
FINAL RATING				
XXX		4	17	9
XX		4	4	10
X		15	2	4
Legend:				
XXX = very good XX = acceptable X = needs improvement, incapable or expensive				

Steps in a Simulation Study

Applying a simulation model requires considerable skill and keen attention to the model behavior in order to derive accurate and reliable results. The procedure recommended in the Chapter on Traffic Simulation from the "Monograph on Traffic Flow Theory" (2) is presented below:

- Identifying and defining the problem domain
- Defining the purpose of the study
- Looking for different means of solving the problem
- Investigation of Simulation models
- Calibration
- Execution
- Validation and Visual inspection
- Interpretation of results

First step in any study is identifying the problem and defining the problem domain. For any transportation study, problem domain consists of defining the aerial extent (which includes highway facilities to be considered like the freeways, arterials, ramps, rural roads, toll facilities), the traffic environment (which include the traffic conditions like over saturation and under saturation, the vehicle composition, driver age distribution, and characteristics of the drivers and the roadway geometrics), and control environment (which include the traffic signals, signs, VMS and route guidance).

Second step is defining the purpose of the study, (what are the goals of the study like capacity analysis, Planning a facility, Demand modeling, Signal optimization, etc), defining the measures of efficiency to be considered, the level of detail necessary for the study keeping an eye on the budget, time constraints and expected accuracy and reliability.

Once the purpose of the study is outlined, the next step is to investigate the means of achieving the desired goals. Extensive literature review is needed, to see if any studies of this kind are done, the kind of approach used and problems encountered during their study. Different simulation and mathematical modeling techniques are to be explored and their strengths and weaknesses are to be tabulated on the basis of underlying assumptions in each model, computing requirements, their costs, clarity of the documentation, extent of the support provided and ease of use, and the animation capabilities of the software. The next step is evaluating if simulation is necessary or if mathematical models can handle the problem. Once it is decided that simulation modeling is beneficial, the best model that fits the requirements of the problem in hand is selected.

With given simulation model in hand, the next step is to gather the data requirements for feeding the simulation model (these include the aerial photos graphics, design drawings for geometrics, signal timing plans, traffic data like AADT, and traffic composition. Once these data are available, the model is tested up on a small segment of the study area in order to calibrate the model. Model calibration is done by adjusting the simulation parameters (like the headway distribution, placement of sign posts, drivers' reaction time) under different scenarios. The model is to be compared with the real life data and probably with the Highway Capacity Manual procedures (which are widely accepted).

The application of a simulation model should be viewed as performing a rigorous statistical experiment. The model must first be executed to initialize its database so that the data properly represents the initial state of the traffic environment. Interpretation of results is the most important and critical activity. Given the complex processes taking place in the real-world traffic environment, the analyst must be alert and check for the following things:

- Check for the model's features that might be deficient in adequately representing some important process
- Check the input data used for the calibration for any unforeseen errors
- Check if the details provided by the simulation runs are adequate
- Check the statistical analysis for any flaws in the results
- Check for the "bugs" present in the model and the behavior of the algorithms used

A careful and thorough review of animation is crucial as it displays the information and the insights from the mass of the traffic environment. Animation is the most powerful tool for analyzing the simulation results. It gives an insight into the cause and effect relationships and keeps an eye on the anomalous results.

Strength and Weakness of Simulation models

Chapter 31 of the Highway Capacity Manual (6) summarizes the strength and weakness of the simulation models as shown in Table 2-4.

Table 2-4: HCM interpretation of Simulation Modeling

Simulation Modeling Strengths
▪ Can vary demand over time and space ▪ Can model unusual arrival and service patterns that do not follow more traditional mathematical ▪ Distributions can experiment off-line without using on-line trial-and-error approach ▪ Other analytical approaches may not be appropriate ▪ Can experiment with new situations that do not exist today ▪ Can provide time and space sequence information as well as means and variances ▪ Can study system in real time, compressed time, or expended time ▪ Can conduct potentially unsafe experiments without risk to system users ▪ Can replicate base conditions for equitable comparison of improvement alternatives ▪ Can study the effects of changes on the operation of a system ▪ Can handle interacting queuing processes ▪ Can transfer un-served queued traffic from one time period to the next
Simulation Modeling Weaknesses
▪ There may be easier ways to solve the problem ▪ Simulation models may require verification, calibration, and validation, which if overlooked makes such models useless or not dependable. ▪ Development of simulation models requires knowledge in a variety of disciplines, including traffic flow theory, computer programming and operation, probability, decision making and statistical analysis. ▪ The simulation model maybe different for analysts to use because of lack of documentation or need for unique computer facilities ▪ Some users may apply simulation models ands do not understand what they represent ▪ Some users may apply simulation models and do not know or appreciate model limitations and assumptions ▪ Simulation models require considerable input characteristics and data, which may be difficult or impossible to obtain ▪ Results may vary slightly each time the model is run

With regard to traffic simulation within an ITS framework, some limitations have also been identified from the "Smartest" Project undertaken by University of Leeds (4). These are as follows:

Modeling congestion: Most simulation models use simple car following and lane changing algorithms to determine vehicle movements. During congested conditions these do not realistically reflect driver behavior. The way congestion is modeled is often critical to the results obtained.

Environmental modeling: Considerable effort is being directed at producing emission models for incorporation into simulation models. For some emissions this is straightforward but for others complex chemical reactions are taking place within car exhausts making predictions difficult. It is also proving difficult to get reliable emission data for a reasonable mix of traffic.

Integrated environments and common data: Simulation models are often used with other models such as assignment models. There are common inputs required by all these models, such as origin-destination data, network topology, and bus route definitions. However, each model often requires the data in a different format so effort is wasted in re-entering data or writing conversion programs.

Safety evaluation: Safety is a very complex issue. Most safety prediction models are very crude, being based on vehicle flows on given roadways or on lane changes in mean vehicle speeds. Simulation models completely ignore vulnerable road users such as cyclists or pedestrians.

PARAMICS Simulation System Overview

PARAMICS is an advanced suite of software tools for microscopic traffic simulation of movement and behavior of individual vehicles on both urban and freeway networks. PARAMICS is widely regarded as the most powerful microscopic traffic simulation software available in today's marketplace. The PARAMICS software is portable and scaleable, allowing a unified approach to traffic modeling across the whole spectrum of network sizes, from single junctions up to national networks.

Background

Quadstone along with SIAS Ltd., a private engineering consultant also based in Edinburgh, developed a Cray supercomputer version of PARAMICS at the University of Edinburgh's Parallel Computing Center in the early 1990's.

The PARAMICS name is an acronym derived from PARAllel computer MICroscopic Simulation. The complete suite of PARAMICS software comprises five software modules:

- Modeller, the core simulation and visualization tool
- Processor, the simulation configuration tool, and batch mode simulator
- Analyser, the post simulation statistics viewing tool
- Programmer, the API interface to PARAMICS
- Monitor, the interface to pollution emissions model

PARAMICS Modeller

PARAMICS Modeller is a commercial transportation modeling tool that has emerged from seven year collaboration between specialists in high-performance software development and experienced transportation engineers.

Modeller provides the three fundamental operations of model build, traffic simulation (with 3-D visualization) and statistical output accessible through a powerful and intuitive graphical user interface. All the aspects of the transportation network are investigated in Modeller including:

- Mixed urban and freeway networks
- Right-hand and left-hand drive capabilities
- Advanced signal control
- Roundabouts
- Public transportation
- Car Parking
- Incidents
- Bus lanes, Truck-lanes, high occupancy vehicle lanes, toll plazas
- VMS and CMS signing strategies

By modeling individual vehicles, Modeller provides the transportation professional with insight into and better understanding of many hundreds of network issues, resulting in a more efficient and effective approach to projects. The high quality visualization of the vehicles in the network makes it the perfect tool for presenting project results to sponsors and non-technical audience.

PARAMICS Processor

PARAMICS Processor is a simulation configuration tool that allows the user to set up network simulations to be run in batch mode. Processor provides a graphical user interface to easily set simulation parameters, select various statistics for output and to vary the attributes of the vehicles released into the network for different simulation runs of the same network. This is useful, for example, when examining the variation within the model when running sets of simulation runs.

Once the Processor graphical interface has been used to configure the different simulations, it can then launch the simulations in batch mode. The batch mode of

Processor simulates offline, without visualizing the vehicle positions, to generate the statistics required for analysis in the minimum amount of time. The statistical results are the same as those statistics output from Modeller, but can be produced in a much shorter time.

PARAMICS Analyser

PARAMICS Analyser is an analysis tool for displaying the output obtained from PARAMICS traffic simulation. The primary aim of Analyser is to display and report on statistical data produced by running the simulation through Modeller and/or Processor.

Analyser's flexible and easy-to-use graphical user interface can be used to load the results from an individual simulation run and visualize a range of statistics such as simulated vehicle paths; traffic flow volumes by link and turn; maximum queue lengths and blocking of traffic; traffic density, speed and delay; simulated journey time data; and user customized link data such as Level of Service.

The information can be displayed graphically or numerically on-screen, or saved as reports in ASCII text format. The text files can then be included in documents or imported to further analysis tools such as spreadsheets and databases.

PARAMICS Programmer

PARAMICS Programmer is an Application Programming Interface (API) that gives freedom to the users to customize many features of the underlying simulation model. The Customization procedure may include:

- Passing addition parameters to the simulation model

- Exchanging the information between the objects used to represent the network.

- Adding additional components like complex routing, assigning algorithms, changing the lane changing behavior etc… to represent the real world conditions

- Tuning the driver and vehicle models and parameters to reproduce local behavior

- Increasing the details of measured data from the simulator

- Inserting additional models like the actuated signalized controller scheme, signal optimization etc.

PARAMICS Monitor

PARAMICS Monitor calculates the levels of traffic emission pollution on a road network. The pollution levels are collected for every link in the network by summing the emissions for all vehicles on the link. These levels can be written to a statistics file at regular intervals, and can be viewed graphically while the simulation is running.

Features

PARAMICS is a dedicated traffic simulation tool. As a high performance model, PARAMICS uses up to the minute software techniques to deliver accurate simulation results in minimum time. The key features are detailed below:

Network

Network coding in PARAMICS is based on “nodes” and “links,” where each link is coded as a connector between two nodes. Network creation is accomplished within a graphical user interface that allows the user to build the network with computer drafting commands either in freehand drawing of links or by drawing on top of a template road geometry file such as an aerial photograph or a CAD drawing. Details associated with each link specify the characteristics of the roadway such as number of lanes, lane width, types of roadway, and design speeds. Similarly nodes or junctions represent the traffic signals, grade separations, and ramp junctions

Driver and Vehicle behavior

Behavior-based traffic models employ factors in order to mimic the behavior of individual drivers. Neither the current literature nor the PARAMICS software documentation contains specific details on the theory behind the driver behavior modeling inherent in PARAMICS. However, reference is made to research conducted at the British Transportation Research Laboratory (TRL) that concludes that driver behavior can be described by two parameters: aggression and awareness. PARAMICS randomly assigns values of aggression and awareness to the driver of each vehicle on a scale of 1-8. These parameters have an effect on such quantities as target headway, top speed, propensity to change lane and gap acceptance of the individuals. One can alter the type of statistical distribution (i.e., Normal, Poisson) of the aggression and awareness parameters to reflect regional variations in driver behavior. With the assigned aggression and awareness parameters, three interacting models then control the movement of each vehicle: a vehicle following model, a gap acceptance model, and a lane changing model

Demand modeling

The level of vehicle demand within a PARAMICS network is specified as a vehicle trip matrix for origin-destination pairs. In general, demand matrices are specified for a period of one hour or more, but with the option to profile the release of vehicles during the demand period. By profiling the demand in 5-minute intervals, the increase and decrease of demand during particular periods of the day can be modeled accurately. PARAMICS supports multiple demand periods where the user can re-specify trip matrices at discrete intervals during the simulation. PARAMICS can therefore be applied to 24-hour simulation periods where the matrix is updated for different periods during the day.

Trip matrices can be specified for more than 20 classes of vehicles. Matrices can therefore be specified for different vehicles (cars, light goods, heavy goods, up to a maximum of 128 vehicle types).

Incident Modeling

Due to the microscopic nature of PARAMICS, broken down vehicles or accidents and the resulting reduction in capacity on links can be accurately modeled and the effects on upstream traffic analyzed. The interface to incidents enables the user to define accidents, break downs or other vehicle events of a particular frequency, duration and location. The passing speed of vehicles on the same link and those on the opposite link (rubbernecking) can also be specified to ensure that the incident effects are modeled accurately.

Public Transport Modeling

The vehicle definitions in PARAMICS provide the flexibility to model articulated vehicles composed of any number of individual vehicle units of any length. It is possible therefore to model buses, Light Rapid Transit (LRT) and trains within PARAMICS. Unlike other vehicles on the network with flexible route choice, public transport vehicles follow fixed routes through the network.

Traffic Assignment

Traffic assignment in PARAMICS applies to all vehicle types except fixed route vehicles, such as buses and trains. The travel cost for each vehicle to reach its destination is calculated at each time step according to the following generalized cost function.

$$Cost = a*T + b*D + c*P$$

Where:

a = Time coefficient in minutes per minute (default 1.0)

b = Distance coefficient in minutes per kilometer (default 0.0)

c = Toll coefficient in minutes per monetary cost (default 0.0)

T = Free-flow travel time in minutes

D = Length of the link in feet

P = Price of the toll in monetary cost units

Coefficients a, b and c can be changed to reflect conditions on the modeled network.

The following assignment techniques can be implemented in PARAMICS:

- All-or-nothing assignment method – assumes that all drivers are traveling with the same knowledge base for route choice and there is no congestion effect. Link costs do not depend on the flow levels.
- Stochastic assignment method – emphasizes the variability in drivers' perceptions of costs and the composite measure that they try to minimize (distance, travel time, and generalized cost).
- Dynamic feedback assignment – assumes that the drivers who are familiar with the road network will reroute if information on current traffic conditions is provided to them.

Vehicles in PARAMICS do not carry routing information for more than two links in advance, other than knowing which destination they are headed for. As they progress through a network they look at the cost of alternative routes and choose the lowest cost route as they see it at that time. This gives vehicles the flexibility to re-route due to network changes, e.g. lane closures or to incidents or events as they happen. The only exceptions are fixed route vehicles, such as buses, which are coded to run along predefined routes.

Studies using PARAMICS

The University of California, Irvine (8) conducted an extensive study to calibrate and evaluate PARAMICS on the basis of its capabilities as an Intelligent Transportation Systems (ITS) tool. PARAMICS was tested for a comprehensive list of aspects of the transportation network modeling; supply/control aspects, demand/behavior aspects, environmental aspects, and simulator performance aspects.

Calibration was conducted by using real life data collected over a 1500 ft long test bed during morning and evening peak periods on the I-405 freeway, California; between Culver and Jeffrey off ramps. The calibrated parameters were used in the validation process over a triangular network comprising two freeways (I-405 and I-5) and one major arterial (Jeffrey Road) at Irvine. Based on their observations authors stated that:

"PARAMICS offers two very important and unprecedented features: high performance and scaleable. To our knowledge, this is the most promising approach to handle realistic real world traffic networks under ITS. Also PARAMICS offers very plausible detailed modeling for many components of the 'desired ideal' simulator."

PARAMICS can be scaled to any network size, from individual intersections to expansive roadway network. PARAMICS is designed as high performance software, which enables the real time simulation of thousands of vehicles, with no loss of detail. This study also revealed limitations and problems associated with PARAMICS and the ways to overcome these problems were presented.

The Portland State University (9) used PARAMICS as a means of evaluating a small urban traffic network. The study network consisted of area surrounding the diamond interchange of Interstate 5 (I-5) and Wilsonville Road, located in the city of Oregon.

To explore the response of the model, it was tested with different traffic volumes 0.5, 0.75, 1.0 and 1.25 times of the 5 day morning and evening peak data collected on this network. Traffic flows, Queue lengths, Delays and Travel times were used to compare the model and the observed data. Travel time collected from the simulation runs yielded relatively low differences with the field collected data. The study also compared the average vehicle delay at all the intersections with the results from the Highway Capacity Software (HCS). The average delay for all the eight movements were relatively small in comparison to the results from HCS.

Liu et al. (10) addressed the use of Application Programming Interface to change the underlying simulation model used in PARAMICS (API). Authors explained how to override the simulator default models such as car following, lane changing, route choices, etc. The paper explains the procedure for coding the signalized intersections in PARAMICS. Complete details of coding Actuated signals, Signal Coordination and Ramp control using API were illustrated. Authors concluded that API

1. Allow researchers to override the simulator's default models such as car following, route choice models, lane changing, etc…

2. Allow them to interface complementary modules (any ITS application such as signal optimization, adaptive ramp metering, and incident detection).

Gardes et al.(11) assessed PARAMICS to serve as a tool for evaluating freeway improvement strategies on Interstate 680 in the San Francisco Bay Area. This study explained the process of model calibration in detail and also looked into the importance of calibrating the models. The calibration process was conducted by simulating different segments of a freeway like straight-pipe freeway section, a lane drop freeway section, and a single on-ramp freeway section. The model was adjusted by changing the seed value, increasing the signpost distance and lane change distance, increasing the speed memory, and adjusting some car following parameters such as the mean target headway and the mean reaction time. The results of the simulation runs were compared with that of the results from the procedures underlined in the Highway Capacity Manual (6). The authors cited that network characteristics, traffic demand, overall simulation configuration, and driver behavior factors are the important elements in the calibration of any simulation model.

Lee et al. (12) described the importance of calibrating the PARAMICS model for local traffic conditions. The authors simulated a one-mile segment of Interstate 5 in Orange County, California. Real-time loop detector data and two field data sets were collected and used in both calibration and validation processes. The authors stated that the two key parameters used in the study were mean target headway and mean reaction time. The authors found that these calibrated parameter values indicated differences between California drivers' behavior and the default values in PARAMICS.

Stewart (13) developed a model using PARAMICS to study the effects of ramp metering on Motorway 8 (M8) and its neighboring surface streets in Scotland. A model was calibrated and validated with respect to the base model by comparing observed link count data, journey time data, automatic traffic count data and video count data over the sections of M8. The study revealed an acceptable correlation of the simulation results with observed statistics for ramp signal frequencies, cycle times and platoon sizes. The author was able to test different scenarios to illustrate the potential of ramp metering; based on his observations he concluded that PARAMICS can be used to replicate the traffic conditions and the driver behavior reasonably.

Basheer et al. (14) used PARAMICS to study the impacts of the High Vehicle Occupancy (HOV) lane implementation for Highway 401 in Toronto, Canada. A model was developed to evaluate a set of various improvement options of Highway 401 by considering three different scenarios: converting one of the existing lanes into HOV lanes, addition of an HOV lane, and addition of a general purpose lane. All these scenarios were conducted under "do-nothing" traffic assignment option available in PARAMICS.

The traffic parameters of flow, speed and delay for different sections of Highway 401 were used to compare the results from different scenarios. Application of PARAMICS to evaluate the various HOV lane improvement options for Highway 401 in Toronto was successful in meeting the primary research objectives, primarily to develop an HOV lane treatment plan. Also, visual inspection during micro-simulation runs identified potential problem areas with regards to ingress/egress locations. In addition, the sensitivity analysis provided valuable insight into the eventual success of the proposed HOV lane plan and any changes needed in it.

Chu et al. (15) used PARAMICS to evaluate the effectiveness of the ramp metering technology on a section of I-405 using three ramp metering algorithms ALINEA, BOTTLENECK and ZONE. The study site covered a 6-mile stretch of the highway between I-405 and I-5 junction and Culver Drive, which included 7 onramps and 4 off-ramps. Generalized total vehicle travel time, average mainline travel time, average on-ramp waiting time and average O-D travel time were used as measures of effectiveness. This study revealed the use of calibration in simulation modeling. Some of the points that came into light during the study were

- Accurate geometry of network and smooth coding of links, are important since drivers' behavior in PARAMCIS is very sensitive to the network geometry
- The signposting setting for links, which is used for defining locations of weaving area are crucial.
- Proportion of each type of vehicles
- Driver behavior factors in car-following and lane-changing models, including the mean target headway and mean driver's reaction time are important (are to be obtained from calibration)

- Better simulation results were obtained when the acceleration and deceleration of cars are set to 2.8 m/s2 and 5.0 m/s2

Based on the work conducted in this evaluation study, various other ATMIS applications can be tested and evaluated by PARAMICS simulation laboratory.

Ramasamy (16) developed a model to study the traffic characteristics on the University of Central Florida campus using PARAMICS. This simulation study assessed what geometric and/or operational improvements need to be done in order to assure continued safe and efficient operations inside the campus. Calibration of the model was done based on the link counts and queues observed at the intersections during the morning and evening peak periods. Range of scenarios was tested for AM and PM peak that includes existing condition scenario, change in alignment (one-way, partly one-way, roundabouts), control changes (signal timing, adding new signals) and physical changes (future scenario). Maximum queue length and percentage time delay were used as measures of effectiveness.

Trapp (17) demonstrated the integration of PARAMICS and Geographic Information Systems (Map Info) and a database using an interface in his paper regarding Microscopic Traffic Flow Modeling of Large Urban Networks. Cheu, et al (18) used PARAMICS to simulate different incident scenarios and used results from the simulation output to test the algorithms for incident detection. Abdulhai, et al (19) studied the impact of the signal priority system for transit using PARAMICS. Leftwich Consulting Engineers (20) applied the PARAMICS software to assist with a program of revitalization and upgrading for Miami's downtown region for the Miami-Dade County Metropolitan Planning Organization.

Summary

The first part of the literature review presented in this chapter provides some basic background information about the traffic simulation and the issues related to the simulation. This part of the chapter gives an idea of the various simulation models available in the market and their capabilities with respect to the size of the network, nature of the problem to be studies, and the ITS capabilities.

The second part provides the background of the PARAMICS micro-simulation model and the studies related to the use of PARAMICS simulation model. The finding from the literature review can be summarized as follows:

- Give an insight of the capabilities of PARAMICS
- Explain in detail about the problems associated with PARAMICS
- Summarizes the finding of the calibration of the PARAMICS simulator.

After extensive research, there was not any available research regarding the use of microscopic traffic simulation for modeling emergency response. This is a relatively new topic, and this study utilizes the capabilities of PARAMICS to develop an emergency response model for Orlando International Airport.

CHAPTER 3
MODEL BUILDING

The PARAMICS model development cycle may be summarized in the following steps:

1. Data collection and creation of a base DXF map with required road geometry.
2. Building the network

   - Network characteristics
   - Demand data
   - Assignment
   - Simulation configuration

3. Preparation of a base model.
4. Collecting and analyzing the model results.
5. Validation of the base model against independent data.
6. Testing different Scenarios.

Steps one to three, consists of data collection, building of the network in PARAMICS and preparation of the base model are discussed in this chapter, while the validation, analysis of the results and the network performance scenarios are discussed under subsequent chapters.

Data Collection

The model is developed for dynamic routing of emergency response vehicles to Orlando International Airport (OIA) from the fire stations in the study area. OIA can be accessed from two directions. The north access is connected to the Semoran Boulevard (SR 436) and the Beeline expressway (SR528), and the south access is connected to the Central Florida Greeneway (SR 417). The area surrounding the OIA was surveyed to get an idea of the aerial extent to be considered for modeling. By studying the map surrounding of the OIA, the study area was determined. The study area consists of the road network in the vicinity of the OIA. Road network extends from Orange Blossom Trail in the east to State Road 417 (SR 417) in the west, covering a stretch of 11.5 miles; and from Hoffner Avenue and Oakridge Avenue in the north to SR 417 in the South covering a stretch of 9 miles. All the major roads, Beeline Expressway (SR 528), Sand Lake Rd, Land Street, Tradeport Dr, Orange Avenue, Boggy Creek Rd, Wetherbee Rd, Semoran Blvd, Goldenrod Rd, Narcoossee Rd are considered. The resulting network consists of 66 zones with 50 signalised intersections and covering an areal extent of around 100 sq miles. Seven fire stations that lie within the study area are chosen and these fire stations considered as zones for routing the emergency vehicles to the airport. Along with these roads, some of minor roads that might affect the traffic volume and cause congestion around the OIA area are considered in this study.

Seven fire stations were considered for modeling emergency routing.

- Orange County Fire Rescue Department (OCFRD) station 51, (1700 W Oak Ridge Rd)

- OCFRD Station 70, E Wallace St
- OCFRD Station 53, LA Quinta Dr
- OCFRD Station 73, 811 1st Street
- OCFRD Station 76, 11351 Narcoossee Rd
- Orlando Fire Department (OFD) Station 8, 6651 Shoal Creek Dr
- OCFRD Station 71, 4405 S Goldenrod Rd.

The detailed map of the study area along with the fire stations considered is shown in the Figure 3-1.

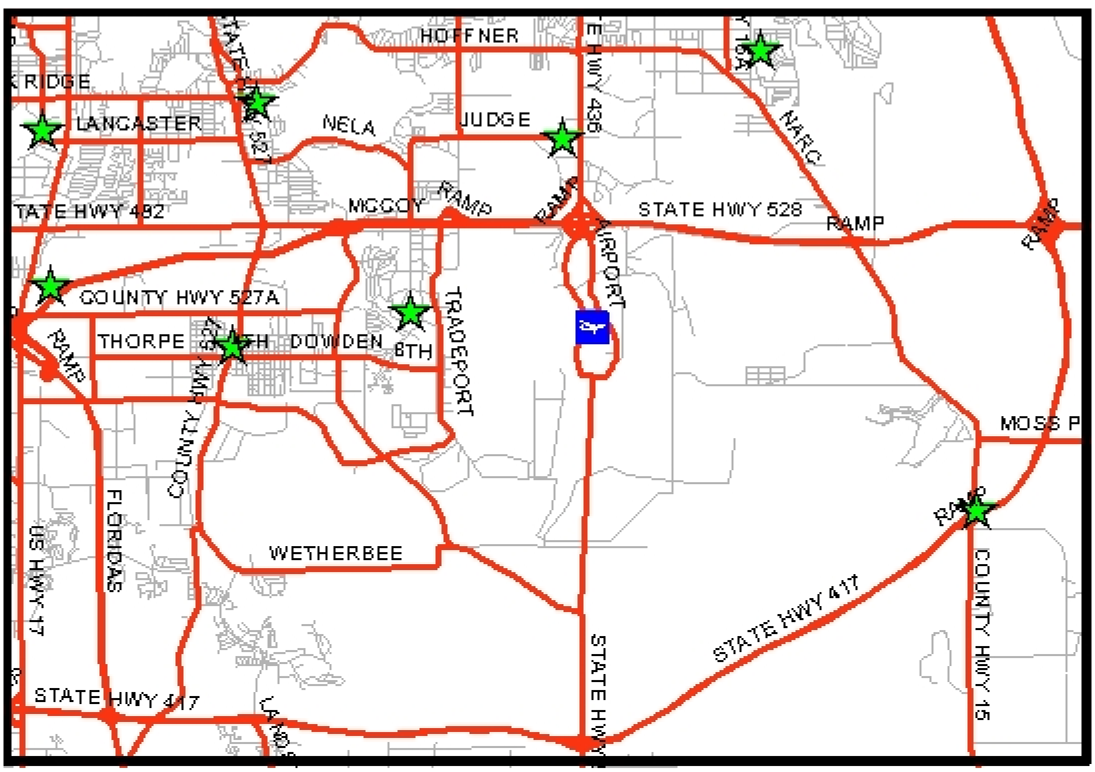

Figure3-1: Map showing the fire station and the road network modeled.

Data collection effort included the attainment and manipulation of the traffic data for the study area. The data was gathered from the expressway authority, the Orange County Traffic Engineering Department and Florida Department of Transportation (FDOT). Data mainly consisted of the traffic volume (AADT), number of lanes, speed limits on the main roads for the year 2001 from the Orange county Traffic Engineering Department website (23). The expressway traffic data including the on/off ramps data were collected from the Orlando Orange County Expressway Authority (OOCEA) website (24). The AADT's, number of lanes, speed limits collected from these sources were cross verified with the GIS data provided in the FDOT GIS database (25). These AADT's were converted to peak hour volumes by multiplying them with corresponding K (factor that convert AADT to peak hour volume) factors. Signal timing at the intersections were collected for the Orange County Data base, since the signal timing were not available for all the signalized intersections in the study, some assumptions were made about the cycle length, number of phases, phase splits depending on the configuration and characteristics of certain intersection. The data collection also included the identification of key locations such as fire station, police stations and hospitals with in the study area for emergency routing, the density of the developments in the area so as to identify the critical locations for creating traffic zones (geographical) areas where trips start and end, and also the toll plazas ramps and critical intersections. As the PARAMICS uses a geometric template to assist in coding the network nodes and links accurately, a geographic map of Entire Orange County in the AutoCAD format is obtained from the Orange County Traffic Engineering Department. The AutoCAD file is trimmed so as to meet the requirements of the study area and was then converted to a DXF (Data

Exchange Format). The file is used as a background for coding the network. Since the AutoCAD file does not the give the entire geometry of the roads considered, aerial photography available in the map quest site were used for further coding of details.

Building the Network

PARAMICS network is coded using a graphical user interface. PARAMICS uses nodes and links for creating a network. A network skeleton was created by placing links directly on the DXF file used as a background. Detailed information on each intersection node was then coded based on aerial photographs and field observations along with the help of GIS maps.

Building the network is explained in the following steps:

STEP 1: Network characteristics include the geometry, link description, signposting, lane restriction, forced lane changes, next lanes (used to configure the possible lanes which the vehicles at the end of one link might take while moving over the connecting next link), etc. The geometry includes the number of lanes, the curvature of the road, and gradient. Link description involves the type of the link, whether it is a highway, an urban road, a toll road, one way or a two way, also the stop delay and cost involved if this particular link pertaining to a toll road. The geometry and the description parameters are gathered from the data collected from various agencies and field data. Signposting provides the drivers with information on the hazards, exits, and also the approaching intersections, this has an effect on the drivers' behavior. Appropriate signposting provides the drivers with information regarding the approaching hazard and gives enough time to react. Signposting for the normal links were set to the default values, while at the intersections and the toll plazas these distances were adjusted to provide sufficient time for the drivers to react. Lane restrictions and force lane changes and next lanes are used to prevent the unrealistic moment of the vehicles, the lane restrictions are used at the toll plazas so that only (Electronic Toll Collection) ETC vehicles are permitted in their respective lanes. The force lane changes and the next lanes are used at the intersections so that lane changing behavior of the vehicles once they leave the stop sign of the intersection is prevented and unrealistic behavior of the vehicles is eliminated.

STEP 2: Demand data includes the origin/destination zone areas, level of origin/destination demand, breakdown by time period, vehicle type, and vehicle proportion. The travel demand in PARAMICS is modeled as zone to zone movements and is represented by an origin/destination matrix of trips. An O-D matrix is a two-dimensional matrix in which the rows and columns represent the origin and destination zones, respectively. Care is taken to ensure the sizes of traffic zones are consistent with the density of the modeled network and that traffic loads onto the network with adequate accuracy. Zones are divided into two type external and internal zones. External zones are the zones that are on the periphery of the network, while the internal zones lie inside the network. The external zones were selected such that, the ends of the major roads which were broken because of the area of interest, were considered as zones, while the internal zones were selected based on the density of residential or commercial areas. Finally all the fire stations are considered as zones. The methodology used in obtaining the O-D matrix in explained in detail in chapter 4. Two approaches have been used for estimating the O-D matrix namely Gravity model approach, and Heuristic approach. O-D estimated by the Heuristic approach yielded better results so this was used for simulation. The time period for simulation has been divided into two parts namely the warm-up period, and the actual simulation period. Time of the warm up period depends on the size of the network, since the size of the network that we choose is around 20 miles considering the winding in the road, the maximum a vehicle might take to travel from one end to the other is less that 30 minutes during off peak period, so a warm-up period of 30 minutes is selected, and the network is loaded with 50% of the peak hour loading. The actual simulation period is around one hour, during the actual simulation period the network is loaded with varying demands ranging from 100% of peak demand to 50% of the peak demand under different scenarios. Default values are chosen for the vehicle types and the vehicle proportions. Familiarity of the drivers is chosen to be 95%.

STEP 3: Assignment deals with link cost factors, coefficients of generalized cost equations, and assignment techniques. Link Cost factors are multiplication factors that may be applied to particular road categories or to particular links in the network (for example addition of toll cost for toll road in addition to the default link cost value). The default link cost, calculated as the time taken to travel along the link at free-flow speeds, is multiplied by the cost factor. These factored costs are then used in the routing cost calculations. Since PARAMICS cannot distinguish between the major and minor roads, in order to avoid movement of higher volumes of traffic through minor roads, link cost factors are coded for those particular link categories, similarly the cost factors are coded to the toll roads. The traffic assignment type has an influence on the drivers' route choice between an origin and a destination. The three assignments techniques available in PARAMICS are all or nothing, stochastic assignment, and dynamic feedback. All-or-nothing” assignment assumes that all drivers traveling between two zones choose the same route and that link costs do not depend on flow levels. Stochastic assignment methods try to account for variability in travel costs (driver’s perception of those costs). These methods assume that the perceived cost of travel on each network link varies randomly, within predefined limits. The calibration of the model is done by using all or nothing assignment technique initially. This is because Heuristic approach, it is tedious to include the alternative routes taken from one zone to another while calculating the OD matrix. One the O-D matrix is estimated using all or nothing assignment the model is checked with the stochastic assignment with 95% driver familiarity.

STEP 4: The parameters involved in the general configuration are time step duration, speed memory, mean target headway, and mean reaction time. The simulation time steps determine when the calculations are carried out during every second of simulation. The default time step is 2 which means that calculation are done every 0.5 seconds of the simulation. Many parameters like the vehicle speeds, and acceleration have some kind of random association with the simulation time step. So the simulation results will differ if different time steps are used. Similar is the case with speed memory, which represents the number of time steps for which a vehicle remembers its speed. The default value for this parameter in PARAMICS is 3. The higher the speed memory value, the freer the movement of the vehicles with little variation in their speeds.

A Study done by the Gardes et al. (11) on I-680 used different time steps to examine the association of the time step with the parameters, such as: vehicle speeds, acceleration, etc. The authors found that for dense network (having high density flows) smaller simulation time steps per second are required to operate the network in a freer manner. They also suggested changing the size of the speed memory from 3 to 8 for smoother movement of the vehicles.

Three basic models are implemented within PARAMICS to control the movement of individual vehicles in the network: the vehicle following, gap acceptance and lane changing models. These models are strongly influenced by two key user specified parameters: the mean headway and the mean reaction time. The overall behavior of the model can be changed considerably by increasing or decreasing the mean target headway and the mean reaction time. The default values of 1 second for the mean headway and 1 second for the reaction time have been calibrated against UK traffic conditions.

Addulhai et al. (8) reported a calibration effort on a part of I-405 California freeway. An empirical procedure was developed to calibrate the mean headway and the mean reaction time. The best results were obtained for headway =1.65 seconds and reaction time = 0.42 seconds. Also, studies indicated that the drivers in US tend to accept smaller gaps and have low reaction times than the default values. Authors (8) suggested using Headway of one second and the mean reaction time ranging from 0.8 to 0.6. Mean target headway of one second and a mean reaction time of 0.6 second are chosen.

Other details in model building

Signal Preemption

Signal preemption is the term used to describe the signal-setting strategies, when emergency vehicles such as fire trucks, ambulances, etc., are involved. In these cases, the emergency vehicle is given a green phase upon its arrival at the intersection, to pass through the intersection uninterrupted, in each and every case such a call-out is made, irrespective of the conditions on the cross street and its impact on the overall traffic. This is necessary because of the nature of the services the emergency vehicles deliver to the public. To create such a kind of systems on all the possible routes that emergency vehicles take, a PLAN and PHASE language provided by PARAMICS is used. The algorithm and the code used to implement this strategy are attached in Appendix A.

Actuated Signals

The signals are actuated to reflect the real world operation of the Vehicle Activated Signals. The traffic information detected at the loops (placed ahead of the intersection) is used to initiate sets of signal plans which have been defined to optimize the complex movements of interaction of streams of traffic. Signaling of each and every intersection was carried out using the multi-phase traffic signals in every signalized junction. Initially no signalized intersection was modeled as an actuated signal system for verification and validation purpose due to the ambiguity and unsatisfactory performance of the actuated signal in PARAMICS. The assumption was that the actuated signals always perform better than the pre-timed signal systems. The cycle length was considered between 60 seconds to 120 seconds based on the flow and the capacity and the turning volumes of the intersection. The 4-phased signal system was mainly considered for 4-way junction and 3 or 4 phases for the T-junction. After the initial validation with the pre-timed signal system, activated signal system was added by using a plan language in PARAMICS consisting of two files: (i) PLAN and (ii) PHASE files. A sample code is shown in Appendix B. The plan language associates the detectors to specific signals and defines the control parameters for changing the signal settings. The input data including cycle lengths, yellow times, all red time, minimum and maximum green times, critical gaps, etc. are taken from the orange county traffic engineering division.

Signal coordination

The traffic signals along the main arterials in our study area are coordinated to during the peak hours to increase mobility of the through traffic, reduce the time delays at the signalized intersections, and to create more uniform speeds. The offset required to coordinate the signals are gathered from the simulation runs based on the time taken by the vehicle to traverse from one signal to another. The signal coordination helps to replicate the real world scenario.

Problems in building the network

One of the main problems in PARAMICS is the movement of vehicles at intersections. This is due to the fact that PARAMICS was developed in England, where the number of approach lanes is equal to that of the lanes at the intersection. While here in US, the number of lanes at intersection is generally more than that of the approach lanes to increase the capacity of the intersection. PARAMICS allows the vehicles to be in their best lanes as they approach the intersection. This approach works fine with the networks in England, but here in US all the vehicles are to be distributed among their respective lane, which is not quite the case in PARAMICS. All the vehicles get accumulated in one or two lanes depending on the approach lanes (for example for an intersection with three approach lanes and a 2 left turn and one right turn bay, all the vehicles get stacked up in the three lanes which are in connection to the approach lanes, leaving the other lanes empty). To solve the aforementioned problems, several approaches may be employed.

First, using the next lanes option available in PARAMICS. The number of approach lanes and the number of lanes and the intersections are different, so two separate links with different lane configuration are needed. For example to model on leg of an intersection say with three approach lanes and two left turn bay and one right turn bay. Two links are needed, Link 1 for the approach segment with a three lane configuration and Link 2 for the segment at the intersection, with a six lane configuration. This implies all the vehicles in 3 lanes of the approach segment should be distributed among the 6 lanes of the Link 2. This doesn't happen in PARAMICS. So to tackle this problem, the default values of the next lanes in PARAMICS are over written, redistributing the traffic in all the lanes, like distributing the vehicles in lane 1 of the Link 1, to lanes 1 and 2 (left turning lanes) of Link 2; vehicles from lane 2 of Link 1 to lanes 3,4,5 (through lanes) of Link 2; and finally vehicles of lane 3 of Link 1 to lanes 5 and 6 (through lane and right turn bay) of lanes Link 2. This kind of distribution alleviated the above stated problem to some extent but doesn't eliminate the problem completely.

Second, separate links are used for left turning movements. The through and right turning movements are combined with the next lanes option. This approach uses two links for every approach and a total of 8 links are required at the intersections to model all the phases at an intersection. But unfortunately PARAMICS limits only 6 links per node. So this method cannot be applied to all the approaches due to the limit on the number of link per node, but this can be used to guide the vehicles in the approaches of the major streets while the first approach can be used to guide the vehicles on the minor streets.

Thirdly, the distribution of the aggression (ranges for 0 to 8 inclusive) and the awareness (ranges for 0 to 8 inclusive) attached to the drivers are changed to observe any improvement in the driver's behavior. Assigning a larger percentage of the drivers with an higher aggression factor and lower awareness helped in distribution of all the vehicles evenly among all the lanes the intersections to some extent.

All the aforementioned approaches aim at alleviating the problem on turning bays to some extent but none of the approaches or combination of approaches could eliminate the problem completely.

CHAPTER 4
OD-MATRIX ESTIMATION

Travel Demand Modeling is a multi-stage process, and there are several different techniques that can be used at each stage. Generally, travel demand modeling involves four interrelated tasks.

- Trip Generation is the prediction of the number of trips produced by and attracted to each traffic zone.
- Trip Distribution is the estimation of Origin-Destination (O-D) flows.
- Modal Split is the prediction of percentage of flow between each origin-destination pair used by different modes of transportation.
- Traffic Assignment places the O-D flows for each mode on specific routes of travel.

These four stages of modeling is used as a sequential decision process in which people decide to make a trip, decide where to go, what mode to take, and which route to take.

This chapter mostly concentrates on the trip distribution analysis. The Traffic Assignment is taken care of by the different assignment capabilities namely All or Nothing, Stochastic and Dynamic Feed Back present offered by PARAMICS, while Model Split is out of the scope of this study. Stochastic method with 95% familiar drivers and 5% perturbation factor has been used as the traffic assignment technique in this study. Two models have been considered for Trip distribution analysis namely the Gravity Model and a Heuristic Model.

Unlike other micro-simulation software (CORSIM, WATSim, etc), PARAMICS doesn't accept the turning volume counts combined with edge link volume counts, for loading the network with vehicles. PARAMICS uses zones for loading the network with vehicles. In order to distribute the trips between these zones, OD-matrix was to be established and a distribution model was needed. The study area consists of the road network in the vicinity of the OIA. The roadway network extends from Orange Blossom Trail in the east to State Road 417 (SR 417) in the west, covering a stretch of 11.5 miles; and from Hoffner Avenue and Oakridge Avenue in the north to, SR 417 in the south covering a stretch of 9 miles. All the major roadways, Beeline Expressway (SR 528), Sand Lake Rd, Land street, Tradeport Dr, Orange Avenue, Boggy Creek Rd, Wetherbee Rd, Semoran Blvd , Goldenrod Rd, Narcoossee Rd are considered. As shown in the Figure 1-1, the study area was cut from the AutoCAD file of the entire orange county which is used as a base map for creating the PARAMICS network. The links which were cut to limit the study area were used as zones for production and attraction of trips. These zones which lie on the periphery of the study area are also called as external zones. There was a need for some internal zones so as to load the entire network with vehicles. The internal zones were selected based on the density of residential or commercial areas with in the study area. Finally all the fire stations are also considered as zones. A map displaying the zones considered is shown in Figure 4-1.

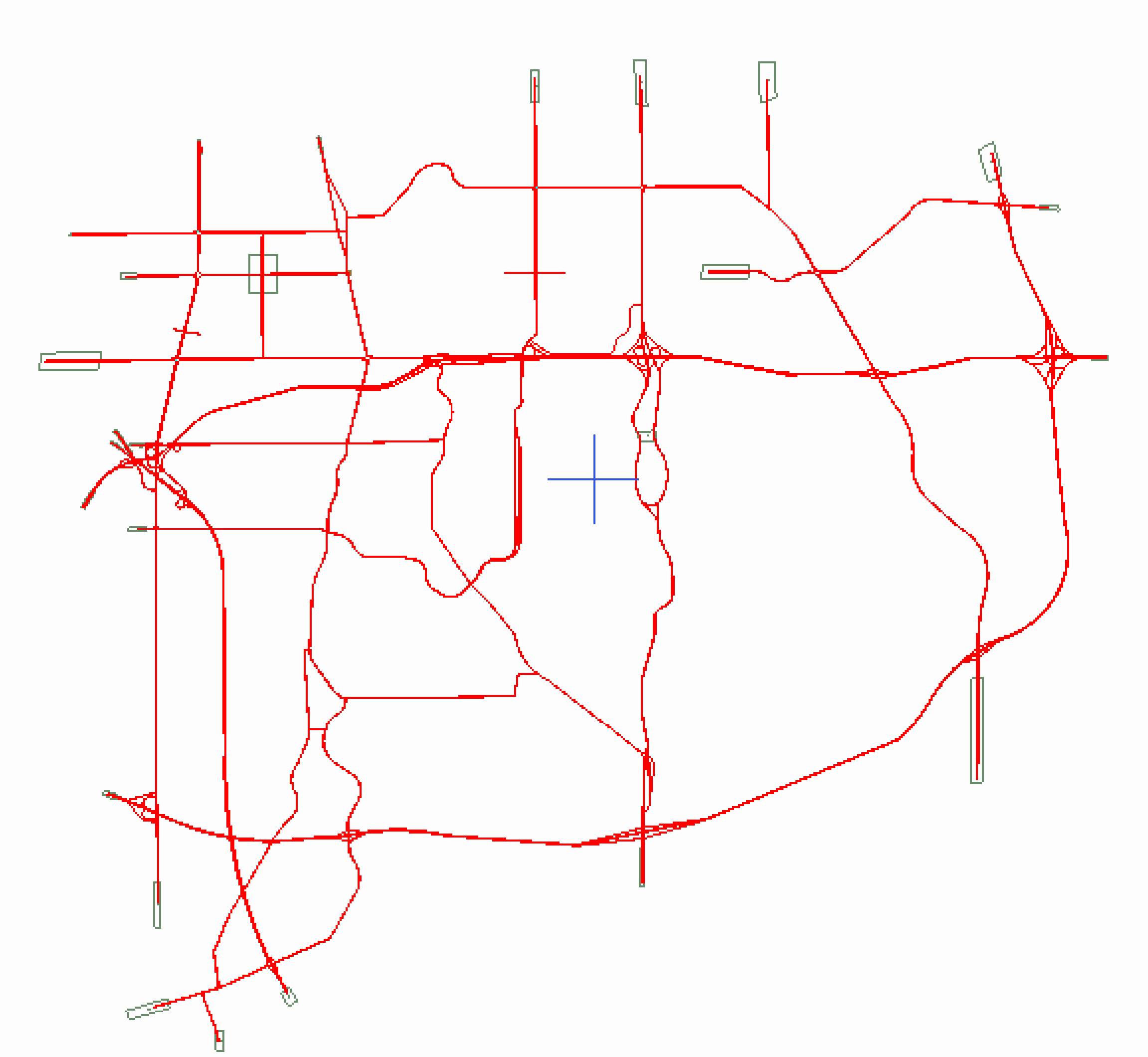

Figure 4-1: Map showing the internal and external zones considered within the study area.

Gravity Model

To date, the most widely used trip distribution model has been the "gravity model. The gravity model is based on the theory of gravity postulated by Isaac Newton in 1686, which states that the gravitational force which acts between two bodies in space is in direct proportional to the mass of the two bodies and inversely proportional to the square of distances between the bodies. The gravity model states that trip interchange between zones is directly proportional to the relative attraction between the zones and inversely proportional to some function of the spatial separation between zones. This function of spatial separation adjusts the relative attraction of each zone for the ability, desire, or necessity of the trip maker to overcome the spatial separation involved. The gravity model has achieved virtually universal use because of its simplicity and accuracy.

Mathematically, the standard form gravity model may be stated as follows:

$$T_{ij} = k \cdot \frac{O_i D_j}{c_{ij}^2} \tag{1}$$

subject to:

$$\sum_j T_{ij} = O_i \tag{2}$$

$$\sum_i T_{ij} = D_j \tag{3}$$

where

T_{ij} = trips between zone i and zone j

O_i = total number of trips starting at zone i

D_j = total number of trips ending at zone j

c_{ij} = cost of traveling from zone i to zone j

k = constant

From the gravity model formulation, it can be seen that four separate parameters are required before the trip interchanges (T_{ij}) can be computed. c_{ij} the cost function and k is a constant which takes care of socioeconomic factors involved, the number of trips "produced"(O_i) and the number of trips "attracted" (D_j) by each traffic zone in the study areas are required.

The spatial separation between zones can be measured by one of several parameters. To date, the most effective measure seems to be distance or travel time. The cost factor (c_{ij}) represents the effect of the spatial separation on the trip interchange between the zones. They indicate the impedance to inter-zonal travel due to spatial separation between zones, but these are not considered in the present discussion. To obtain travel time factors for the present period, it is currently necessary to go through a process of trial and adjustment. This process, often referred to as calibration, identifies the appropriate decay function or "friction factor", that represents the impedance of persons to make trips of various durations or distances. The adjustments are made incrementally with successive iterations of the model until the trip length frequency distribution produced by the model closely matches the frequency distribution from the travel survey or demonstrates an acceptable shape and average trip length.

Zone-to-zone adjustment factor (k) reflects the effects on travel patterns of social and economic characteristics which are not otherwise accounted for in the model. The "k" factors are developed for individual trip interchanges and are assigned values that adjust the estimated trips for the interchanges of concern to match the observed values.

Equations (2) and (3) make that the row and column sums of the O-D matrix to be the number of trips generated in each zone and the number of trips attracted, respectively. These constraint equations can be satisfied by introducing sets of constraints Ai and Bj (i.e., balancing factors) associated with production and attraction zones, respectively. The modified gravity model has the following form:

$$T_{ij} = A_i B_j O_i D_j f(c_{ij}) \tag{4}$$

where

$$A_i = \left[\sum_j B_j D_j f(c_{ij}) \right]^{-1} \tag{5}$$

$$B_j = \left[\sum_i A_i O_i f(c_{ij}) \right]^{-1} \tag{6}$$

A_i and B_j can be solved iteratively.

Zone Productions and Attractions

First step in gravity model calibration is to find the number of trips generated from the origins and the number of trips ending at the destinations. The link termination of all the routes in the study area are considered as zones, also a few internal zones are selected based on the density of local roads network. The eight fire stations in the network area were also considered as zones. Final network consisted of 26 zones including the airport and excluding the fire station zones. Trips generated and ended at these zones were calculated based on the AADT data.

The average annual daily traffic (AADT) data was obtained from the Orange County traffic engineering website and the OOCEA website. This data was also cross verified with the GIS data provided on the Florida department of transportation GIS webpage. Along with the AADT at each link, the directional split (i.e., D-factor) and the K-factor which is used to convert the AADT in to peak hour volume were provided.

The peak directional hourly flow can be calculated by the following formula:

DIRECTIONAL PEAK VOLUME = (ADT) * (K-Factor) * (D-Factor)

For most of the links in the study area the K-Factor ranged from 0.082 to 0.086, and the D-factor varied from 0.52 to 0.58, so an average K-factor of 0.086 and an average D-factor of 0.56 were selected. So as to maintain the equilibrium, each zone is considered to release and attract the same number of trips. The productions and attractions of the 26 zones considered are provided in the Table 4-1.

Table 4-1: Productions and Attractions from the zones considered.

Zone	AADT	K-Factor	D-Factor	Peak Hour Volume
1	39000	0.085	0.56	1856
2	65000	0.085	0.56	2841
3	24000	0.085	0.56	1049
4	24000	0.085	0.56	1049
5	24000	0.085	0.56	1049
6	50000	0.085	0.56	2185
7	12000	0.085	0.56	524
8	39000	0.085	0.56	1704
9	24000	0.085	0.56	1049
10	54000	0.085	0.56	2360
11	12000	0.085	0.56	524
12	26000	0.085	0.56	1136
13	50000	0.085	0.56	2185
14	24000	0.085	0.56	1049
15	24000	0.085	0.56	1049
16	32000	0.085	0.56	1398
17	24000	0.085	0.56	1049
18	12000	0.085	0.56	524
19	32000	0.085	0.56	1398
20	24000	0.085	0.56	1049
21	35000	0.085	0.56	1530
22	30000	0.085	0.56	1311
23	24000	0.085	0.56	1049
24	55000	0.085	0.56	2404
25	25000	0.085	0.56	1093
26	60000	0.085	0.56	2622

Calibration

Calibration involves estimating the values of various constants and parameters in the model structure. Gravity model can be calibrated using the friction factor k_{ij} and zone to zone cost adjustment factor c_{ij}. Estimating model coefficients and constants is usually done by solving the model equation for the parameters of interest after supplying observed values of both the dependent and independent variables.

The cost of traveling form zone "i" to zone "j" is based on the following considerations:

(i) Distance between zone i to zone j,

(ii) The number of intersections (both signalized and stop controlled) between zone i to zone j, and

(iii) Toll roads based on the number of toll plazas. The following is the equation used to estimate the cost:

$$C_{ij} = \alpha_{ij} + \beta_1 D_{ij} + \beta_2 \cdot \psi \cdot I_{ij} + T_{ij}$$

where,

α_{ij} = constant ($)

β_1 = distance-cost coefficient ($/mile)

D_{ij} = the trip length between zone i to zone j (mile)

β_2 = intersection-cost coefficient ($/intersection) due to the delay at an intersection as well as the complexity of route

I_{ij} = the number of intersections between zone i to zone j

T_{ij} = the total amount of toll

In our analysis K_{ij} is considered as an adjusting factor, to control the assignment of trips to different zones based on their proximity. Since the zones in the network are not distributed throughout the network, and cluster of zones are observed in particular areas of the study area considered, K_{ij} factor is used to balance the distribution of the trips between the zones so as to distribute the trip over the entire network. The network is divided into different sectors as shown in the Figure 4-2, each sector consisting of a group of zones that are close to each other. K_{ij} factor between the zone i and j which belong to the same sector are given a high value of K_{ij} avoiding the assignment of larger percentage of trips between them. Similarly a low value of K_{ij} mostly zero is assigned between the zones i of one sector and zone j of another sector.

The number of intersections and the number of toll plazas for every zone to zone are taken based on the shortest path given by PARAMICS while using the “all-or-nothing assignment”. Distances, intersections, and toll plaza matrix between different zones is shown in Tables 4-2, 4-3 and 4-4.

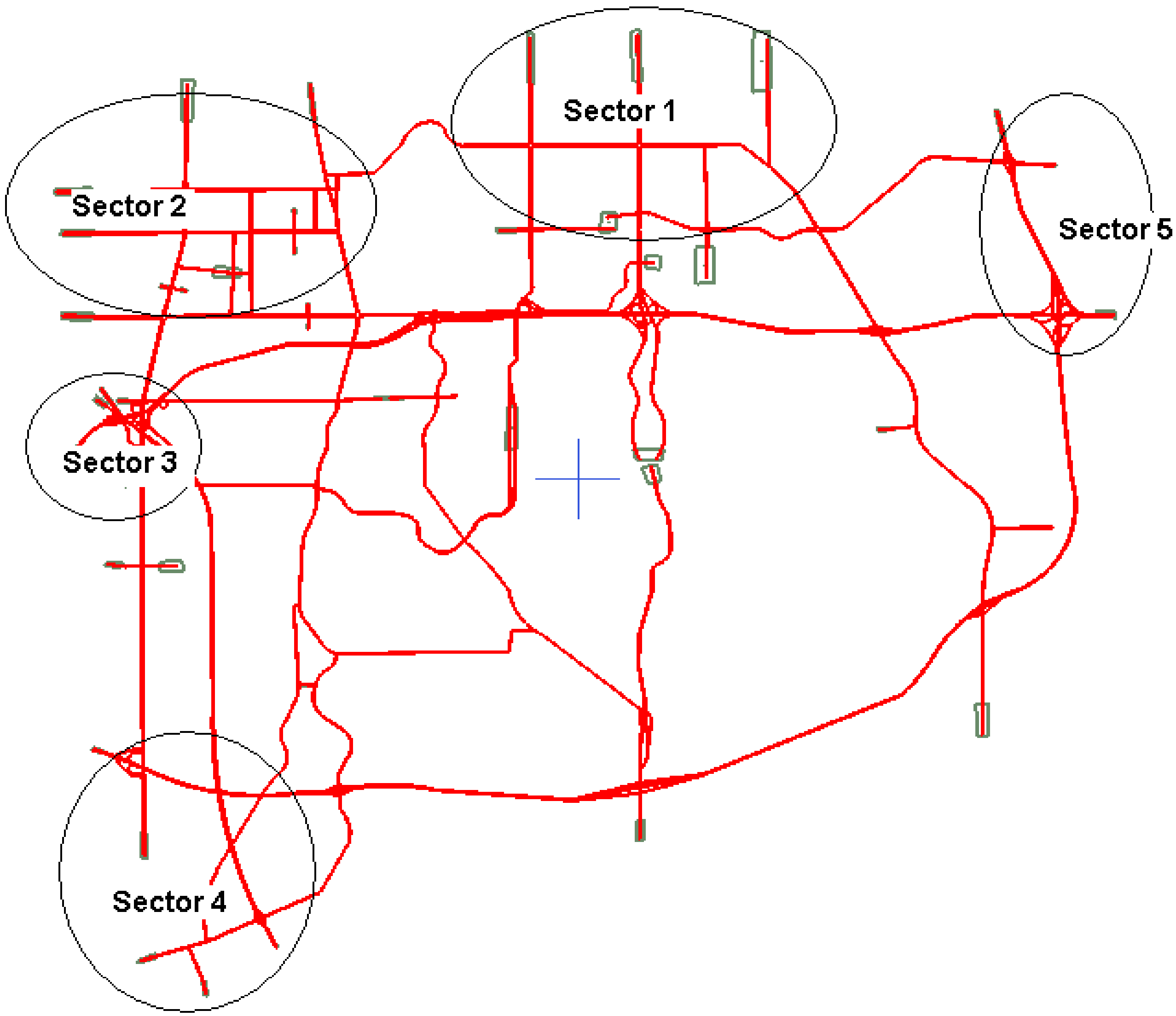

Figure 4-2: Network showing the division of sectors based on the closeness between the zones

Table 4-2: Distances between the zones in 100's of feet.

ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	0	190	224	208	130	308	288	397	344	376	338	546	546	585	585	642	570	732	598	540	540	425	425	299	233	371
2	190	0	113	110	99	210	190	298	246	265	240	448	448	596	596	543	657	819	673	771	759	640	640	540	470	458
3	224	113	0	110	99	210	190	298	246	265	240	448	448	596	596	543	657	819	673	771	759	640	640	540	470	458
4	208	110	110	0	67	174	154	242	210	230	204	412	412	561	561	508	623	785	639	737	737	606	606	526	442	424
5	130	99	99	67	0	174	154	242	210	230	204	412	412	561	561	508	623	785	639	737	737	606	606	526	442	424
6	308	210	210	174	174	0	102	212	179	179	153	361	361	510	510	457	597	760	626	712	713	590	581	481	416	416
7	288	190	190	154	154	102	0	124	79	90	71	273	273	273	422	422	369	519	616	720	720	622	583	502	421	450
8	397	298	298	242	242	212	124	0	102	102	102	304	304	425	425	360	551	838	692	790	790	669	659	659	505	526
9	344	246	246	210	210	179	79	102	0	45	65	270	273	468	468	468	519	831	685	783	783	638	652	552	496	519
10	376	265	265	230	230	179	90	102	45	0	65	270	273	468	468	468	519	831	685	783	783	638	652	552	496	519
11	338	240	240	204	204	153	71	102	65	65	0	270	273	468	468	468	519	831	685	783	783	638	652	552	496	519
12	546	448	448	412	412	361	273	304	270	270	270	0	219	219	462	462	409	465	834	679	771	977	630	660	491	481
13	546	448	448	412	412	361	273	304	273	273	273	219	0	219	462	462	409	465	834	679	771	977	630	660	491	481
14	585	596	596	561	561	510	422	425	468	468	468	219	219	0	43	91	402	697	859	955	955	852	887	773	708	708
15	585	596	596	561	561	510	422	425	468	468	468	462	462	43	0	91	402	697	859	955	955	852	887	773	708	708
16	642	543	543	508	508	457	369	360	468	468	468	462	462	91	91	0	350	650	795	408	408	870	961	910	806	568
17	570	657	657	623	623	597	519	551	519	519	519	409	409	402	402	350	0	335	498	593	593	555	639	474	529	260
18	732	819	819	785	785	760	762	838	831	831	831	465	465	697	697	650	335	0	239	352	352	307	392	460	528	387
19	598	673	673	639	639	626	616	692	685	685	685	834	834	859	859	795	498	239	0	160	160	240	325	393	461	320
20	540	771	771	737	737	712	720	790	783	783	783	679	679	955	955	408	593	352	160	0	40	187	286	340	408	412
21	540	759	759	737	737	713	720	790	783	783	783	771	771	955	955	408	593	352	160	40	0	187	286	340	408	412
22	425	640	640	606	606	590	622	669	638	638	638	977	977	852	852	870	555	307	240	187	187	0	157	225	292	296
23	425	640	640	606	606	581	583	659	652	652	652	630	630	887	887	961	639	392	325	286	286	157	0	199	267	303
24	299	540	540	526	526	481	502	659	552	552	552	660	660	773	773	910	474	460	393	340	340	225	199	0	80	203
25	233	470	470	442	442	416	421	505	496	496	496	491	491	708	708	806	529	528	461	408	408	292	267	80	0	230
26	371	458	458	424	424	416	450	526	519	519	519	481	481	708	708	568	260	387	320	412	412	296	303	203	230	0

Table 4-3: Number of Intersections between the zones

ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	0	3	3	5	3	6	7	7	10	9	9	11	11	9	11	6	9	7	4	6	6	5	4	3	2	4
2	3	0	3	5	3	6	7	7	10	9	9	11	11	9	11	6	9	7	4	6	6	5	4	3	2	4
3	3	3	0	2	2	3	4	4	7	6	6	8	8	6	6	4	10	9	5	7	5	8	8	7	6	5
4	5	5	2	0	1	2	3	3	6	5	6	8	8	5	5	3	9	6	5	7	7	7	6	5	6	5
5	3	3	2	1	0	2	3	3	6	5	6	8	8	5	5	3	9	6	5	7	7	7	6	5	6	5
6	6	6	3	2	2	0	1	3	2	3	5	5	5	5	1	7	5	3	3	1	3	3	2	1	1	1
7	7	7	4	3	3	1	0	1	2	2	4	4	3	3	0	8	4	0	2	0	2	2	2	1	1	0
8	7	7	4	3	3	3	1	0	2	1	2	4	4	3	3	0	8	4	0	2	0	2	2	1	1	0
9	10	10	7	6	6	2	2	2	0	2	4	6	6	7	7	3	8	7	3	5	3	5	4	5	4	3
10	9	9	6	5	5	3	2	1	2	0	4	6	6	7	7	3	8	7	3	5	3	5	4	5	4	3
11	9	9	6	6	6	5	4	2	4	4	0	6	6	7	7	3	8	7	3	5	3	5	4	5	4	3
12	11	11	8	8	8	5	4	4	6	6	6	0	3	3	5	5	1	5	4	3	4	2	4	4	3	2
13	11	11	8	8	8	5	3	4	6	6	6	3	0	3	5	5	1	5	4	3	4	2	4	4	3	2
14	9	9	6	5	5	5	3	3	7	7	7	3	3	0	1	3	8	8	6	8	6	10	8	7	7	7
15	11	11	6	5	5	1	0	3	7	7	7	5	5	1	0	3	8	8	6	8	6	10	8	7	7	7
16	6	6	4	3	3	7	8	0	3	3	3	5	5	3	3	0	4	6	4	6	8	7	2	1	1	6
17	9	9	10	9	9	5	4	8	8	8	8	1	1	8	8	4	0	4	2	4	2	3	6	2	4	1
18	7	7	9	6	6	3	0	4	7	7	7	5	5	8	8	6	4	0	2	4	2	5	6	7	8	3
19	4	4	5	5	5	3	2	0	3	3	3	4	4	6	6	4	2	2	0	2	0	3	4	5	6	0
20	6	6	7	7	7	1	0	2	5	5	5	3	3	8	8	6	4	4	2	0	2	3	4	5	6	1
21	6	6	5	7	7	3	2	0	3	3	3	4	4	6	6	8	2	2	0	2	0	3	4	5	6	1
22	5	5	8	7	7	3	2	2	5	5	5	2	2	10	10	7	3	5	3	3	3	0	2	3	4	3
23	4	4	8	6	6	2	2	2	4	4	4	4	4	8	8	2	6	6	4	4	4	2	0	2	3	2
24	3	3	7	5	5	1	1	1	5	5	5	4	4	7	7	1	2	7	5	5	5	3	2	0	2	1
25	2	2	6	6	6	1	1	1	4	4	4	3	3	7	7	1	4	8	6	6	6	4	3	2	0	2
26	4	4	5	5	5	1	0	0	3	3	3	2	2	7	7	6	1	3	0	1	1	3	2	1	2	0

Table 4-4: Number of Toll plazas between the zones

ZONE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	1	1	2	2	0	0	0	0	1
2	0	0	0	0	0	0	0	2	0	1	0	0	0	1	1	1	0	1	1	2	2	1	1	1	0	1
3	0	0	0	0	0	0	0	2	0	1	0	0	0	1	1	1	0	1	1	2	2	1	1	1	0	1
4	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	1	1	2	2	1	1	1	1	1
5	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	1	1	2	2	1	1	1	1	1
6	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	1	1	2	2	1	1	1	1	1
7	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	2	2	3	2	1	1	1	1	1
8	0	2	2	1	1	1	1	0	0	1	1	1	1	1	1	1	3	3	4	4	3	3	2	2	2	2
9	1	0	0	0	0	0	0	0	0	1	0	0	0	1	1	1	0	2	2	3	3	2	1	1	1	1
10	0	1	1	0	0	1	1	1	1	0	0	0	0	1	1	1	0	2	2	3	3	2	1	1	1	1
11	1	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	2	2	3	3	2	1	1	1	1
12	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	2	2	3	3	2	1	1	1
13	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	2	2	3	3	2	1	1	1
14	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	2	2	2	1	1	1	1	1
15	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	2	2	2	1	1	1	1	1
16	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	2	2	2	1	2	2	2	1
17	1	0	0	0	0	0	0	3	0	0	0	1	1	1	1	1	0	1	1	2	2	1	1	0	0	0
18	1	1	1	1	1	1	2	3	2	2	2	0	0	1	1	1	1	0	1	1	1	0	0	0	0	0
19	1	1	1	1	1	1	2	4	2	2	2	2	2	2	2	2	1	1	0	1	1	1	1	1	1	1
20	2	2	2	2	2	2	3	4	3	3	3	2	2	2	2	2	2	1	1	0	1	0	0	0	0	1
21	2	2	2	2	2	2	3	3	3	3	3	3	3	2	2	2	2	1	1	1	0	0	0	0	0	1
22	0	1	1	1	1	1	2	3	2	2	2	3	3	1	1	1	1	0	1	0	0	0	0	0	0	1
23	0	1	1	1	1	1	1	2	1	1	1	2	2	1	1	2	1	0	1	0	0	0	0	0	0	0
24	0	1	1	1	1	1	1	2	1	1	1	1	1	1	1	2	0	0	1	0	0	0	0	0	0	0
25	0	0	0	1	1	1	1	2	1	1	1	1	1	1	1	2	0	0	1	0	0	0	0	0	0	0
26	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	0	0	0

All the distances, intersection, and toll cost are converted to a consistent unit.

Distance cost coefficient (β_1- cost per 100ft)

Distance cost consists of fuel and maintenance cost, and time cost. At an average of 10 miles per one gallon of fuel (which includes the maintenance costs). At an average of $2.00 per gallon of fuel, fuel costs are calculated. Time cost is based on $10 per hour average pay, and the considering an average speed of 30 mph on any during the peak hour, time cost is calculated.

Cost due to the delay incurred at an intersection

Assuming that during the peak hour the level of service of the intersection is around E, so an average delay of 60sec is taken per intersection. Based on the $10 per an hour, the cost per 1 min is selected.

Toll cost

An average cost of $0.50 is selected for each toll plaza.

Changing the value of K_{ij} from 6 to 10, the OD-Matrix is obtained using a C++ program. The source code of the program is attached in the appendix. Using this OD-Matrix the PARAMICS model is run, the results from the runs (the peak hour volume) are compared with the actual AADT at 17 different points in the network. The results are shown in Table 4-5 and part OD-Matrix estimated is shown in Table 4-6.

By analyzing the results we can see that there is no particular pattern found between the link counts from the simulation runs and the actual traffic volume calculated from the AADT of the links, using different values of K_{ij} ranging for 6 to 10 and also varying the cost per intersection, toll plaza, and fuel costs. The error between the simulated links counts and the actual links counts was high. So there was a need to shift to a different distribution model. So a heuristic approach was used to distribute the trips between the zones. Heuristic Method is discussed in the subsequent section of this chapter.

Table 4-5: Comparison of simulated results with that of the actual link counts

			Towards Airport			Error %		
Data	**ACTUAL**		K=7	K= 8	K=9	K=7	K= 8	K=9
Points	AADT	Peak flow	Simulated flow	Simulated flow	Simulated flow			
1	32000	1382	1107	1090	1121	20	21	19
2	51500	2225	1430	1460	1600	36	34	28
3	26000	1123	529	596	1200	53	47	-7
4	16100	696	965	1004	967	-39	-44	-39
5	11200	484	244	448	431	50	7	11
6	18100	782	870	992	906	-11	-27	-16
7	49500	2138	2028	2031	2013	5	5	6
8	53000	2290	2105	2056	2123	8	10	7
9	70000	3024	2333	2503	2178	23	17	28
10	70000	3024	2217	2473	2200	27	18	27
11	51200	2212	1233	1755	2078	44	21	6
12	38000	1642	529	1080	1075	68	34	35
13	58000	2506	1812	428	1820	28	83	27
14	26000	1123	282	1532	1000	75	-36	11
15	55500	2398	934	1042	944	61	57	61
16	14800	639	917	792	936	-43	-24	-22
17	21000	907	1082	1034	1070	-19	-14	-18
					AVERAGE	23	12	9

Table 4-6: OD-Matrix from the Gravity Model

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	--	--	25	26
1	0	90	30	27	29	62	31	103	43	137	29	49	97	59	57	70	39	18	--	--	27	121
2	90	0	60	53	55	122	74	182	103	289	70	104	204	95	93	132	70	30	--	--	119	190
3	30	60	0	19	19	44	30	69	40	112	28	39	76	35	35	48	23	10	--	--	36	63
4	27	53	19	0	18	41	35	91	43	130	28	37	73	34	34	46	22	10	--	--	30	60
5	29	55	19	18	0	41	34	90	42	130	28	37	73	34	34	46	22	10	--	--	30	60
6	62	122	44	41	41	0	17	62	30	87	19	117	231	93	105	115	66	27	--	--	93	178
7	30	72	30	34	34	17	0	10	5	14	3	22	47	23	19	17	15	5	--	--	13	25
8	103	182	69	91	90	62	10	0	20	61	13	81	146	72	73	121	32	14	--	--	47	90
9	43	103	41	43	43	30	5	20	0	27	6	40	77	27	27	36	19	6	--	--	21	40
10	137	289	112	130	130	87	14	61	28	0	18	122	238	82	83	110	59	19	--	--	64	122
11	29	70	28	28	28	19	3	13	6	18	0	26	50	17	17	23	12	4	--	--	13	25
12	49	104	39	37	37	117	23	81	40	122	26	0	37	22	18	21	38	19	--	--	33	66
13	97	204	76	73	73	231	48	146	77	238	50	37	0	44	34	41	75	37	--	--	65	130
14	59	96	35	34	34	94	17	72	27	82	17	22	44	0	33	36	37	14	--	--	27	52
15	57	93	36	34	34	105	19	73	27	83	17	18	34	33	0	37	38	14	--	--	27	52
16	70	132	48	46	46	115	19	121	36	110	23	21	41	36	36	0	56	18	--	--	30	75
17	39	70	23	23	22	66	11	32	19	59	12	38	76	37	38	56	0	18	--	--	29	121
18	18	30	10	10	10	27	4	14	6	19	4	19	37	14	14	18	18	0	--	--	14	41
19	67	112	38	35	35	96	13	48	23	71	15	30	58	33	34	44	44	41	--	--	44	137
20	54	77	26	24	24	71	10	36	16	49	10	31	60	26	26	58	28	25	--	--	48	93
21	81	116	41	36	36	102	14	60	25	76	16	38	74	40	40	83	44	40	--	--	71	138
22	101	117	38	36	36	103	14	53	24	73	15	26	51	35	35	43	40	37	--	--	22	130
23	80	91	29	28	28	82	12	45	20	62	13	29	56	27	27	31	25	22	--	--	18	126
24	204	195	61	58	58	180	26	83	41	125	26	55	109	55	56	59	75	35	--	--	38	351
25	27	119	36	30	30	93	14	47	21	64	13	33	65	27	27	30	29	14	--	--	0	134
26	121	190	63	60	60	178	26	90	40	122	25	66	130	52	52	76	121	41	--	--	134	0

Heuristic Approach for OD Estimation

The O-D matrix estimated using gravity model yielded higher percentage of errors between the simulated and actual link volume counts. After several trials, by changing different parameters in the gravity model one parameter at a time, no pattern was observed from one simulated link counts to the other so as to zero on to best values of the parameters in the gravity model that yield O-D matrix with reasonable percentage of error. So another approach for trip distribution was needed. Heuristic method, which is based on using the link volume counts and balancing each junction volumes, was used. Following are the assumptions made to estimate the OD-Matrix for the microscopic traffic simulation model.

Assumptions:

1. OD generated would be for the peak hour volume
2. Movement of vehicles within zones does not occur.
3. Minor streets/residential streets were not modeled in detail. However suitable and required minor/residential street that connect residential area/complexes to the major network were considered.

Methodology:

1. First, all major highways are taken one at a time. All the major intermediate links where the hourly traffic volumes for both directions are available are identified.

2. Two ends of the links are declared zones if possible. If one end merges with other intersection or roads, attention is given as that end collectively should absorb or release required number of vehicles in both directions for the highway under consideration.

3. First zone releases all the vehicles to the second zone. Similarly second zone release all the vehicles to the first zone.

4. If there are intermediate links along that highway that have different link-volumes then that should be adjusted by vehicles coming from or going to other zones.

5. If the vehicles generated are more than the number of vehicles reaching another link/zone then they should be diverted to some other zone depending upon the condition of the intersecting links/roads. As vehicle can turn left or right, adjustment has to be done and it cannot be done immediately. We have to just make note of this fact and it should be brought into consideration when that other link/road of interest is being loaded with link volumes.

6. If number of vehicles going is less than number of vehicles reaching another zone/link then the additional amount of vehicles should come from another zone/link. Here there are two possibilities. Either vehicle can come turning left or turning right from the intersecting road/link but this can be determined only when the second road is considered for the loading with the traffic volume.

7. All the above steps (1-6) are repeated so as to balance the link volume counts from the heuristic model with the link data collected.

8. The simulated link volume data are compared with actual link volume counts. Any errors are noted and analyzed to find the root cause that error. Observation of animation of the simulation also explained other possible sources of errors pertaining to the software and configuration of the roads/intersection.

9. After studying the problem and finding the probable causes of the problem, adjustments are done accordingly. Those adjustments or smoothening of the OD pairs could be according to any of the points mentioned below.

- Redefining right turning volume/left turning volume
- Possibility of missing a zone which actually contributes much vehicular movement in the area of interest
- Blocking of the vehicles because of a bug in the software
- Improperly defined priority in configuration
- Improper signal timing
- Other software problems such as, lane changing behavior, improper stoppage of the turning vehicles along “through lane” etc.

After modification, the current OD pairs simulation is again run and compared against the actual link volume counts. Any discrepancies are again noted and smoothening is again done. The iterations are continued till the simulated link volume is within the statistical tolerance limit of actual link volume counts. After performing several iterations, a reasonable OD matrix which can be used for analysis was estimated. A part of OD matrix obtained using aforementioned heuristic approach is shown in the Table 4-7.

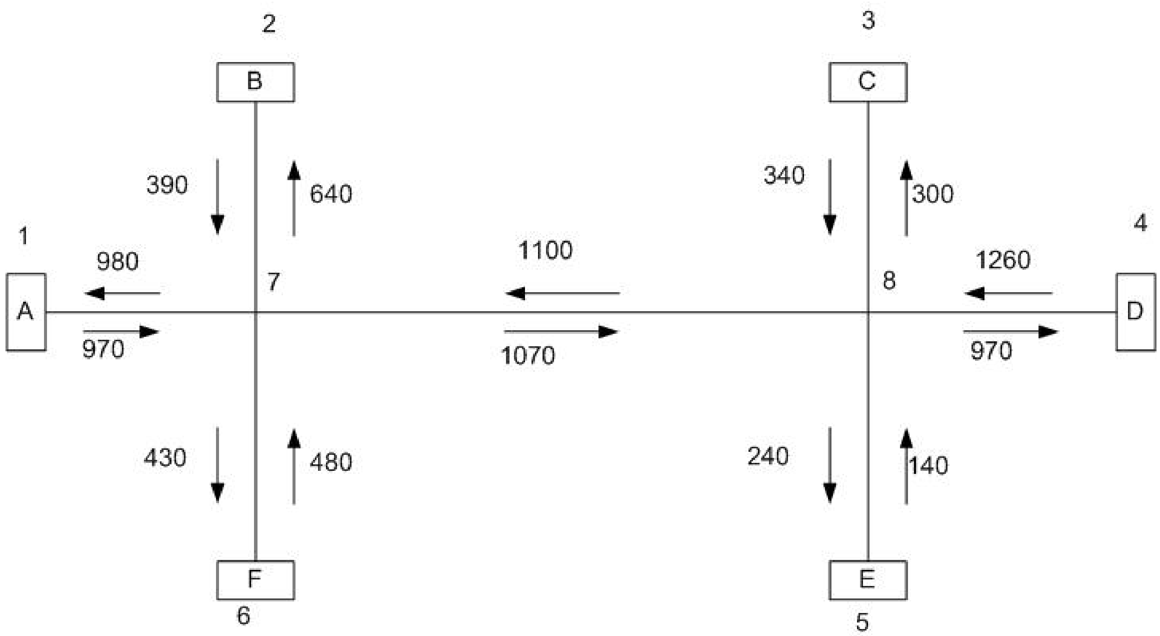

Figure 4-3: Sample network for demonstrating the heuristic approach of O-D Matrix estimation

A sample network with 6 zones and two intersections is shown in Figure 4-3. The link volumes of all the links are also shown in the Figure 4-3. In order to estimate the zone to zone production and attractions the following method is employed.

Zone A to F are considered to generate and attract the same number of vehicles, as that of the link volume that they are associated with. So for example zone F generates 480 trips and attracts 430 trips. Now consider the major links 1-4, 2-6, and 3-5. First it is assumed that vehicles move from zone 1-4, 2-6 and 3-5 only and no other combinations are possible. With this kind of assignment the number of vehicles generated at zone A does not equal to the number of vehicles attracted at zone D. Similar is the case with all other zones. The differences between the zone productions of the form-zones, to the zone attractions of the to-zones are calculated. The calculations are shown in the Figure 4-4. This difference in the vehicle counts is distributed among the different zones so as to balance the link volume counts of all the links. There after the intersections are examined to verify the turning volume at the intersections. Based on the number of left turn and right turn pockets the vehicles are redistributed, and the balancing is done simultaneously.

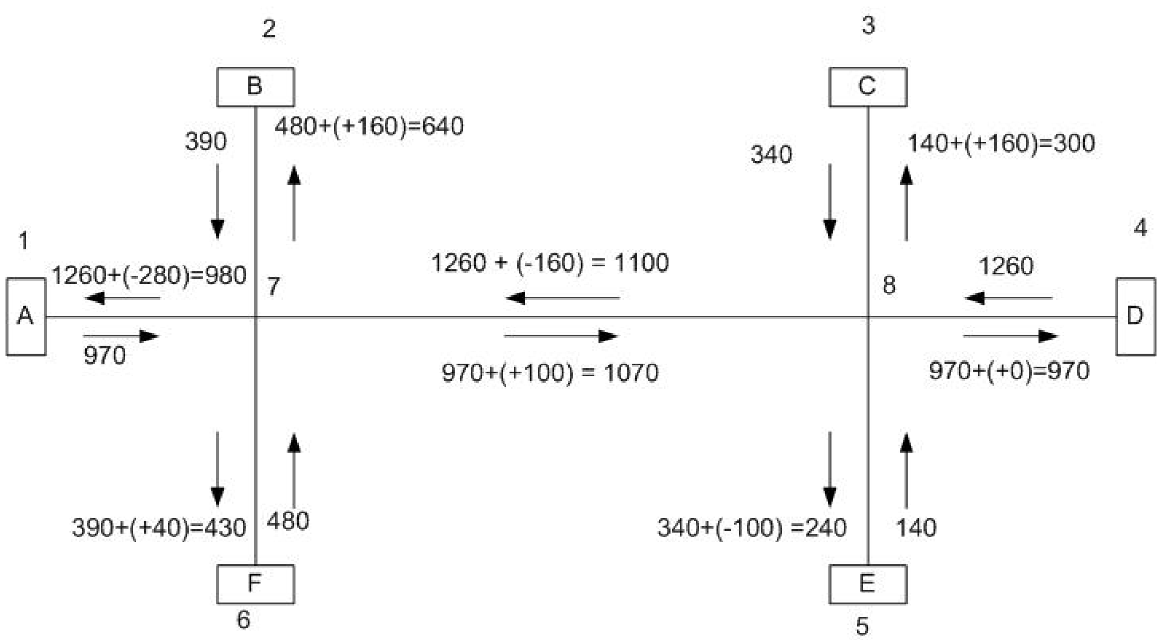

Figure 4-4: A sample calculation for estimating the OD Matrix using Heuristic approach

Table 4-7: Part of OD-Matrix estimated using heuristic method

		Zone	Zone	Zone	Zone	Zone	Zone	Zone	Zone	Zone	Zone	Zone	--
Location		1	2	3	4	5	6	7	8	9	10	11	--
Semoran North	from 1	0	200	0	142	0	0	706	0	0	0	0	--
Airport	from 2	1140	0	15	25	0	100	0	25	75	0	115	--
Golden Rod	from 3	0	0	0	392	0	0	0	0	0	15	0	--
Conway	from 4	0	0	368	0	200	0	115	0	0	0	0	--
Oak Ridge West	from 5	0	0	200	0	0	400	0	0	0	0	0	--
Sand Lake West	from 6	0	0	0	0	0	0	0	0	0	0	0	--
Beeline West	from 7	314	639	0	0	0	0	0	0	0	0	0	--
Orange avenue South	from 8	0	0	0	0	0	0	0	0	0	0	0	--
Boggy Creek South	from 9	0	55	0	0	0	0	0	0	0	0	279	--
SR 15 South	from 10	0	0	350	0	0	0	0	0	0	0	65	--
SR 417 East	from 11	0	22	0	0	0	0	0	0	396	115	0	--
Fire Semoran	from 12	0	0	0	0	0	0	0	0	0	0	0	--
Fire Hoffner	from 13	0	0	0	0	0	0	0	0	0	0	0	--
Fire Boggey Creek	from 14	70	0	0	0	0	350	0	100	50	0	0	--
SR 417 West	from 15	0	21	0	0	0	0	0	0	90	150	559	--
OBT South	from 16	0	0	0	0	0	350	0	0	0	0	0	--
Turnpike North	from 17	0	0	0	0	0	0	0	0	0	0	0	--
Beeline East	from 18	421	640	488	95	0	0	0	0	0	0	1011	--
Turnpike South	from 19	0	0	0	0	0	0	0	0	0	0	0	--
Landster Boulevard North	from 20	0	0	0	0	0	0	0	0	0	0	80	--
Landster Boulevard South	from 21	0	0	0	0	0	0	0	0	0	0	23	--
Lake Nona	from 22	0	0	0	0	0	0	0	0	0	290	253	--
Orange avenue North	from 23	50	0	0	0	186	0	0	650	25	0	0	--
OBT North	from 24	0	0	0	0	200	80	0	0	0	0	0	--
Orlando Central Parkway E	--	--	--	--	--	--	--	--	--	--	--	--	--

CHAPTER 5
CALIBRATION AND VALIDATION

Due to the stochastic nature of simulation models, a large number of simulation runs are to be conducted for calibration of the model and estimation of the measures of effectiveness with reasonable accuracy. Each PARAMICS model run with different "random seed" under identical operational conditions produces different results.

The seed value is a starting value for the random number generator, from which a set of random numbers is generated. These random numbers are used to calculate different parameters in the simulation, such as car following, lane changing, and driver behavior to mention a few. For example a simulation run with a random seed of 100 might assign to vehicle 1 an aggression parameter of 6, vehicle 2 with an aggression parameter of 4, etc, while a simulation run with a random seed of 101 might assign different aggression parameters other than 6 and 4 for vehicles 1 and 2, respectively. Using the same random number under similar network conditions will produce the same results (i.e., Measures of Performance). To include the randomness, a different random seed numbers are to be used, but, at the same time traffic models need more or less stable set of results with not much variability.

For better results, a random number table that provides both stability and accuracy to the model is to be used. So the following interrelated steps have been adopted to select the random numbers.

- Estimation of number of simulation runs required to produce the desired results.
- Collection of viable "random numbers" to obtain the desired results.

Both the steps mentioned above depend on each other.

Estimation of simulation runs

The following equation can be used to compute the required number of simulation runs,

$$n_r \geq \frac{s^2 z^2_{\alpha/2}}{\varepsilon^2} \tag{1}$$

where:

s^2 = variance (based on trial runs)

$z^2 \alpha/2$ = threshold value for a 100(1- α) percent confidence interval

n_r = number of runs required

ε = maximum error of the estimate

In general, comparison of the following parameters under different random numbers is used to determine the number of simulation runs required.

These are as follows:

- Traffic flows
- Queue lengths (maximum and average) and stop time

- Delays (network wide and at individual junctions)
- Traffic speeds
- Traffic density
- Travel times

For smaller networks, delays might be used reasonably to get the behavior of the simulator, while traffic speeds, and traffic density may not provide much insights about how the simulated network is behaving, hence for larger networks traffic flows and travel times are considered more appropriate. To decide upon the number of simulation runs required, travel times has been chosen as the performance measure and for selecting the viable simulation seed numbers, traffic flows from the different zones are used as a performance measure.

To begin, 10 random seed numbers have been selected. Travel time between one zone to another, is taken as the performance measure. Eight such zones have been selected and using the OD matrix obtained using the heuristic method; simulation has been performed for 10 simulation runs. These eight zones are the fire station zones. By using these zones we can get the better estimate of the number of simulation runs required. The travel times for different seed numbers for different zones are shown in Table 5-1.

Table 5-1: Simulated travel time from selected zones to selected zone under different seed numbers

	Travel Times for Fire stations to Airport						
Seed number	*OFD 8*	*OCFRD 70*	*OCFRD 53*	*OCFRD 51*	*OCFRD 73*	*OCFRD 71*	*OCFRD 76*
191	0:04:08	0:10:09	0:11:26	0:13:00	0:08:50	0:06:27	0:10:57
198	0:04:05	0:09:56	0:09:16	0:13:13	0:08:51	0:07:06	0:11:00
2626	0:04:02	0:09:30	0:09:07	0:12:55	0:09:09	0:06:45	0:09:36
3883	0:04:18	0:09:09	0:09:29	0:11:23	0:09:55	0:06:40	0:10:21
5430	0:04:21	0:09:56	0:09:16	0:13:22	0:08:11	0:07:06	0:10:50
6083	0:04:15	0:10:02	0:09:19	0:13:13	0:10:11	0:06:41	0:09:38
6556	0:04:02	0:09:42	0:10:21	0:12:57	0:10:01	0:06:34	0:10:03
7331	0:04:12	0:11:03	0:09:35	0:14:04	0:10:00	0:07:15	0:10:20
8613	0:04:10	0:10:21	0:09:51	0:12:17	0:09:26	0:06:32	0:11:56
8734	0:04:17	0:09:36	0:08:46	0:13:48	0:09:13	0:06:40	0:09:25

Using the simulated travel time data from the above table 5-1 and using equation (1), the number of simulation runs required are calculated. One such sample calculation for travel time from zone 36 to zone 2 is shown below.

Mean travel time = 9:56 minutes

s of this data = 31 sec

$s^2 = 961 \text{ sec}^2$

$\alpha = 0.05$ (corresponds with 95% confidence)

$\alpha/2 = 0.025$ (corresponds with 95% confidence)

$z = 1.96$ from statistical table for a two tailed test

$\varepsilon = 30$ s (assuming an error 5% of the mean travel time)

Similar calculations have been performed on the simulated travel time from eight zones. The results are presented in table 5-2.

Table 5-2: Summary of the number of simulation runs required.

	Mean Travel Time	*St.dev (sec)*	*Allowable Error (sec)*	*Number of Simulation runs*
OFD8 to Airport	0:04:11	7	13	2
OCFRD 70 To Airport	0:09:56	31	30	5
OCFRD 53 to Airport	0:09:39	46	29	10
OCFRD 51 to Airport	0:13:01	45	39	6
OCFRD 73 to Airport	0:09:23	39	28	8
OCFRD 71 to Airport	0:06:47	17	20	3
OCFRD 76 to Airport	0:10:25	47	31	9

As shown in the Table 5-2, for this study it was determined that 10 simulation runs should be sufficient in order to establish an estimate for travel time between the zones considered with a 5% maximum allowable error in travel time and a 95% level of confidence.

Selection of viable random numbers (seed values)

With count of the simulation runs "n_r=10" second step can be implemented. Simulation is conducted under similar conditions with different seed number (greater than nr), for our case 14 random seed numbers including the one used to find the number of simulation runs is used. It is recommended in the PARAMICS reference manual to use the results of the simulation runs pertaining to the entire network. As discussed in the previous sections the traffic flows from different zones may be used for this propose, this satisfies the PARAMICS manual recommendation and are also easy to collect. The main idea is to select the random number which lie close to the mean of all the data collected from different simulation runs. The seed numbers for which the zone release counts that different very much from the mean were discarded.

The simulation has been run for 14 seed numbers and the release counts from all the zones in the network are collected. The fire station zones are not considered for this analysis. The data collected in shown in Table 5-3.

Table 5-3: A sample of vehicle release count data from all the zones in the network

	Zone release counts											
Seed Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	..	..
191	842	1073	380	491	598	895	562	528	399	382	..	..
198	901	1122	404	470	571	960	622	511	418	461	..	..
1459	813	1068	376	464	517	896	568	552	408	411	..	..
2626	799	1123	407	508	521	923	563	547	423	425	..	..
3001	985	1195	490	564	654	1020	685	593	569	544	..	..
3883	870	1103	391	447	515	979	562	512	403	381	..	..
5430	884	1134	394	494	543	923	546	528	426	416	..	..
6083	874	1105	435	478	511	878	563	537	445	391	..	..
6231	831	1069	399	463	523	995	615	571	479	442	..	..
6556	830	1111	381	477	534	897	536	557	418	421	..	..
7311	834	1111	400	472	518	888	612	524	474	423	..	..
7960	1023	1240	494	626	674	1037	654	660	564	494	..	..
8613	848	1123	405	512	542	936	582	567	457	454	..	..
8734	845	1085	379	463	563	882	534	533	460	453	..	..

Since we do not know which distribution the data containing the vehicle release counts from the zones fall in, so Chebyshev’s rule is used to get the confidence interval, and to flag the bad seed values from the good ones. Chebyshev's Rule states that the probability that an observation differs from its mean by at least k standard deviations is $1/k^2$. Conversely, the probability that an observation differs from its mean by at most k standard deviations is $(1 - 1/k^2)$. If we want the range within which a certain percentage of the values lie, this approach can be used.

For our analysis number of standard deviation "k = 3"has been selected, to distinguish between the good and bad seed values. This implies that the seed numbers for which the observations that deviate more that '3' standard deviations from the mean are flagged out.

For k = 3,

$1\text{-}1/k^2 = 1 - 0.1111 = 0.8889 = 88.89\%$

So, by using a value of 3 for k, we can establish a confidence interval of 88.89%. Detailed analysis is shown in the Table 5-4. From the Table 5-4 we can observe that for seed numbers 198, 3001, 6231, and 7960 the release vehicle counts from the zones do not lie within 3 standard deviations from the mean, so these seed numbers are discarded. Final set of seed numbers used for getting the results are 191, 1459, 2626, 3883, 5430, 6083, 6556, 7311, 8613, 8734.

Table 5-4: Selection of viable seed numbers

	SEED NUMBERS																	
zone	**191**	**198**	*1459*	*2626*	*3001*	*3883*	*5430*	*6083*	*6231*	*6556*	*7311*	*7960*	*8613*	*8734*	*Mean μ*	*Stdev σ*	*μ - 3 σ*	*μ +3 σ*
20	103	216	79	80	-58	102	102	105	99	86	91	161	104	101	98	58	271	0
22	285	456	247	287	227	282	266	276	302	255	286	650	263	271	311	111	644	0
31	257	521	269	304	284	269	247	287	354	289	258	335	302	278	304	69	511	96
37	121	141	119	135	5	126	126	110	158	104	121	135	120	133	118	35	224	13
52	50	283	51	48	-1	46	54	52	116	43	47	127	37	47	71	68	277	0
58	141	179	119	140	150	152	143	148	296	131	146	191	134	137	158	44	289	26

T- represents the vehicle release counts lie between 3 standard deviations from the mean

F - represents the vehicle release counts do not lie between 3 standard deviations from the mean

20	T	T	T	T	F	T	T	T	T	T	T	T	T	T
22	T	T	T	T	T	T	T	T	T	T	T	F	T	T
31	T	F	T	T	T	T	T	T	T	T	T	T	T	T
37	T	T	T	T	F	T	T	T	T	T	T	T	T	T
52	T	F	T	T	T	T	T	T	T	T	T	T	T	T
58	T	T	T	T	T	T	T	T	F	T	T	T	T	T

Validation

Using the OD matrix and some of the seed numbers selected above, the simulation has been run. Hourly link counts have been collected at different locations on the network and these hourly counts are validated against the hourly traffic counts obtained from the Orange county traffic engineering department. Simulated traffic counts have been collected at 16 different points using the seed values of 191 and 1459 in the network in both the directions and compared with the actual counts. The traffic distribution pattern in the network when simulation under the rest of the seed numbers is assumed to be same as that of the simulated traffic pattern under the seed values of 191 and 1459

The results are shown in the Table 5-5. From Table 5-5 we can notice that the difference between the simulated hourly traffic volume and the actual traffic volume are with in acceptable limits of 10% error for most of the links, there are some deviations for some link counts, which can be acceptable and the overall error for all the links considered is less than 10%.

Table 5-5: Comparison of Actual hourly traffic counts and simulated hourly traffic counts collected using seed values 191 and 1459.

		Actual hourly counts	Simulated hourly counts		Error %	
	Data Collection Points		191	1459	191	1459
1	Northbound semoron from Hoffner	1970	1598	1628	18.9	17.4
1	Southbound semoron to Hoffner	1454	1614	1556	-1.0	-7.0
2	Northbound semoron to Hoffner	1945	2012	1996	-3.4	-2.6
2	Southbound semoron from Hoffner	1426	1521	1529	-6.7	-7.2
3	Northbound Goldenrod from Hoffner	1448	1269	1310	12.4	9.5
3	Southbound Goldenrod to Hoffner	841	762	805	9.4	4.3
4	Hoffner (semoron to Golden rod)	880	598	638	32.1	27.5
4	Hoffner (Golden Rod to Semoron)	606	556	577	8.3	4.8
5	SR 15 (Golden rod to Beeeline)	530	557	600	-5.1	-3.2
5	SR 15 (Beeline to Golden Rod)	993	973	1015	2.0	-2.2
6	SR 15 (Beeeline to lake nona)	604	544	566	9.9	6.3
6	SR 15 (Lake Nona to Beeline)	645	727	680	-12.7	-5.4
7	Westbound Sand Lake from OBT	1743	1793	1828	-2.9	-4.9
7	Eastbound Sandlake to OBT	1667	1805	1779	-8.3	-6.7
8	Westbound Sand Lake from Wineguard	1593	1477	1524	7.3	4.3
8	Eastbound Sandlake to Wineguard	1962	2085	2077	-6.3	-5.9
9	OBT southbound to Oak ridge	1864	1910	1857	-2.5	0.4
9	Oakridge to OBT Northbound	2322	1979	2048	14.8	11.8
10	OBT (Oakridge to Orlando Central Pkway)	1885	2133	2047	-13.2	-8.6
10	OBT (Orlando Central Pkway to Oak ridge)	2453	2088	2118	14.9	13.7
11	OBT South (Orl. Cen. Pkway to Sandlake)	2357	2333	2282	1.0	3.2
11	OBT (Sandlake to Orlando Central Pkway)	2301	2050	2055	10.9	10.7
12	OBT (south of sandlake)	1777	1729	1718	2.7	3.3
12	OBT (northbound to Sandlake)	1845	1809	1853	2.0	-0.4
13	Orange Avenue (lancaster to sand lake)	1232	1289	1193	-4.6	3.2
13	Orange Avenue (sandlake to lancaster)	1681	1628	1674	3.2	0.4
14	Orange Avenue (Sandlake to Landstreet)	1628	1565	1537	3.9	5.6
14	Orange Avenue (Landstreet to Sandlake)	1170	1253	1193	-7.1	-2.0
15	Conway Southbound to hoffner)	865	921	912	-6.5	-5.4
15	Conway (hoffner to north)	1304	1324	1295	-1.5	0.7
16	417 North Northbound	2385	2533	2537	-6.2	-6.4
16	417 North Southbound	1274	1305	1247	-2.4	2.1
17	528 East eastbound	2590	2584	2552	0.2	1.5
17	528 East westbound	2670	2658	2745	0.5	-2.8
				mean	1.6	1.5

CHAPTER 6
ANALYSIS

The main purpose of the analysis is to determine the sequence in which the emergency vehicles from fire stations should be dispatched to the airport in the case of an emergency. Travel times of the emergency vehicles from all fire stations are collected from the simulation runs and dispatch priority is assigned according to their respective travel times. Stations with shorter travel time are given higher priority than that of higher travel time. In order to find out the travel times under different traffic conditions the following main scenarios were simulated.

1. Base scenario

2. Incident scenarios

Base scenario is performed under three different loading conditions.

- 10% loading (loading the network with 100% of the OD matrix obtained from the heuristic method) is considered as peak hour condition
- 70% loading is considered as off peak period condition
- 30% loading is considered as free flow condition

During the 100% loading condition which is also called the peak hour scenario, the network is loaded with 100% of the OD-matrix estimated. Similarly for simulating the off peak period and free flow condition 70% and 30% of the estimated OD-matrix is loaded, respectively. Before releasing the fire trucks, the number of trucks to be dispatch for every simulation period must be estimated. Since the signals preempt at each intersection, releasing more vehicles within a shorter time period will affect the traffic patterns in the network. So an average of one emergency vehicle per fifteen minutes is assumed to be reasonable, so that it does not considerably change the traffic patterns on the network. Due to the randomness present in the PARAMICS simulator, some fluctuations in the release patterns are accepted.

With these conditions, simulation has been performed in a batch mode using the PARAMICS processor for all the good seed numbers selected in the previous chapter. The results of simulation are shown in Figures 6-1 and 6-2, and Table 6-1.

Table 6-1: Travel time from fire stations to airport under 100% loading
Fire Stations

	Fire Stations						
Seed no	*OFD 8*	*OCFRD 70*	*OCFRD 53*	*OCFRD 51*	*OCFRD 73*	*OCFRD 71*	*OCFRD 76*
191	0:04:08	0:10:09	0:11:26	0:13:00	0:08:36	0:05:45	0:10:57
1459	0:04:05	0:09:56	0:09:16	0:13:13	0:08:11	0:05:53	0:11:50
2626	0:04:02	0:09:30	0:09:07	0:12:55	0:09:09	0:06:03	0:09:36
3883	0:04:18	0:09:09	0:09:29	0:11:23	0:09:55	0:06:00	0:10:21
5430	0:04:21	0:09:56	0:09:16	0:13:22	0:08:11	0:06:06	0:11:50
6083	0:04:15	0:10:02	0:09:19	0:13:13	0:10:11	0:05:58	0:09:38
6556	0:04:02	0:09:42	0:10:21	0:12:57	0:11:41	0:05:57	0:10:03
7331	0:04:12	0:11:03	0:09:35	0:14:04	0:11:50	0:05:52	0:10:20
8613	0:04:10	0:10:21	0:09:51	0:12:17	0:09:26	0:05:59	0:11:56
8734	0:04:17	0:09:36	0:08:46	0:13:48	0:09:13	0:06:08	0:09:25
mean	0:04:11	0:09:56	0:09:39	0:13:01	0:09:38	0:05:58	0:10:36

Table 6-2: Travel time from fire stations to airport under 70% loading
Fire Stations

	Fire Stations						
Seed no	*OFD 8*	*OCFRD 70*	*OCFRD 53*	*OCFRD 51*	*OCFRD 73*	*OCFRD 71*	*OCFRD 76*
191	0:04:00	0:09:00	0:09:03	0:11:53	0:07:53	0:05:38	0:08:37
1459	0:04:01	0:09:26	0:08:17	0:11:53	0:07:55	0:05:43	0:08:43
2626	0:04:02	0:10:08	0:08:38	0:11:26	0:08:17	0:05:41	0:08:42
3883	0:04:13	0:09:12	0:09:18	0:11:45	0:08:25	0:05:32	0:08:32
5430	0:04:03	0:09:43	0:09:36	0:11:47	0:08:12	0:05:43	0:09:11
6083	0:04:10	0:09:14	0:08:29	0:11:22	0:08:02	0:05:46	0:08:55
6556	0:04:06	0:10:00	0:08:29	0:12:22	0:07:58	0:05:39	0:08:20
7331	0:04:07	0:08:58	0:08:33	0:11:34	0:08:30	0:05:35	0:08:46
8613	0:04:13	0:09:12	0:09:18	0:11:45	0:08:25	0:05:48	0:08:32
8734	0:04:00	0:11:01	0:08:38	0:11:55	0:08:41	0:05:40	0:08:37
mean	0:04:05	0:09:36	0:08:50	0:11:46	0:08:14	0:05:40	0:08:42

Table 6-3: Travel time from fire stations to airport under 30% loading
Fire Stations

	Fire Stations						
Seed no	*OFD 8*	*OCFRD 70*	*OCFRD 53*	*OCFRD 51*	*OCFRD 73*	*OCFRD 71*	*OCFRD 76*
191	0:04:03	0:08:42	0:08:31	0:10:49	0:07:13	0:05:23	0:08:16
1459	0:04:03	0:08:20	0:08:35	0:10:58	0:07:28	0:05:20	0:08:11
2626	0:04:01	0:08:28	0:08:08	0:10:40	0:07:18	0:05:21	0:08:09
3883	0:04:02	0:08:54	0:08:08	0:10:44	0:07:34	0:05:17	0:08:26
5430	0:03:59	0:08:28	0:08:13	0:10:46	0:07:41	0:05:15	0:08:18
6083	0:04:04	0:08:18	0:08:38	0:10:37	0:07:11	0:05:21	0:08:14
6556	0:03:53	0:08:43	0:08:52	0:10:39	0:07:33	0:05:13	0:07:55
7331	0:03:54	0:08:11	0:08:11	0:11:11	0:07:36	0:05:19	0:08:08
8613	0:04:02	0:08:54	0:08:08	0:10:44	0:07:34	0:05:23	0:08:26
8734	0:03:48	0:08:41	0:08:11	0:10:52	0:07:01	0:05:23	0:08:12
mean	0:03:59	0:08:34	0:08:21	0:10:48	0:07:25	0:05:19	0:08:13

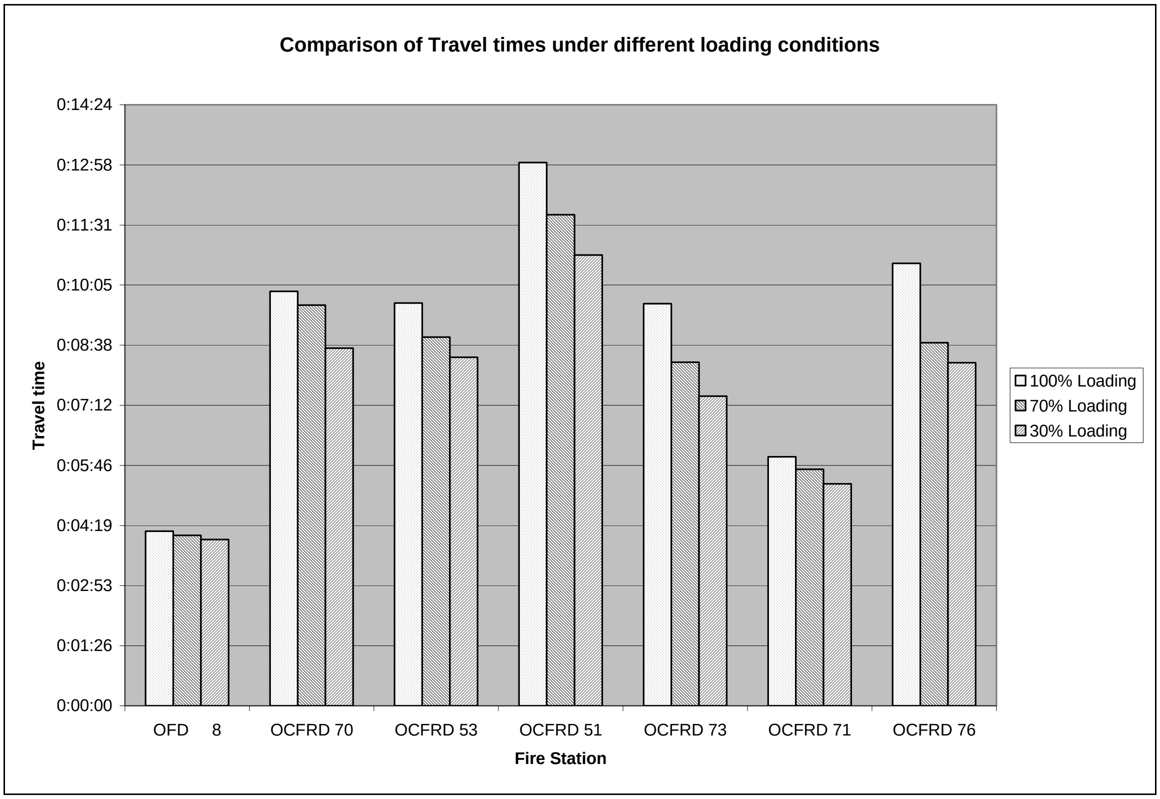

Figure 6-1: Comparison of travel times under different loading condition

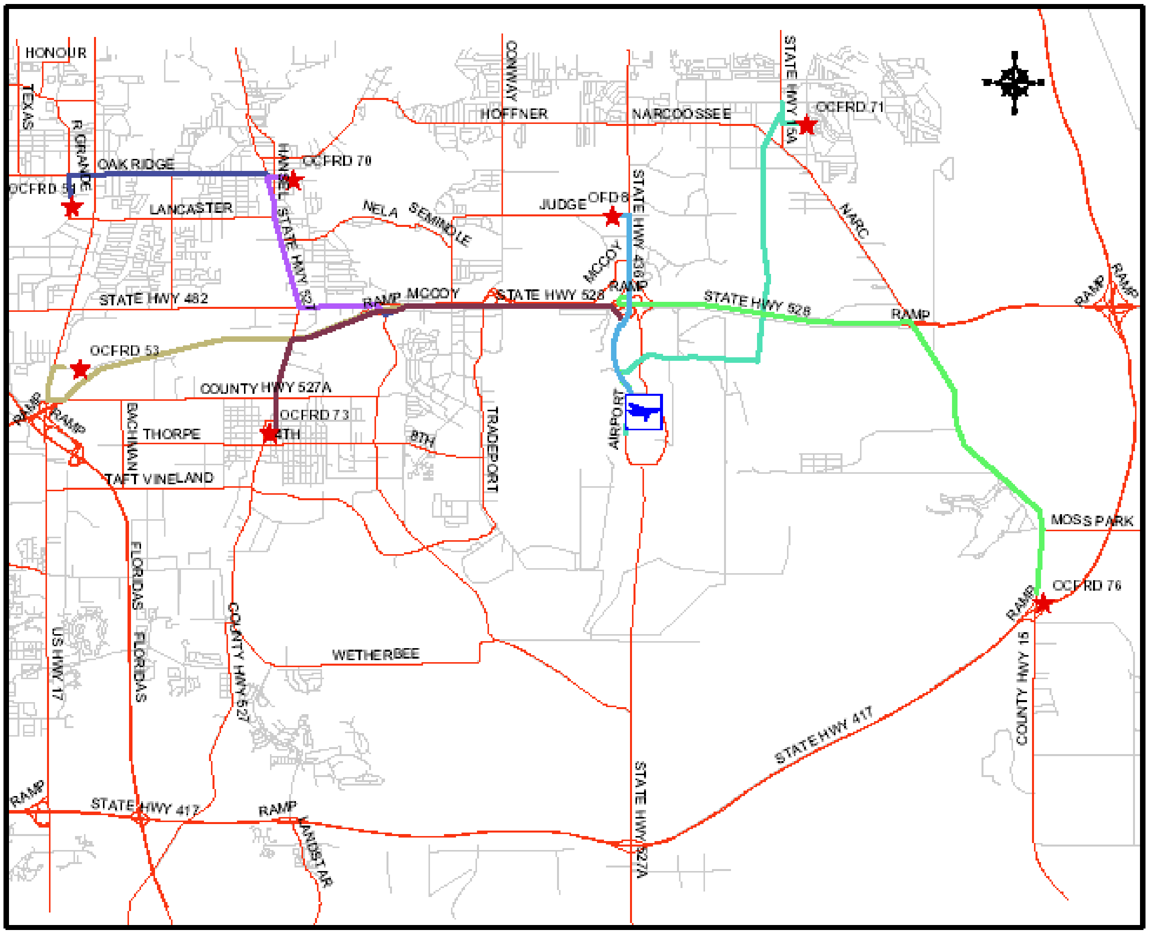

Figure 6-2: Map showing the shortest routes from different fire stations to airport.

The t-test of paired two samples for means of simulated travel times between the following pairs: 100% loading and 70% loading, 100% and 30% loading and 70% and 30% is done to show that there is no significant difference between the three sets of the results. The results show that there is significant difference among the response times from the fire stations between the 100% loading, 70% loading, and 30% loading using 90% confidence interval.

It can been concluded by observing the results, that station OFD 8 has a minimum average travel time of 4:11 minutes, so emergency vehicles should be dispatched first in case of an emergency. The fire station OCFRD 51 has the longest average travel time so dispatch of fire trucks from this station should be considered last. It can be observed from the results that travel times between the stations OCFRD 53 and OCFRD 73 for 100% loading are almost similar; so a paired t-test for means of the travel times of these fire stations is conducted. The results are shown in the Table 6-4.

Table 6-4: T-test for comparing the travel times between the stations OCFRD 53 and OCFRD 73 for 100% loading.

	OCFRD 53	*OCFRD 73*
Mean	578.6995 s	578.2007 s
Variance	2077.949 s^2	6070.689 s^2
Observations	10	10
Hypothesized Mean Difference	0	
df	15	
t Stat	0.017475	
P(T<=t) one-tail	0.493144	
t Critical one-tail	1.753051	
P(T<=t) two-tail	0.986288	
t Critical two-tail	2.131451	

It can been seen from the Table 6-4 that there is no significant difference between the travel times for station OCFRD 53 and OCFRD with 95% confidence. The order in which the fire stations should be discharged for quick response is shown in Table 6-5.

Table 6-5: Order of dispatching the fire trucks from fire stations

Fire Station number	*Order of Dispatch*	*Travel time (minutes)*
OFD 8	1	4:11
OCFRD 71	2	5:58
OCFRD 73	3	9:38
OCFRD 53	4	9:39
OCFRD 70	5	9:56
OCFRD 76	6	10:36
OCFRD 51	7	13:01

Incident scenarios

Incident scenarios are conducted to determine the alternative routes to the airport, if an incident occurs on the shortest part between the fire station and the airport. To decrease the complexity of the network, minor roads were not considered and some of the minor roads considered were terminated and used as zones, due to this it was not possible to simulate all the possible scenarios. Lack of these minor roads in the roadway network did not affect the base scenario. Five viable scenarios have been considered in our study.

1. Incident on Semoran Blvd.
2. Incident on Beeline Expressway (between the Semoran Blvd and Narccossee Rd).
3. Incident on Beeline Expressway (between the McCoy Rd and Orange Blossom Trail).
4. Incident on the Orange Avenue
5. Incident on Oak Ridge Rd
6. Incident on Goldenrod Rd extension (between Beeline and Narccoossee)

The north exit of the airport handles 80% of the traffic entering and leaving the airport and this exit is directly connected to the Semoran Blvd and Beeline Expressway. Incidents on either Semoran or Beeline will have a significant impact on the traffic patterns in an around the airport, so the scenarios dealing with the incidents on these two roads are considered first.

Incident on the Semoran Blvd obstructs the shortest path between the fire stations OCF 8, OCFRD 8 and the airport. Since station OCF 8 is the nearest fire station to the airport, any incident on Semoran hinder the movement of fire trucks from station OFC 8. Alternative routes are simulated by introducing a lane blockage condition in PARAMICS simulator. Incident on Beeline Expressway (between the Semoran Blvd and Conway rd) influences the shortest path between fire station OCFRD 76 and the airport. Incident on Beeline Expressway (between the McCoy Rd and Orange Blossom Trail) has an influence on the shortest path between fire station OCFRD 53 and the airport. Incidents on Orange Avenue affects the travel pattern of the emergency vehicle dispatched for the fire stations OCFRD 51 and OCFRD 70. Finally incident an on Oak Ridge Road affects the travel pattern of the fire trucks dispatched from station OCFRD 51.

The alternative routes chosen by the fire truck under different incident scenarios are shown in the Figures 6-3 to 6-8. The thick black lines in the figures represent the shortest path used by the fire trucks under normal condition with out any incidents, while the thick red lines represent the alternative routes collected from the PARAMICS simulation model. The results of the alternative scenarios are shown in tables 6-6 to 6-11, respectively.

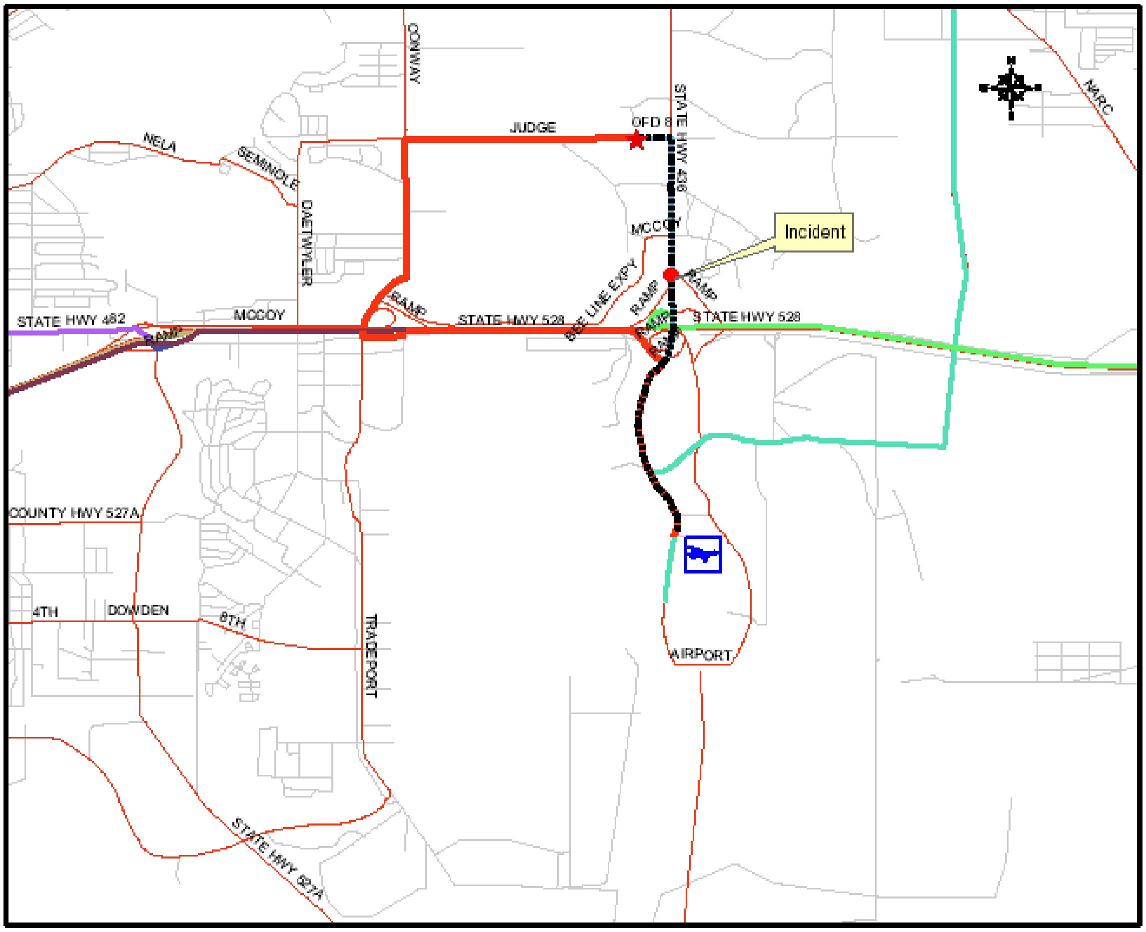

Figure 6-3: Alternative routes with an incident on Semoran Blvd

Table 6-6: Order of dispatching the fire trucks from fire stations

Fire Station number	*Order of Dispatch*	*Travel time (minutes)*
OCFRD 71	1	5:58
OCFRD 73	2	9:38
OCFRD 53	3	9:39
OFD 8	4	9:55
OCFRD 70	5	9:56
OCFRD 76	6	10:36
OCFRD 51	7	13:01

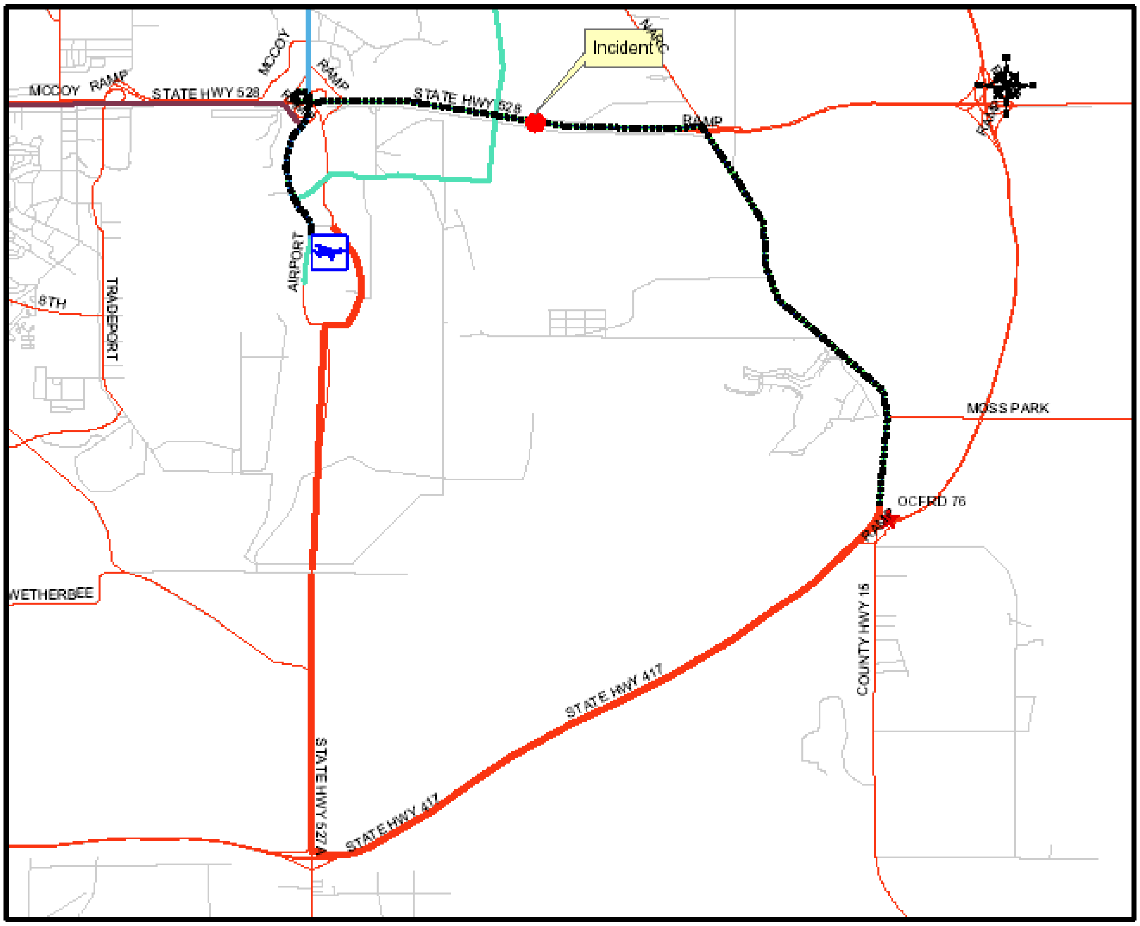

Figure 6-4: Alternate routes with an incident on Beeline Expressway (between the Semoran Blvd and Narccossee Rd)

Table 6-7: Order of dispatching the fire trucks from fire stations

Fire Station number	*Order of Dispatch*	*Travel time (minutes)*
OFD 8	1	4:11
OCFRD 71	2	5:58
OCFRD 73	3	9:38
OCFRD 53	4	9:39
OCFRD 70	5	9:56
OCFRD 76	6	12:03
OCFRD 51	7	13:01

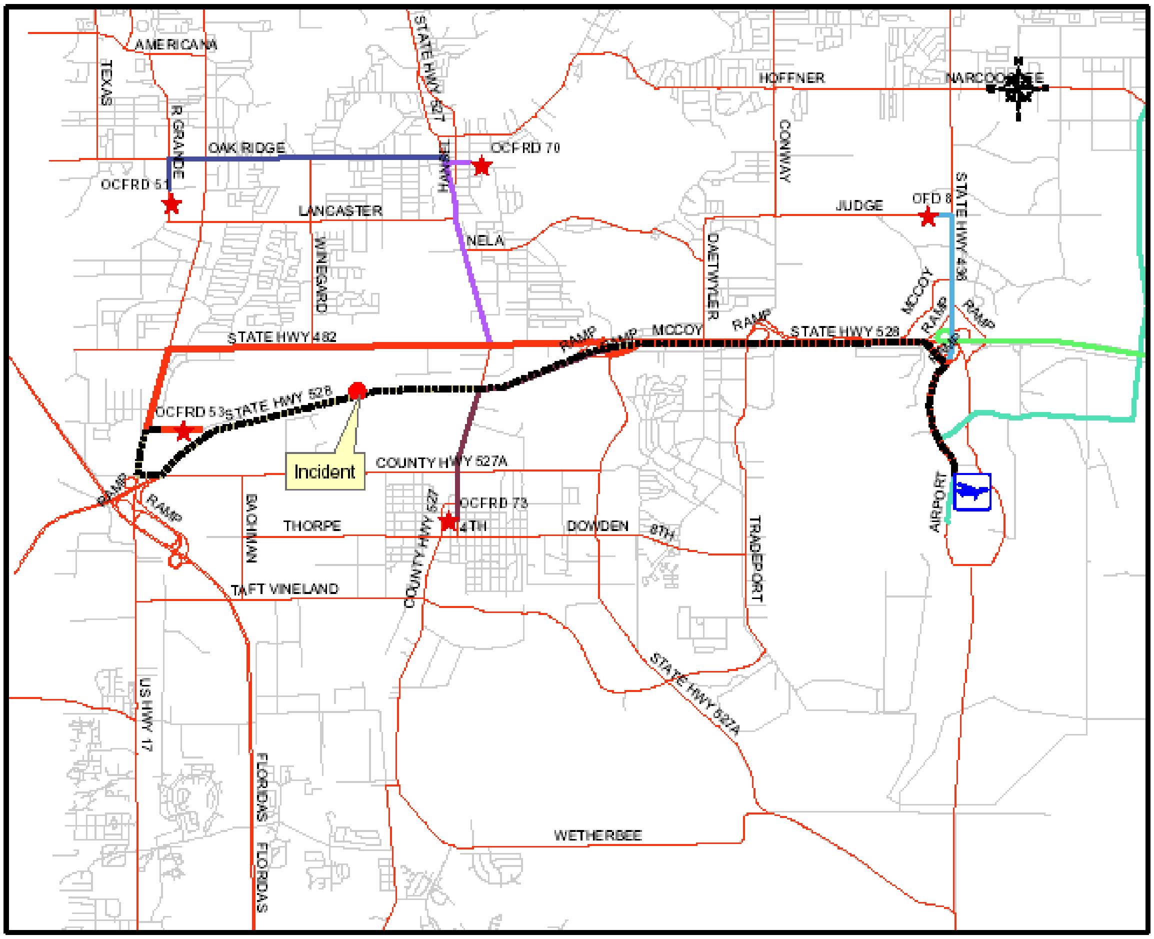

Figure 6-5: Alternative routes with an incident on Beeline Expressway (between the McCoy Rd and Orange Blossom Trail).

Table 6-8: Order of dispatching the fire trucks from fire stations

Fire Station number	*Order of Dispatch*	*Travel time (minutes)*
OFD 8	1	4:11
OCFRD 71	2	5:58
OCFRD 73	3	9:38
OCFRD 53	4	9:49
OCFRD 70	5	9:56
OCFRD 76	6	10:36
OCFRD 51	7	13:01

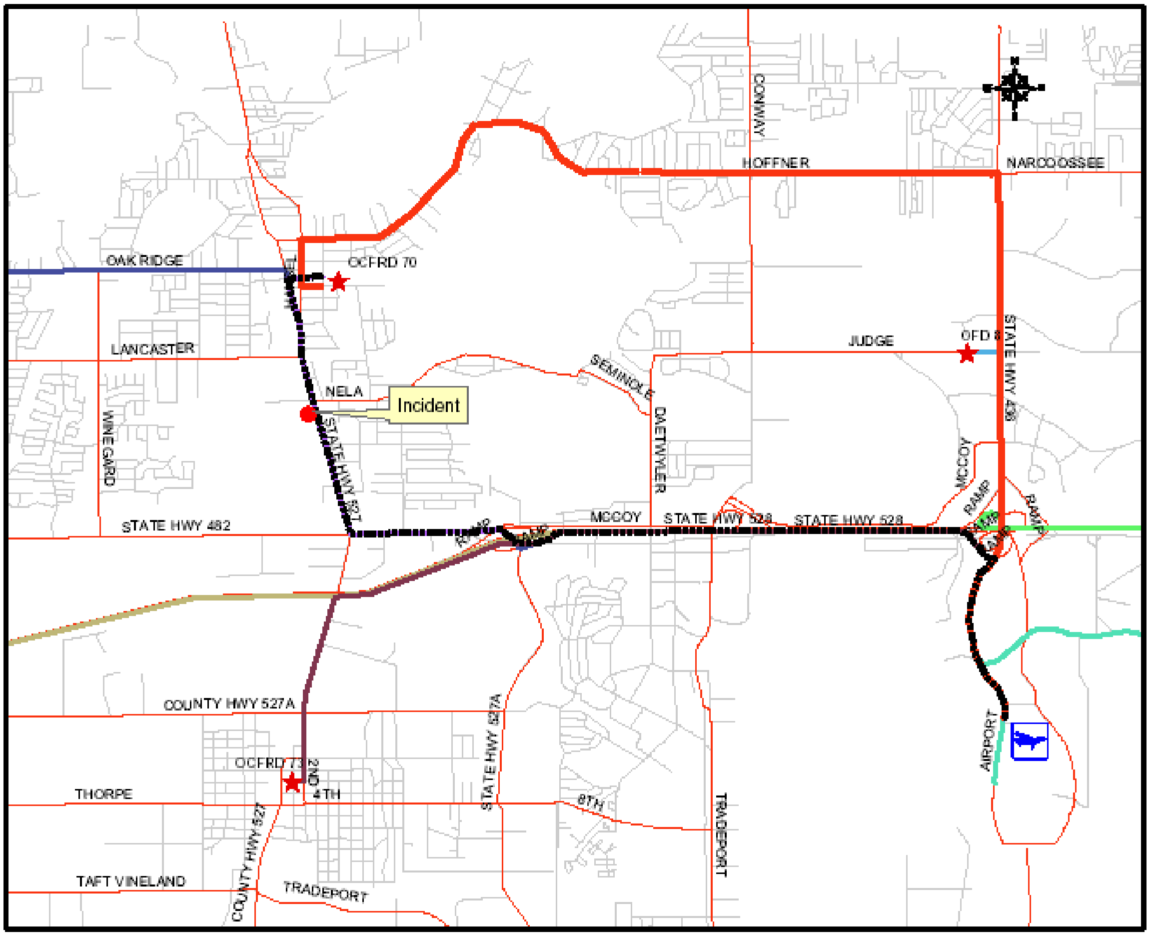

Figure 6-6: Alternative routes with an incident on the Orange Avenue

Table 6-9: Order of dispatching the fire trucks from fire stations

Fire Station number	*Order of Dispatch*	*Travel time (minutes)*
OFD 8	1	4:11
OCFRD 71	2	5:58
OCFRD 73	3	9:38
OCFRD 53	4	9:39
OCFRD 76	5	10:36
OCFRD 70	6	11:27
OCFRD 51	7	13:11

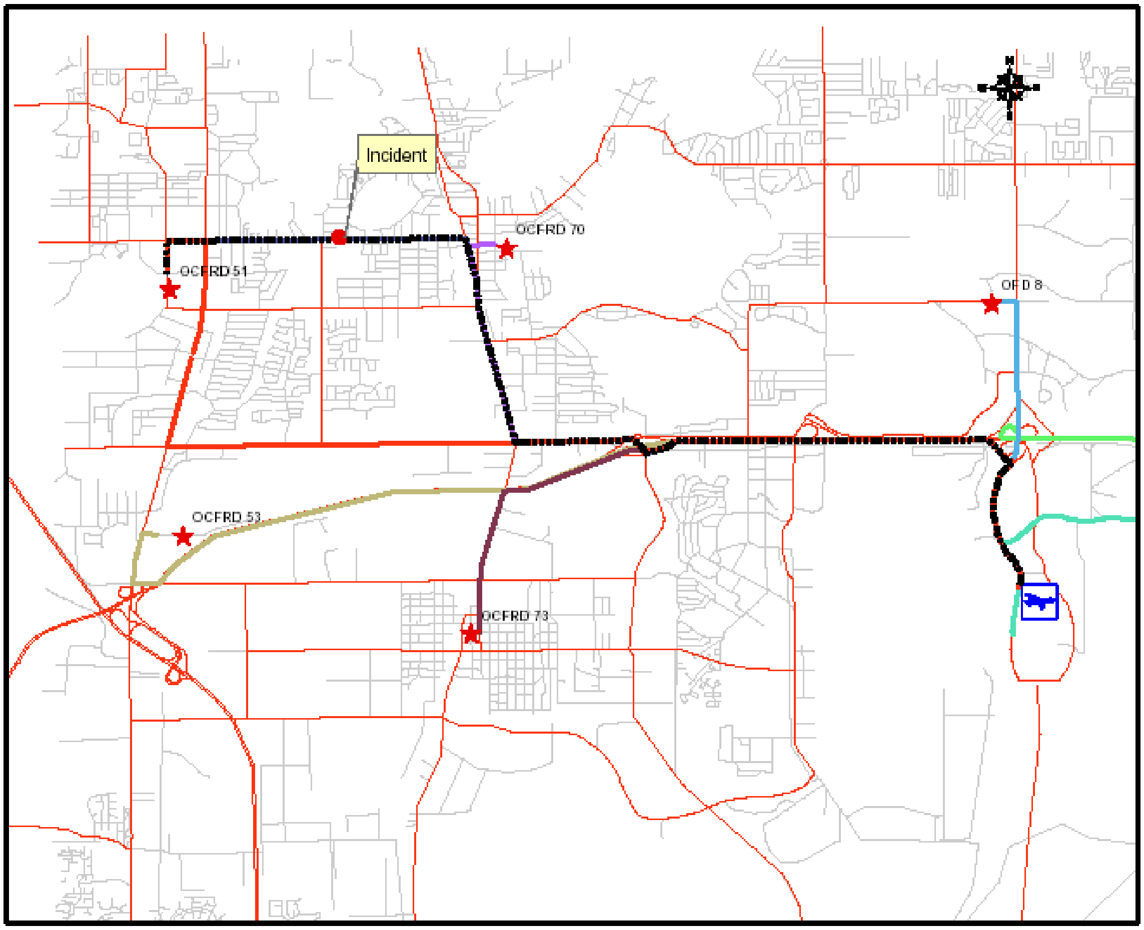

Figure 6-7: Alternative routes with an incident on the Oak Ridge Rd

Table 6-10: Order of dispatching the fire trucks from fire stations

Fire Station number	*Order of Dispatch*	*Travel time (minutes)*
OFD 8	1	4:11
OCFRD 71	2	5:58
OCFRD 73	3	9:38
OCFRD 53	4	9:39
OCFRD 70	5	9:56
OCFRD 76	6	10:36
OCFRD 51	7	13:11

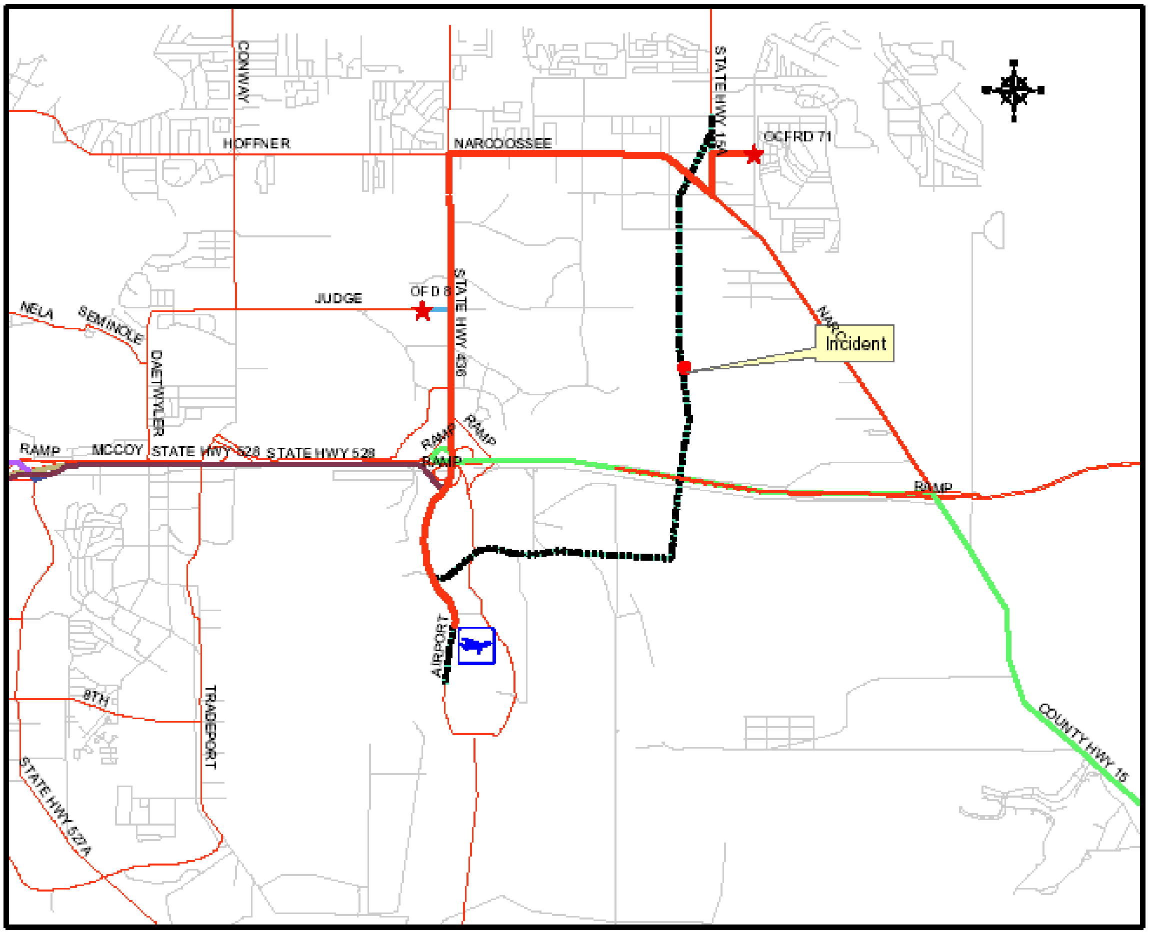

Figure 6-8: Alternative routes with an incident on Goldenrod Rd extension (between Beeline and Narccossee Rd)

Table 6-11: Order of dispatching the fire trucks from fire stations

Fire Station number	*Order of Dispatch*	*Travel time (minutes)*
OFD 8	1	4:11
OCFRD 71	2	6:47
OCFRD 73	3	9:38
OCFRD 53	4	9:39
OCFRD 70	5	9:56
OCFRD 76	6	10:36
OCFRD 51	7	13:01

CHAPTER 7
CONCLUSIONS AND FUTURE SCOPE

The results of this research have demonstrated the potential of using the traffic simulation model PARAMICS for emergency response modeling. This was the primary objective of the study. To accomplish this objective, traffic simulation was performed on the network around the vicinity of the Orlando International Airport.

The study area was coded in PARAMICS using the AutoCAD map obtained from the Orange County Traffic Engineering Department as a base map. The resulting network consisted of 66 zones with 50 signalized intersections. Seven fire stations within the study area are considered for dispatching the fire trucks in case of an emergency at the airport. Signal preemption for emergency vehicles, was coded using the PLAN-PHASE option available in PARAMICS at the intersections, so as to realistically model the model the movement of the fire trucks.

Gravity and Heuristic models were used to distribute trips for estimating the origin-destination matrix. The gravity model was calibrated using Friction factors and zone to zone adjustment factors, but due to the higher percentage of error between the simulated volume counts on the links and the field collected link volume counts, an alterative approach, Heuristic approach was used for estimating the o-d matrix. It involved balancing the vehicle counts entering to and exiting from each node.

The study network was calibrated for the base condition during the evening peak hour, using the release counts from the zones under fifteen different seed values. The release counts from each zone, for all the seed values were compared with the mean of the release counts. Ten seed values which yielded the better results (seed numbers with release counts close to the mean of the release counts from all the seed numbers) were selected. The model was validated by comparing the simulated vehicle counts at 17 different locations within the network, in both the directions with that of the field collected data at these locations during the peak hour.

After the network has been validated, base scenarios has been conducted for the peak hour by loading 100% of the O-D matrix obtained using heuristic approach, off-peak hour by loading 70% of the O-D matrix, and the free flow conditions by loading 30% of the O-D matrix. Fire trucks are released from the 7 fire stations considered with in the network. The travel times from the fire stations to the airport were collected using the 10 seed values that were selected.

The results show that fire station OFD 8 which is on the Shoal Creek Dr has a shortest response time of 4 minutes 11 seconds, followed by fire stations, OCFRD71, OCFRD 73, OCFRD 53, OCFRD 70, OCFRD 76, and OCFRD 76 respectively in the order of their response times under base conditions.

Six different scenarios were studied to see the effect of incidents on the shortest routes taken by the fire trucks. The links considered for introducing the incidents in the network are as follows: on Semoran Blvd, on Beeline Expressway between Semoran Blvd and Narccoossee Rd, on Beeline Expressway between McCoy Rd and Orange

Blossom Trail, on Orange Avenue, on Oak Ridge Rd and Golden Rd extension between Beeline Expressway and Narccoossee Rd. Under different incident scenarios the sequence in which the fire stations are to be responded from in case of an emergency at the airport were tabulated.

Future work can be derived from this research and analysis study. These are as follows:

- Network can be extended so as to include all the hospitals in the vicinity of the airport and test the routing strategies for evacuating the victims from the airport in case of a disaster.
- The extended network can be used to test different scenarios like baring the traffic from using the routes taken by the emergency vehicles, and model the route diversion for the traffic.
- The following research can also be extended to study the effects of signal preemption for emergency vehicles on traffic control measures, roadway capacity, and delays incurred to the vehicles on the side streets.
- This kind of model can also be applied for studying the strategies for evacuation of victims during other natural calamities, like hurricane, earthquakes, etc.

APPENDIX A
ACTUATED SIGNAL CODE

The dual-ring, concurrent concept is illustrated briefly in Figure A-1. Note that eight phases are shown, each of which accommodates one of the through or left turning movements. A "barrier" separates the north-south phases from the east-west phases. Any phase in the top group (Ring 1) may be displayed with any phase in the bottom group (Ring 2) on the same side of the barriers without introducing any traffic conflicts. For simplicity, the right turns are omitted and assumed to proceed with the through movements.

In full-actuated signal control, all phases at an intersection are actuated, so the length of each phase, and consequently the cycle length, will vary with each cycle. Some phases may be skipped if there is no vehicle actuation. To simulate the real controller better, the order and sequence of phases can also be altered.

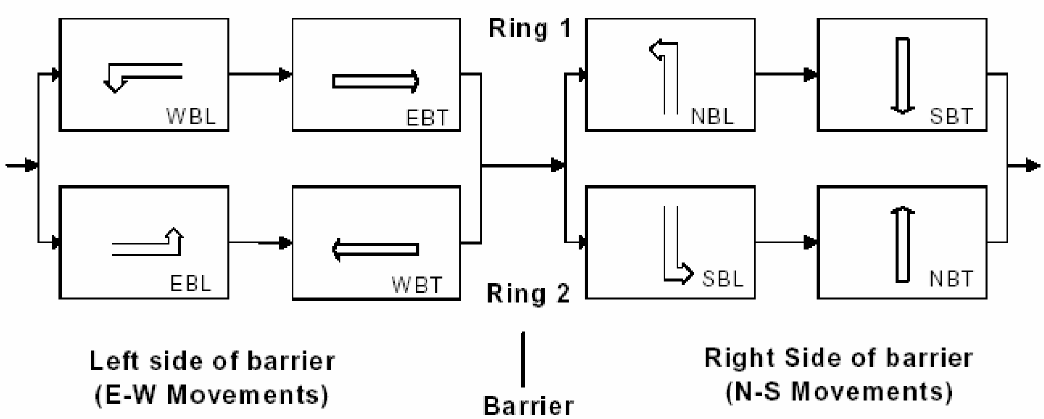

Figure A-1: Phase ring diagram for a typical actuated signal

In order to implement the above dual-ring concept, the pseudo code for the main control logic is given in the following:

1. Actuated Signal API set up using api_setup( ), includes signal data input, memory allocation, and initial signal phase set up.
2. At every time step, net action is called:

```
For controller intersection = 1: n
{
a. Inquiry the current signal information using signal_inquiry ( ).
b. If (left green time == 0)
{
Amber and red times are counted.
If (amber and red times are reached)
Set the next signal phase parameters through signal_action( ).
}
else
{
vehicle presence detection (pp_presence_dection ( )).
execute the current signal plan (pp_excute_plan ( ))
 {
If (left green time < extension && vehicle presence for extension && expired
green < (maximal green – extension))
{
green time increased by (extension – left green).
```

```
}
If (left green time <= time step)
Find the next phase by vehicle presence
}
}
}
```

CODE

The plan and phase files given below are used to control the phase 1 and 5 of a 4 way-8 phase junction, with protected left turn leading.

PLAN

```
plan count 1
plan 1 definition
loops 2
parameters 2
if (running){
if ( gap[1] running > parameter [1] ){
green1 - 1 balance[ + 1 ];
hold [ + 2 ];
}else if (gap[2] running > parameter [2] ){
green1 - 1 balance[ + 2 ];
hold [ + 1 ];
}
else{
report gap[1];
}
}else{
free [ + 1];
free [ + 2];
}
```

PHASE
use plan 1
on node 5 phase 1
with loops
L2 lane 3
L1 lane 3
with parameters
5
6
use plan 1
on node 5 phase 5
with loops
L4 lane 3
L3 lane 3
with parameters
3
4

APPENDIX B
TRAFFIC SIGNAL PREEMPTION

Traffic signal preemption code for a typical three phase operated traffic signal.

PLAN

```
## SIGNAL PRIORITY PLAN FOR TWO LANES

plan 5 definition

loops 2

variable;

if (running)

{

if ((count[1] type[2] > 0) || (count[2] type[2] > 0) )

{

  green1 - 50;

  green2[ + 1 ] = 0;

       green2[ + 2 ] = 0;

       green3[ + 3 ] = 0;

       clear [1];

       clear [2];

}
```

```
}

plan 6 definition
loops 2
variable;
if (running)
{
if ((count[1] type[2] > 0) || (count[2] type[2] > 0) )
{
  green1 - 50;
  green2[ + 1 ] = 0;
        green2[ + 2 ] = 0;
        clear [1];
        clear [2];
}
}

plan 7 definition
loops 2
variable;
if (running)
{
if ((count[1] type[2] > 0) || (count[2] type[2] > 0))
```

```
{
  green1 - 50;
        green2[ + 1 ] = 0;
  clear [1];
  clear [2];
}
}
plan 8 definition
loops 2
variable;
if (running)
{
if ((count[1] type[2] > 0) || (count[2] type[2] > 0) )
{
  green1 - 50;
        clear [1];
        clear [2];
}
}
```

PHASES

```
use plan 6
on node 115 phase 4
```

with loops

F4 lane 1

F4 lane 2

use plan 7

on node 115 phase 1

with loops

F4 lane 1

F4 lane 2

use plan 8

on node 115 phase 2

with loops

F4 lane 1

F4 lane 2

APPENDIX C

C++ CODE FOR OD-MATRIX USING GRAVITY MODEL

```
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <string.h>
#include <ctype.h>

#define MAX_NZONE 100

FILE *input_file, *output_file;
double production[MAX_NZONE+1], attraction[MAX_NZONE+1],
      cij[MAX_NZONE+1][MAX_NZONE+1],
      alpha[MAX_NZONE+1], beta[MAX_NZONE+1],
      od[MAX_NZONE+1][MAX_NZONE+1];
int no_zone, iteration;

/*---------------------------------------------------------------------------------*/
int test_char(char c){

        if( c>='!' && c<='z')
            return(1);
        else
            return(0);

}
/*---------------------------------------------------------------------------------*/
char *get_string(char *buf, int _th){
    static char S_Temp[100];
    int i,  p,  index ;

    memset(S_Temp,'\0',100);
    p = 0;
    for(i=1; i<=_th; i++){
          while( !test_char(buf[p]) ){
              if(buf[p] == '\n')
                return(S_Temp);
              else
                p++;
          }
          if(i == _th) break;
```

```
            while( test_char(buf[p]) ) p++;
    }

    index = 0;
    while(test_char(buf[p])){
        S_Temp[index] = buf[p];
        index++;
        p++;
    }

    if(index > 100){
       printf("# This number exceeds limit .....\n");
       exit(1);
    }

    return(S_Temp);

}
/*-------------------------------------------------------------------------------*/
double getreal(char *buf, int _th){
     double num;

      num = atof(get_string(buf, _th));

      return(num);

}
/*-------------------------------------------------------------------------------*/
int  getint(char *buf, int _th){
     int num;
     num = atoi(get_string(buf, _th));
     return(num);
}
*^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^*/
void print_result(void){
    int  i, j;
    double sum, total, d_sum[MAX_NZONE+1];

    total = 0;
    for(i=1; i<=no_zone; i++){
       for(j=1; j<=no_zone; j++){
          od[i][j] = alpha[i]*beta[j]*cij[i][j];
          total += od[i][j];
       }
    }
    for(j=1; j<=no_zone; j++){
```

```
            d_sum[j] = 0;
            for(i=1; i<=no_zone; i++) d_sum[j] += od[i][j];
         }

         for(i=1; i<=no_zone; i++) fprintf(output_file,"%15.5f%15.5f\n",
alpha[i],beta[i]);
         fprintf(output_file,"\n");
         for(i=0; i<=no_zone+1; i++) fprintf(output_file,"----------");
         fprintf(output_file,"\n");
         fprintf(output_file,"          ");
         for(i=1; i<=no_zone; i++) fprintf(output_file,"%10d",i);
         fprintf(output_file,"    Oi    \n");
         for(i=0; i<=no_zone+1; i++) fprintf(output_file,"----------");
         fprintf(output_file,"\n");
         for(i=1; i<=no_zone; i++){
            fprintf(output_file,"%10d",i);
            sum = 0;
            for(j=1; j<=no_zone; j++){
               sum += od[i][j];
               fprintf(output_file,"%10.0f",od[i][j]);
            }
            fprintf(output_file,"%10.0f\n",sum);
         }
         fprintf(output_file,"    Dj    ");
         for(i=1; i<=no_zone; i++) fprintf(output_file,"%10.0f",d_sum[i]);
         fprintf(output_file,"%10.0f\n", total);
         for(i=0; i<=no_zone+1; i++) fprintf(output_file,"----------");
         fprintf(output_file,"\n");

      }

      /*^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^*/
      void get_data(void){
         char  buf[MAX_NZONE*10];
         int i, j;

         memset(buf,'\0',MAX_NZONE*10);
         fgets(buf,MAX_NZONE*10,input_file);
         no_zone = getint(buf,1);
         iteration = getint(buf,2);
                  printf("%d %d\n",no_zone, iteration);

         memset(buf,'\0',MAX_NZONE*10);
         fgets(buf,MAX_NZONE*10,input_file);
         for(i=1; i<=no_zone; i++){
                  production[i] = getreal(buf,i);
```

```
             printf("%f\n",production[i]);
   }

    memset(buf,'\0',MAX_NZONE*10);
    fgets(buf,MAX_NZONE*10,input_file);
    for(i=1; i<=no_zone; i++){
            attraction[i] = getreal(buf,i);
            printf("%f\n",attraction[i]);
   }

    for(i=1; i<=no_zone; i++){
       memset(buf,'\0',MAX_NZONE*10);
       fgets(buf,MAX_NZONE*10,input_file);
       for(j=1; j<=no_zone; j++){
                    cij[i][j] = getreal(buf,j);
                    printf("%2d %2d: %f\n", i, j, cij[i][j]);
            }
    }
}
/*---------------------------------------------------------------------------------*/
unsigned short test_file_char(char c){

       if( (c>='a' && c<='z') || (c>='A' && c<='Z') ||
          (c>='0' && c<='9') ||  c=='_'             )
            return(1);
       else
            return(0);
}
/*^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^*/
void open_file(void){

    if((input_file=fopen("INPUT.GRV","r")) == NULL){
      printf("Input file error..\n");
      exit(1);
    }
    if((output_file=fopen("OUTPUT.GRV","w")) == NULL){
      printf("Output file error..\n");
      exit(1);
    }

}
/*******************************************************************/
void main(void){
    int i, j, no;
    double  p_alpha[MAX_NZONE+1], p_beta[MAX_NZONE+1],
         max, value, DIFFER = 0.01;
```

```
    open_file();
    get_data();

    for(i=1; i<=no_zone; i++){
        alpha[i] = 1;
        beta[i] = 1;
    }

    for(no=1; no<=iteration; no++){
        for(i=1; i<=no_zone; i++){
            p_alpha[i] = alpha[i];
            p_beta[i] = beta[i];
        }
        for(i=1; i<=no_zone; i++){
            alpha[i] = 0;
            for(j=1; j<=no_zone; j++) alpha[i] += beta[j]*cij[i][j];
            alpha[i] = production[i]/alpha[i];
        }
        for(j=1; j<=no_zone; j++){
            beta[j] = 0;
            for(i=1; i<=no_zone; i++) beta[j] += alpha[i]*cij[i][j];
            beta[j] = attraction[j]/beta[j];
        }
        max = -10e10;
        for(i=1; i<=no_zone; i++){
            value = (alpha[i]-p_alpha[i])/alpha[i];
            if(value >max) max = value;
            value = (beta[i]-p_beta[i])/beta[i];
            if(value >max) max = value;
        }
        if(max < DIFFER) break;
    }

    print_result();

}
```

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