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16. Abstract <p>In order to automate the travel demand forecasting process in urban transportation planning, a number of commercial computer based travel demand forecasting models have been developed, which have provided transportation planners with powerful and flexible tools in modeling a traffic network for planning or traffic impact studies. It is commonly recognized that none of the existing travel demand forecasting software is perfectly suited for all application network scenarios and traffic conditions. A particular model, which is strong in one application scenario, may be weak in a different application scenario. This report intends to present a comparative study of two widely used computer based travel demand forecasting models: QRS II vs. EMME/2. The comparative study is designed to identify main features and differences of the two models, with an attempt to provide some useful information to practitioners. The comparative description of basic features of two models in this report includes model structure, network development, data input, network modification, parameter calibration, and modeling output. In the comparison of advanced features, the <i>calculate</i> function in QRS II and <i>macro</i> language in EMME/2 are presented. A real-world small urban network, South Missouri City Network, is used to support the comparison effort. The study has found that both QRS II and EMME/2 models are reliable to model real-world networks. However, QRS II is relatively easy to use for inexperienced users because of its comprehensive default parameters, calculation formulas, procedures and the embedded four-step travel demand forecasting process. On the other hand, EMME/2 provides more powerful and flexible modules for users to perform more complex tasks.</p>					
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Travel Demand Forecasting Models: A Comparison of EMME/2 and QRS II Using a Real-World Network

by

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ABSTRACT

In order to automate the travel demand forecasting process in urban transportation planning, a number of commercial computer based travel demand forecasting models have been developed, which have provided transportation planners with powerful and flexible tools in modeling a traffic network for planning or traffic impact studies. It is commonly recognized that none of the existing travel demand forecasting software is perfectly suited for all application network scenarios and traffic conditions. A particular model, which is strong in one application scenario, may be weak in a different application scenario. This report intends to present a comparative study of two widely used computer based travel demand forecasting models: QRS II vs. EMME/2. The comparative study is designed to identify main features and differences of the two models, with an attempt to provide some useful information to practitioners. The comparative description of basic features of two models in this report includes model structure, network development, data input, network modification, parameter calibration, and modeling output. In the comparison of advanced features, the *calculate* function in QRS II and *macro* language in EMME/2 are presented. A real-world small urban network, South Missouri City Network, is used to support the comparison effort. The study has found that both QRS II and EMME/2 models are reliable to model real-world networks. However, QRS II is relatively easy to use for inexperienced users because of its comprehensive default parameters, calculation formulas, procedures and the embedded four-step travel demand forecasting process. On the other hand, EMME/2 provides more powerful and flexible modules for users to perform more complex tasks.

EXECUTIVE SUMMARY

Urban transportation planning involves the evaluation and selections of highway and/or transit facilities to meet the present and future needs because of land uses. For example, a baseball stadium, Enron Field, has been constructed in Houston Downtown. It will generate new trips and thus increase travel volumes in this area. Therefore, it will require additional transportation facilities and services, such as parking spaces, transit accessibility, and creation or expansion of roads to accommodate additional traffic volumes. Transportation planning is necessary to evaluate alternatives and select the best one according to criteria.

While the urban transportation planning process involves a number of sequential tasks, travel demand forecasting is the heart of the entire process, which is a technique to estimate traffic flows on roads of a transportation system. The methods for travel demand forecasting are from a simple extrapolation of observed trends to a complex computer-based process involving extensive data gathering and mathematical modeling. No matter what method is used, the travel demand forecasting process requires various data such as household, income, car ownership, employment, etc. The methods used in travel demand forecasting depend on data available and specific constraints on the project.

To perform travel demand forecasting process, many calculations must be conducted. These calculations are usually too complicated to be operated manually. Therefore, computers are used to operate these complicated calculations. In the past decades, numerous computer-based travel demand forecasting models have been developed to perform travel demand

forecasting process. In general, the computer-based travel demand forecasting models automate the sequential four-step process of travel demand forecasting: trip generation, trip distribution, modal choice, and traffic assignment. Examples of such computer-based models include QRS II, EMME/2, TRANPLAN, MINUTP, TP+, TransCAD, and TRANSIMS.

While the existence of so many computer-based travel demand forecasting models provides a comprehensive list of choices for transportation planners, it is also confusing with respect to which model is more suited for a particular application scenario. It is a consensus among practitioners that none of the existing models is perfectly suited for all scenarios. A particular model, which is strong in one application area, may be weak in a different application area. In this context, there is a need to identify main features and differences of existing demand forecasting models, such that transportation planners can have a useful reference guide in choosing a model for a particular study. As the first step in this effort, this research will conduct a comparative study on two widely used computer-based travel demand forecasting models: QRS II vs. EMME/2. To this end, the research established three objectives:

1. Compare basic features of QRS II and EMME/2;
2. Compare QRS II and EMME/2 using a real-world network; and
3. Compare advanced features of QRS II and EMME/2.

The research has resulted in the following comparison results:

- (1) QRS II provides a tool of network editor, GNE, for network development, which is an individual program. EMME/2 provides a network editor, which is an integral module of EMME/2. QRS II uses GNE to develop a network and enter data in an interactive graphic manner. EMME/2 provides two methods to develop a network: using an interactive graphic worksheet or using batch entry. Not all data related to nodes and links are entered when developing a network in EMME/2.
- (2) The first task for developing a network in QRS II is loading an application schema, which pre-defines network characteristics. In order to use EMME/2, the first task is creating a databank and implement dimensions.
- (3) QRS II defines eight node types and eight link types; however, EMME/2 provides only two node types and user-defined link types. In QRS II, users can name nodes and links based on the real-world road names, so users can easily match the results with a real world network. In EMME/2, users name nodes and links using numbers, so users cannot match the results with a real world network so easily as they do in QRS II. A link is defined using the node numbers at the two terminuses of the link.
- (4) In order to analyze the turning volume in QRS II, users must name the links using "<T>" and define the approach code to a link. Sometimes users have to split a link to set

different approach codes for one link. However, EMME/2 provides a turn table for defining all turns at an intersection. Each intersection can be plotted in an interactive graphic way, and the layout of an intersection includes all turns at the intersection. Therefore, it is easier to read turning volumes at intersections in EMME/2 than in QRS II.

- (5) In estimating transit ridership in QRS II, users first must develop a regular highway network, and then develop a separate transit network. Every transit centroid must have a corresponding centroid or external station on the highway network. In EMME/2, users develop a transit network based on a base highway network. Nodes and links on a transit network must be on the base network.
- (6) Although both QRS II and EMME/2 can zoom in and zoom out a network, QRS II prints only entire network, while EMME/2 can print either an entire network or selected part of the network.
- (7) Both QRS II and EMME/2 can perform the four-step travel demand forecasting process. QRS II provides a large number of default parameters and default calculation formulas and procedures. However, in EMME/2, users must create matrices and define functions that are needed to perform calculations, especially for steps other than traffic assignment.
- (8) QRS II performs highway and transit network assignments separately. However, EMME/2 can perform highway and transit network assignments either separately or simultaneously, which reflects a real world transportation system.

(9) Both QRS II and EMME/2 can be calibrated to match the forecasted results with real-world collected traffic counts. Therefore, both are reliable models for application in practice.

(10) QRS II provides *Calculate* for users to write program for specific tasks. The program is simple and specific to an application schema. EMME/2 provides *macro* language for users to write program. It is more complex, but more powerful. It is used to implement complex repetitive procedures.

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CHAPTER 1

INTRODUCTION

Urban transportation planning involves the evaluation and selections of highway and/or transit facilities to meet the present and future needs because of land uses. For example, a baseball stadium Enron Field has been constructed in Houston Downtown. It will generate new trips and thus increase travel volumes in this area. Therefore, it will require additional transportation facilities and services, such as parking spaces, transit accessibility, and creation or expansion of roads to accommodate additional traffic volumes. Transportation planning is necessary to evaluate alternatives and select the best one according to criteria.

While the urban transportation planning process involves a number of sequential tasks described by Figure 1.1 (ITE, 1992), travel demand forecasting is the heart of the entire process, which is a technique to estimate traffic flows on roads of a transportation system. The methods for travel demand forecasting are from a simple extrapolation of observed trends to a complex computer-based process involving extensive data gathering and mathematical modeling. No matter what method is used, the travel demand forecasting process requires various data such as household, income, car ownership, employment, and so on. The methods used in travel demand forecasting depend on data available and specific constraints on the project.

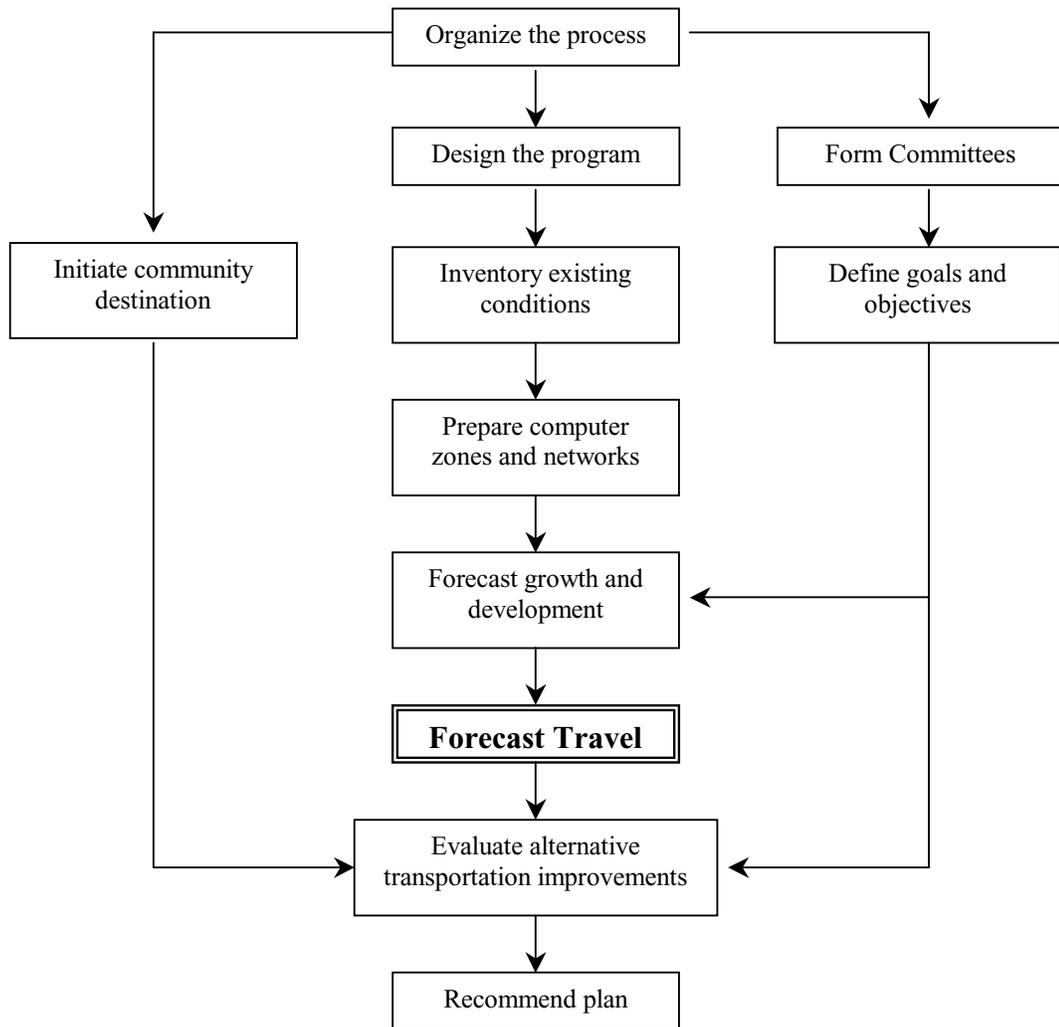


Figure 1.1 The Urban Transportation Planning Process
 (Source: Transportation Planning Handbook, Institute of Transportation Engineers, Prentice-Hall, 1992.)

To perform travel demand forecasting process, many calculations must be conducted. These calculations are usually too complicated to be operated manually. Therefore, computers are used to operate these complicated calculations. In the past decades,

numerous computer-based travel demand forecasting models have been developed to perform travel demand forecasting process.

In general, the computer-based travel demand forecasting models automate the sequential four-step process of travel demand forecasting: trip generation, trip distribution, modal choice, and traffic assignment.

1.1 Overview of Four-Step Travel Demand Forecasting

Figure 1.2 illustrates the sequential four-step travel demand forecasting process. The outputs of each step are the inputs to the following step.

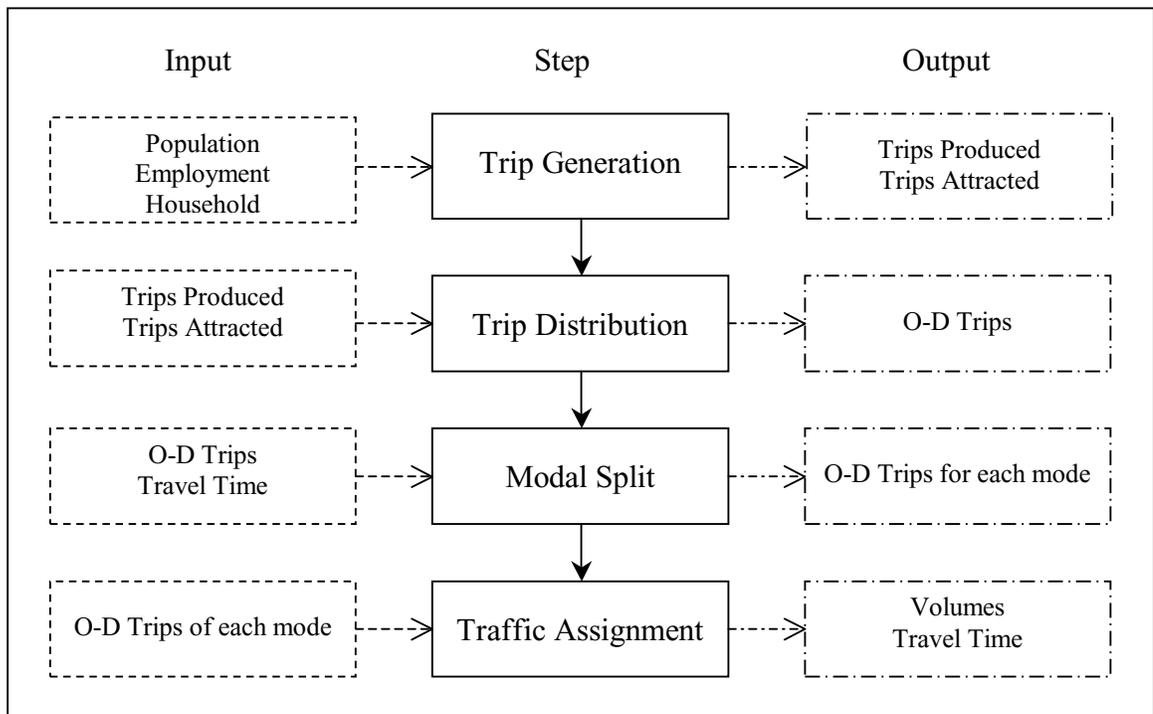


Figure 1.2 Sequential Four-Step Travel Demand Forecasting Process

1.1.1 Trip Generation

The trip generation step is to estimate the number of person-trips, which will begin or end in each traffic analysis zone within a study area for a typical day of the target year. Each trip has two ends, which are described in terms of trip purposes such as work trips, school trips, shopping trips, and social or recreational trips. Trip ends at residential zones are referred to as productions, and trip ends at nonresidential zones are referred to as attractions. According to land use, trips can also be classified as home-based or as non-home-based. A home-based trip consists of trips that either begin or end at a resident zone. For example, a home-based work trip would be considered to have a trip end produced in the resident zone and attracted to the work zone. A non-home-based trip consists of trips that neither begin nor end at a resident zone.

Commonly used methods for trip generation include regression models, trip-rate analysis models, and cross-classification models. A brief description of these models is provided as follows.

(1) Regression models

Although both a linear regression and a nonlinear regression can be used in trip generation models, a widely used regression model for trip generation is the linear multiple-regression model:

$$Y = a_0 + a_1X_1 + \cdots + a_nX_n \quad (1.1)$$

where

Y is the dependent variable, which is the total number of trips generated,

X_i is the relevant independent variable reflecting characteristics of land use ($i = 1, 2, \dots, n$), and

a_i is the parameter of the model that is estimated based on the regression calibration ($i = 1, 2, \dots, n$).

As a general rule in performing regression analysis, a selected independent variable must be linearly related to the dependent variable. It must also be highly associated with the dependent variable; otherwise, it could not have explanatory power. If two potential explanatory variables are highly correlated, they must not be included in the same equations.

(2) Trip-rate analysis models

Trip-rate analysis models are based on the average trip production or trip attraction rates related to the important trip generators within the study region. Trip generation rates can be determined from survey data or some existing sources such as the *Trip Generation* of the Institute of Transportation Engineers (ITE, 1997) and *Trip Generation Analysis* of Federal Highway Administration (FHWA, 1975).

(3) Cross-classification models

The cross-classification is a technique developed by FHWA to determine the number of trips associated with residential land uses. Cross-classification model groups individual

households together according to common socioeconomic characteristics such as auto ownership, household size, and income. Average trip productions rates are then calculated for each group based on survey data. For example, Oahu Metropolitan Planning Organization (1982) produced a table (Table 1.1) that specifies points of demarcation between the levels of density defined as high (urban), medium (suburban), and low (rural). Each cell of the table is the daily trip production rate per household expressed in terms of person-trips per household per day.

Table 1.1 Cross-Classification Trip Rate Table
by Oahu Metropolitan Planning Organization

Cross class	Vehicles per household	Persons per household			
		1	2,3	4	5+
Urban (high density)	0	0.57	2.07	4.57	6.95
	1	1.45	3.02	5.52	7.9
	2+	1.82	3.39	5.89	8.72
Suburban (medium density)	0	0.97	2.54	5.04	7.42
	1	1.92	3.49	5.99	8.37
	2+	2.29	3.86	6.36	8.74
Rural (low density)	0	0.54	1.94	4.44	6.82
	1	1.32	2.89	5.39	7.77
	2+	1.69	3.26	5.76	8.14

1.1.2 Trip Distribution

The second step in the sequential four-step travel demand forecasting processing is trip distribution, which determines the number of trips that would be made between one zone and all the other zones. The most common methods of trip distribution include gravity model, growth factor models, and opportunities models. A brief description of two popular models: gravity model and Fratar model, is provided in the following.

(1) Gravity model

The gravity model is based on the Newton's law of gravitation, which states that the number of trips between two zones is directly proportional to the number of trip productions and trip attractions and is inversely proportional to the travel time between the two zones. The mathematical formula is as follows (Garber et al., 1997).

$$T_{IJ} = P_I \frac{A_J F_{IJ} K_{IJ}}{\sum_J A_J F_{IJ} K_{IJ}} \quad (1.2)$$

where

T_{IJ} is the number of trips between a trip production zone I and a trip attraction zone J ,

P_I is the number of trips produced by zone I ,

A_J is the number of trips attracted by zone J ,

F_{IJ} is the travel time factor, which is an inverse function of travel time, and

K_{IJ} is the socioeconomic adjustment factor for the interchange IJ .

(2) Fratar model

Gravity model considers the number of trips and the travel time between the two zones; however, sometimes the travel time between zones is not available. The only data available are the origins and destinations of trip generation volumes for the target year. At that time, growth factor models are used primarily to estimate trips between zones within the study area and zones in cities external to the study area. Since the growth

factor models rely on an existing O-D matrix, they cannot be used to forecast traffic between zones where no traffic currently exists.

The widely used growth factor model is the Fratar model. Fratar model states that the target year trip generation is calculated by multiplying the base year trip generation by a simple growth factor. This growth factor is based on the anticipated land use changes that are expected to occur within the zone between the base year and the target year. Then, the Fratar model estimates the target year trip distribution through an iterative procedure.

1.1.3 Modal Choice

The third step in the sequential four-step travel demand forecasting process is modal choice, which determines the number/percentage of trips between zones that use different modes such as automobile, bus, light-rail, and so on. The factors that affect the selection of one mode or another are as follows:

- The characteristics of available modes, e.g. the level of travel service provided by transit or highway system, travel time, travel cost, parking cost, time spent outside the vehicle during a trip, headway, comfort, convenience, safety, and accessibility to employment;
- The characteristics of the trip makers, e.g. income, age, sex, car ownership, population, employment, and distance to CBD; and

- The characteristics of the trip, e.g. the number of trip purposes used, length of trip, time of day, and orientation to CBD.

The most widely used mode choice models include diversion curve model and Logit model.

(1) Diversion curve model

Diversion curve relates modal split to the travel time ratio, the travel cost ratio, and the travel service ratio by two modes. Figure 1.3 illustrates a typical diversion curve model for work trips. Similar curves for other trip purposes can also be calibrated. In Figure 1.3, the independent variables used in diversion curve model include the ratio of transit to auto travel time (TTR), the ratio of transit to auto costs (CR), the ratio of transit to auto service (L), which is defined as the time spent outside the vehicle, and the traveler's income category (EC).

The application of this model is simple. The number of trips by transit is the number obtained from the trip distribution phase multiplied by the appropriate percentage obtained from Figure 1.3.

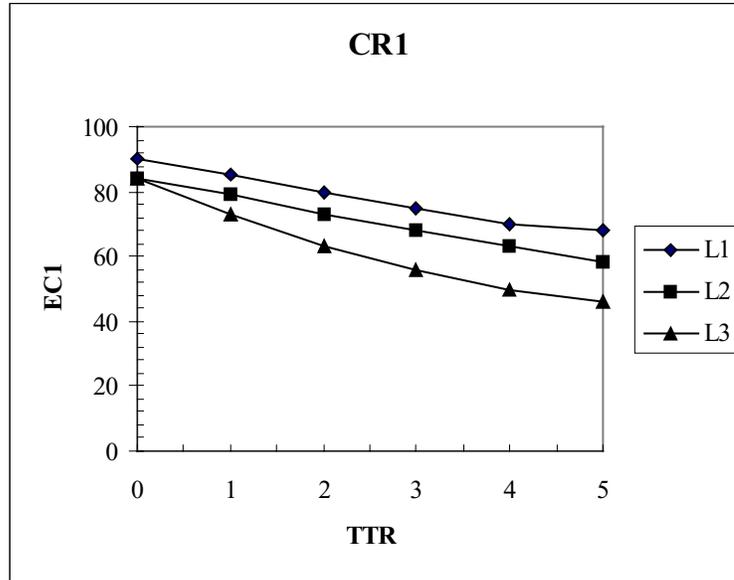


Figure 1.3 An Example of Modal Choice Model of Diversion Curves

The diversion curve model can only be applied to where only two modes of travel are available, e.g. automobile and public transit. When more than two modes of travel are available, the logit model has to be used.

(2) Logit model

The Logit model estimates the proportion of trips by a special mode M according to the relative utility of each mode as a summation of each modal attribute. Following is a formula of Logit model (Papacostas et al., 1993).

$$p(M) = \frac{e^{U_M}}{\sum_{i=1}^n e^{U_i}} \quad (1.3)$$

where

$p(M)$ is the proportion of trips by mode M ,

U_M is utility of mode M , and

U_i is utility of mode i ($i = 1, 2, \dots, n$).

The utility function is typically expressed as a linearly weighted sum of the independent variables, that is,

$$U = a_0 + a_1X_1 + a_2X_2 + \dots + a_rX_r \quad (1.4)$$

Where

U is the utility of a mode,

r is the number of attributes,

X_i is the attribute value such as time, cost, and so on ($i = 1, 2, \dots, r$),

a_i is coefficient for attribute i ($i = 1, 2, \dots, r$), and

a_0 is a mode-specific constant.

If only two modes, auto (A) and transit (T), are considered, the probability of selecting the auto mode can be described as

$$P(A) = \frac{e^{U_A}}{e^{U_A} + e^{U_T}} \quad (1.5)$$

where

$P(A)$ is the percentage of trips attracted by auto,

U_A is the utility of auto, and

U_T is the utility of transit.

1.1.4 Traffic Assignment

The final step in sequential four-step travel demand forecasting is to determine the number of auto and buses on the actual street and highway routes. This process is called traffic assignment. The result of trip assignment is the average daily or peak hour traffic volumes that will occur on the traffic network within the study area.

The widely used traffic assignment models perform equilibrium assignment. In an equilibrium assignment, there are usually several equally good paths through the network for each original-destination pair. Although various equilibrium assignment methods can be found in technical literature, all of them were developed based on two traffic assignment principles developed by Wardrop (1952). Wardrop's first principle can be stated as that drivers may try to choose the paths to minimize their own travel times through the network. This is also called user optimization principle or user equilibrium principle. Wardrop's second principle can be stated as that traffic is assigned in such a manner as to minimize the total travel time of all drivers in the whole network. This is also called system optimization principle. Among many algorithms for traffic assignment formulation, the Frank-Wolfe (Frank et al., 1965) algorithm is the one that is most widely used.

Although the widely used traffic assignment models perform equilibrium assignment, the concepts of non-equilibrium assignment, in which the path for each original-destination pair is the shortest path, are still important because the most widely used equilibrium

assignment procedures usually use a non-equilibrium assignment as a sub-component within their assignment algorithms (Yu, 1994). Non-equilibrium models include all-or-nothing assignment, multipath assignment, and capacity-restrained assignment.

(1) All-or-nothing assignment

The all-or-nothing assignment allocates the entire trips for all O-D pairs to their relative shortest paths, which are calculated based on free flow link travel time. The flow on a link is the sum of all O-D flows that include this link on their shortest paths.

(2) Multipath assignment

All-or-nothing assignment assumes that all drivers traveling between a pair of zones select the same path. Obviously, it is not realistic. In reality, when all trips are assigned to a path included in shortest paths, it is initially the best one. This path may increase travel time because of the assignment trips, so some of trips on this path will have an incentive to select a new less travel time path. Therefore, it is possible to assign trips between these paths according to some realistic rules. For example, Irwin et al. (1962) suggested the following inverse-proportion function to calculate the percentage of trips to be assigned to each of a number of interzonal routes.

$$p(r) = \frac{t_{Lr}^{-1}}{\sum_x t_{Lx}^{-1}} \quad (1.6)$$

where

$p(r)$ is the percentage of trips to be assigned to route r ,

t_{IJr} is the travel time of route r from zone I to zone J , and

x is the number of routes from zone I to zone J .

(3) Capacity-restrained assignment

Capacity-restrained assignment assumes that the link travel time is a function of the assigned link volumes. In a capacity-restrained assignment, the trips are initially assigned to shortest paths between a pair of O-D zones that are calculated based on free flow link travel times. Then the link travel times are recalculated based on a flow travel time function that reflects the nature of the relationship between link flow and link travel time. New shortest paths are subsequently calculated and the traffic volumes are reassigned to new shortest paths.

The Bureau of Public Roads (BPR) function is one of travel time relationships that have been widely used to calculate the link travel times in capacity-restrained assignment.

BPR function is expressed mathematically as

$$t = t_0 \left[1 + \alpha \left(\frac{V}{C} \right)^\beta \right] \quad (1.7)$$

where

t is the travel time of a given link at flow of V in seconds,

t_0 is free-flow travel time of the link in seconds,

V is the link flow in vph,

C is the link capacity in vph, and

α, β are dimensionless coefficients.

The magnitudes of coefficients α and β are a function of the characteristics of specific link that is being modeled, where a typical value of α is 0.15 and of β is 4 (Vythoukcas, 1990).

1.2 Models Used in Practice

Section 1.1 described the traditional four-step travel demand forecasting process including the widely used models in each step. In performing travel demand forecasting for a real-world and relatively large network, the actual calculation process is more complicated than one could imagine. In order to simplify the calculation procedure, many practice computer software have been developed to automate the traditional four-step travel demand forecasting process as well as perform non-traditional travel demand forecasting procedures. Examples of such computer-based models include QRS II, EMME/2, TRANPLAN, MINUTP, TP+, TransCAD, and TRANSIMS.

1.2.1 QRS II

QRS II, Quick Response System II, was developed and upgraded at the Center for Urban Transportation Studies of the University of Wisconsin at Milwaukee. The DOS version of

QRS II was first released in 1987 and it is a DOS version (Horowitz, 1997). Its latest version is QRS II 5.1 (AJH Associates, 2000). QRS II was interfaced with a powerful interactive graphics, General Network Editor (GNE) for developing a network and inputting data. GNE's latest version is GNE 6 (AJH Associates, 2000).

Using GNE, users can develop a network, enter verbal descriptions and numerical data about each element of the network, modify the network and its data, computer intermediate results through a series of worksheets, search for network elements that meet certain criteria, and display results from QRS II. The main feature of QRS II is the availability of a comprehensive set of default parameter values provided by the model. This feature provides inexperienced users with tremendous easiness in setting up their modeling networks. Using QRS II, four-step travel demand forecasting process can be performed in one execution on a computer.

1.2.2 EMME/2

EMME/2, Equilibre Multimodal (in French)/Multimodal Equilibrium (in English), was first developed at the Center for Research on Transportation (CRT) of the University of Montreal. The first version of EMME/2 was released in the early 80's at CRT. Since 1986 further development of EMME/2 have been done by INRO Consultants. The latest version of EMME/2 is release 9 (INRO, 2000).

EMME/2 provides modules to develop and modify a network, input data, develop and modify matrices and functions, and display and output results. The major advantage of EMME/2 is its incorporation of multimodal equilibrium: in all applications both auto- and transit-related characteristics can be modeled simultaneously, which closely approximates real-world conditions (i.e. auto and transit modes are competing in an urban environment). This property not only offers the ability to assess the impact of transit services on road networks, but also aids in the identification of more efficient routes for transit services.

1.2.3 TRANPLAN

TRANPLAN, TRANsportation PLANning, was developed by Urban Analysis Group (UAG). The first DOS version of TRANPLAN was released in 1985 (Fennessy, 2000). The latest version is TRANPLAN 9.0 (UAG, 2000). TRANPLAN provides a network editor, Network Information System (NIS), to develop, display, and modify highway and transit network and related data. The latest version is NIS 9.0 (UAG, 2000).

TRANPLAN is a set of integrated programs for the transportation planning process. It encompasses the four-step travel demand model of trip generation, trip distribution, modal choice, and trip assignment for both highway and transit systems. It is driven by a set of icons and menus that provide the users with a flexible set of thematic mapping tools. Networks and related attributes can be graphically displayed using colors and patterns. Polygon boundaries (e.g. traffic analysis zones) can be defined and displayed

with user control over color and patterns. NIS's flexible configuration options allow users to customize the software's operation.

In order to perform travel demand forecasting, users develop a network using NIS and compile a control file, which specifies the combination of functions to be run and for each function the needed inputs, options, and outputs. Users may develop certain parts of an application by other programs and interface the results with TRANPLAN functions.

1.2.4 MINUTP

MINUTP was developed by UAG. The first DOS version of MINUTP was released in 1981 (Seiders, 2000). Its latest version is MINUTP 2000 (UAG, 2000).

MINUTP is a comprehensive computer-based travel demand forecasting system. It is used for travel demand forecasting, alternatives analysis, environmental impact statement analysis, site impact analysis, traffic impact studies, and many other related purposes.

The MINUTP system is comprised of individual model components. The system is designed to be run primarily as a batch job, but it also can be run in a pseudo-interactive manner. In the batch manner, a job stream can be established that contains control information for the job flow and the parameters for each individual component. To execute, prepare the job stream on a file and then issue the MINUTP command. That command will cause the MINUDR program to prompt for certain information. When the

information is appropriately supplied, the programs are executed in the order as designated in the job stream file.

1.2.5 TP+

TP+, Transportation Planning, was developed by UAG. The first version was released in 1997 (UAG, 2000). Its latest version is TP+ 2.0 (UAG, 2000). TP+ provides the graphical user interface program, Viper (Visual Planning Environment). Version 2.0 of Viper is current release (UAG, 2000).

TP+ is a new package and implements many new and modern paradigms. TP+ provides features for users to perform all aspects of the modeling process. The main feature of TP+ is a language compiler and runtime interpreter. This means that users can develop either simple or very complex scripts that will be interpreted by the software when a process runs. Users are free to change and modify the runs as they progress.

Viper is used to develop, modify, and display network, transit lines, and GIS shapes files. It reads network files that are stored in TP+, TRANPLAN, and MINUTP format. It can also read and write ESRI shape files and convert between these formats. Viper also provides the capabilities to modify TP+, TRANPLAN, and MINUTP script files and launch TP+, TRANPLAN, and MINUTP runs directly. Viper works with data stored in dBASE compatible database files in order to provide the highest level of database

connectivity. This interaction with database files makes importing and exporting data with GIS systems straightforward.

1.2.6 TransCAD

TransCAD was developed by Caliper Corporation. The first version of TransCAD was released in 1988. The latest version of TransCAD is version 3.5 (Caliper, 2000).

TransCAD is the first and only Geographic Information System (GIS) designed specifically for use by transportation professionals to store, display, manage, and analyze transportation data. TransCAD combines GIS and transportation modeling capabilities in a single integrated platform. It can be used for all modes of transportation. TransCAD provides a comprehensive solution for many types of transportation applications: network analysis, transportation planning and travel demand modeling, vehicle routing and logistics, and districting and location modeling.

TransCAD supports many styles of travel demand modeling including sketch planning methods, four-step travel demand forecasting models, advanced disaggregate modeling techniques, simultaneous models for multiple choices, and the most extensive set of traffic assignment models. The main advantage of TransCAD is GIS-based and fully integrated GIS and demand forecasting modeling capabilities. TransCAD can not only import data from virtually all major GIS, CAD, and planning software packages, but also

export data in ASCII, shape files, dxf, and dbf formats. TransCAD also links easily to ArcView, ArcInfo, MapInfo, GIS+, and Mapitude.

1.2.7 TRANSIMS

TRANSIMS (Transportation Analysis and SIMulation System) has been being developed by Los Alamos National Laboratory since 1995. It is an integrated system of travel demand forecasting models designed to give transportation planners accurate and complete information on traffic impacts, congestion, and pollution.

TRANSIMS is an activity-based new generation travel demand forecasting model, which is totally different from all traditional travel demand forecasting models including the four-step demand forecasting model. TRANSIMS creates a virtual metropolitan region with a complete representation of the region's individuals, their activities, and transportation infrastructure. Trips are planned to satisfy the individual's activity patterns. Then TRANSIMS simulates the movement of individuals across the traffic network, including their use of vehicles such as cars or buses, on a second-by-second basis. This virtual world of travels mimics the traveling and driving behavior of real people in the region. The interactions of individual vehicle produce realistic traffic dynamics from which analysts using TRANSIMS can estimate vehicle emissions and judge the overall performance of the transportation system.

Comparing with previous travel demand forecasting models that survey people about elements of their trips such as origins, destinations, routes, timing, and modes, TRANSIMS starts with data people's activities and trips they take to carry out those activities, then builds a model of household and activity demand. The model forecasts how changes in transportation policy or infrastructure might affect those activities and trips. TRANSIMS tries to capture every important interaction between travel subsystem, such as an individual's activity plans and congestion on the transportation system. Because TRANSIMS tracks individual travelers, it can evaluate transportation alternatives and reliability to determine who might benefit and who might be adversely affected by land use changes

1.3 Objectives of Research

Section 1.1 has provided a brief description of traditional travel demand forecasting process. Section 1.2 demonstrated that theories are implemented by numerous computer-based travel demand forecasting models in practice. While the existence of so many computer-based travel demand forecasting models provides a comprehensive list of choices, for transportation planners, it is also confusing with respect to which model is more suited for a particular application scenario. It is a consensus among practitioners that none of the existing models is perfectly suited for all scenarios. In this context, there is a need to identify main features and differences of existing demand forecasting models, such that transportation planners can have a useful reference guide in choosing a model for a particular study. As the first step in this effort, this research will conduct a

comparative study on two widely used computer-based travel demand forecasting models: QRS II vs. EMME/2. To this end, the research established three objectives:

1. Compare basic features of QRS II and EMME/2;
2. Compare QRS II and EMME/2 using a real-world network; and
3. Compare advanced features of QRS II and EMME/2.

Through the comparison of basic features of QRS II and EMME/2 such as model structure, network development, network modification, data entry, parameter calibration, and model outputs, the research attempts to identify the major differences and common features of two models. To support the comparison effort, modeling a real-world network will be performed using both QRS II and EMME/2.

CHAPTER 2

LITERATURE REVIEW

This chapter summarizes some of previous research related to travel demand forecasting and computer-based travel demand forecasting models with an intention to establish the need for the study in this report.

2.1 Review of State-of-the-art

The research related to travel demand forecasting methods dates back to 1950s when the four-step travel demand forecasting process was first adopted. Since then, significant advances have been achieved in modeling each step of four-step demand forecasting process. Especially, the development of advanced dynamic assignment theories, although which were developed in response to the development of Intelligent Transportation Systems (ITS) strategies, has considerably changed the dynamics and the traditional thinking of travel demand forecasting models. This section will only give a review of some of recent works related to travel demand forecasting.

In the area related to trip generation, Scobee et al. (1998) provided a method that involves obtaining complete household and person characteristics for each household member. The method is presented for generating synthesized household trip production rates by using 1995/1996 Delaware Household Travel Survey. Strambi and Van De Bilt (1998)

used a criterion-based segmentation modeling tool, Chi-Squared Automatic Interaction Detection (CSAID), to analyze household trip generation rates. Falocchio and Michel (1992) developed the trip generation rates for reconstruction project in Manhattan. Kumar and Levinson (1993) developed an afternoon peak-hour trip generation model for both work and nonwork trips. In Kumar's work, a model of home-end trip generation is estimated using the household travel survey as a cross-classification of the demographic factors of age and household size in addition to dwelling type. Non-home-end generation uses employment by type and population. Thakuriah et al. (1993) gave a method to assess nonresponse bias in estimates of trip generation model parameters.

In the area of trip distribution, Levinson and Kumar (1994) developed a multimodal trip distribution function for the metropolitan Washington D.C. region. In addition, a methodology for measuring accessibility, which is used as a measure of effectiveness for networks, using the impedance curves in the distribution model is described. Boyce and Zhang (1997) described a method for calibrating a combined model of travel choices for the Chicago, Illinois. This model and its simultaneous calibration method seek to ensure that travel choices are represented consistently, thereby offering an operational method for implementing and solving the four-step travel forecasting procedure with feedback.

In the area of model choice, Badoe and Miller (1995a) performed work trip modal choice using logit model. They used 1964 data for the Greater Toronto Area (GTA) to represent 1986 work trip modal choice in the GTA. Badoe and Miller (1995b) also presented an empirical study of the long-range temporal transferability properties within a fixed

geographic area of disaggregate logit models of work trip modal choice. Shalaby and Steuart (1996) did an investigation through a comparative analysis of trip end and trip interchange modal choice for work trips in the GTA. Two model sets are developed; one includes trip end models and the other includes trip interchange models.

In the area of traffic assignment, Kurth et al. (1996) implemented a regional traffic assignment process based on capacity estimation techniques and volume delay functions documented in the Highway Capacity Manual. Prashker (1990) developed a transit assignment algorithm that takes into account the actual capacity of transit lines and assigns trips to more than a single path when the shortest path reaches its capacity. Shih et al. (1997) developed a trip assignment model for timed-transfer transit system. Sun and Mouslos (2000) presented a methodology of traffic assignments in urban transportation. The discussions included expanded network representation, designation of lane groups, allocation of green times, estimation of saturation flow rates, and calculation of delay adjustment factor. As an example of research on dynamic traffic assignment, Janson (1991) presented a link flow formulation and a convergent solution algorithm for the dynamic user equilibrium (DUE) traffic assignment problem for road networks with multiple trip origins and destinations. This convergent dynamic algorithm (CDA) used the Frank-Wolfe method of linear combinations to find successive solutions to DUE while holding node time intervals fixed from each origin.

2.2 Review of State-of-the-practice

In addition to state-of-the-art reviewed in the preceding section, there has been a number of research work conducted relative to the use of computer based travel demand forecasting models. For example, Metaxatos et al. (1995) developed a *macro* that implements the origin-destination and route choice model in EMME/2. Using data from the city of Winnipeg, Manitoba, Canada, they obtained good results. One of the scopes of their effort is to motivate transportation professionals to use more sound planning tools. Hunt et al. (1998) used EMME/2 to develop a new urban travel demand forecasting model for city of Edmonton in Canada. The network consists of 500 zones and over 9000 links. This model has been successfully calibrated for the City of Edmonton and surrounding region, covering a population of just over 860,000. It is currently being applied in the evaluation of policy alternatives for the City for the next 25 years. As such, this system represents a significant advancement in the state-of-the-art in practice using existing software and well-accepted general techniques to extend practical transportation demand modeling and evaluation.

Mann and Dawoud (2000) developed TP/4in1, which executes the four-step travel demand forecasting process in one execution on the computer and does it using network and zonal data from the Washington, D.C., regional model, with 2,191 zones and 16,000 nodes. The major advantage of this software over other software is that it is designed for the novice transportation planner who does not have time to learn more sophisticated software such as MINUTP, TRANPLAN, and son on. Once a region's MPO model is

streamlined to fit within the structure of TP/4in1, it could be executed by any suburban jurisdiction planner or it could be built from scratch for any new urbanized area. Running the model frequently or for only a few times per year is feasible for those unfamiliar with transportation modeling.

2.3 Existing Comparison Studies

Although there have been numerous studies on the use of a specific computer based travel demand forecasting model, there have been very few studies on the comparison of different models. According to an informal survey by Horowitz and Farmer (1999), which was conducted to 45 out of 50 states, the application of travel demand forecasting models was used unevenly across states, including data collection methods, calibration procedures, range of modes, network structure, and individual model steps. Islam, et al. (1995) evaluated and rated four travel demand forecasting software: QRS II, System II, TRANPLAN, and MINUTP, with respect to 14 characteristics. All four software could be used for travel demand forecasting. However according to the total evaluation points, the two top-rated models were TRANPLAN and QRS II. Rutherford and Pennock (1985) indicated that QRS II is easy to understand and operate with few exceptions. Babin et al. (1982) indicated that EMME/2 is more comprehensive than other interactive graphic models that have been developed to date.

In a summary, existing literatures have reported many successful applications of existing models including QRS II and EMME/2. However, none of research has attempted to

identify specific features and limitations of each model in modeling a real-world network in a comparative manner.

CHAPTER 3

DESIGN OF STUDY

This chapter describes the design of study in this report, including model selection, comparison approach, and limitations of study.

3.1 Model Selection

In order to compare computer-based travel demand forecasting models, a minimum of two models should be selected from many of existing models as listed in section 1.2. In this research, QRS II and EMME/2 were selected for comparison. Both QRS II and EMME/2 have been used widely throughout the country and the world. The study is anticipated to help users understand the main differences and common features of QRS II vs. EMME/2. The selection of QRS II and EMME/2 in this research should be construed as the first step of a comprehensive comparison of more applicable models.

3.2 Comparison Approach

In order to perform an in-depth comparison of QRS II vs. EMME/2, it is necessary to use a real-world network in the comparison process. The entire comparison approach involves the following elements:

1. Reviewing existing literatures about travel demand forecasting models, especially on the use of QRS II and EMME/2 models;
2. Reviewing the user's manuals of QRS II and EMME/2 to identify and compare basic features of two models;
3. Modeling the South Missouri City network using QRS II and EMME/2 to enhance the comparison process; and
4. Summarizing, analyzing, and comparing the results from literature review, manual review and modeling SMC network to complete the comparison process.

3.3 Limitations of Study

The authors acknowledges the following limitations in the research:

1. Although necessary, the research could not compare more travel demand forecasting models such as TRANPLAN and TransCAD due to the scale of this research project. However it is recommended that a follow-up comparison be conducted on more models.

2. Because the transit lines do not actually exist in the study area in the case study, the comparison of transit network has to use a hypothetical transit line.

3. Although basic features of two software packages can be compared comprehensively, advanced features cannot be compared thoroughly. Advanced features of any model are always complicated and it is not exaggerate to say that nobody could capture all details of advanced features completely. Therefore, this research only examines partial features of *calculate* function of QRS II and *macro* language of EMME/2.

4. The research will focus on the traffic assignment step of QRS II and EMME/2 in modeling the real-world network, as EMME/2 can replicate the result of trip generation, trip distribution, and modal choice of QRS II, if the relevant matrices and functions are properly set up.

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter will first provide a comparison of basic features of QRS II vs. EMME/2. Then an extended comparison of two models using a real-world network is conducted. Finally, selected advanced features of two models are examined.

4.1 Comparison of Basic Features

The basic features of QRS II and EMME/2 are compared, which include network development, travel demand forecasting procedures, and model outputs.

4.1.1 Network Development

In order to use either QRS II or EMME/2 for the purpose of travel demand forecasting, the first task is always developing a network. This section intends to provide a comparative description of QRS II and EMME/2 in the network development.

(1) The tool in network development

QRS II provides GNE, a tool of network development, with which users can quickly draw a graphics of network within a window and enter data related to the characteristics

of nodes or links. The network can be modified easily, and important results can be displayed. The sketchpad is operated by either using the mouse or by using the keyboard.

GNE's main window is similar in form and function to many other Windows applications. The main window consists of title bar, the menu bar, the sketchpad tool bar, and the sketchpad. All are illustrated as Figure 4.1

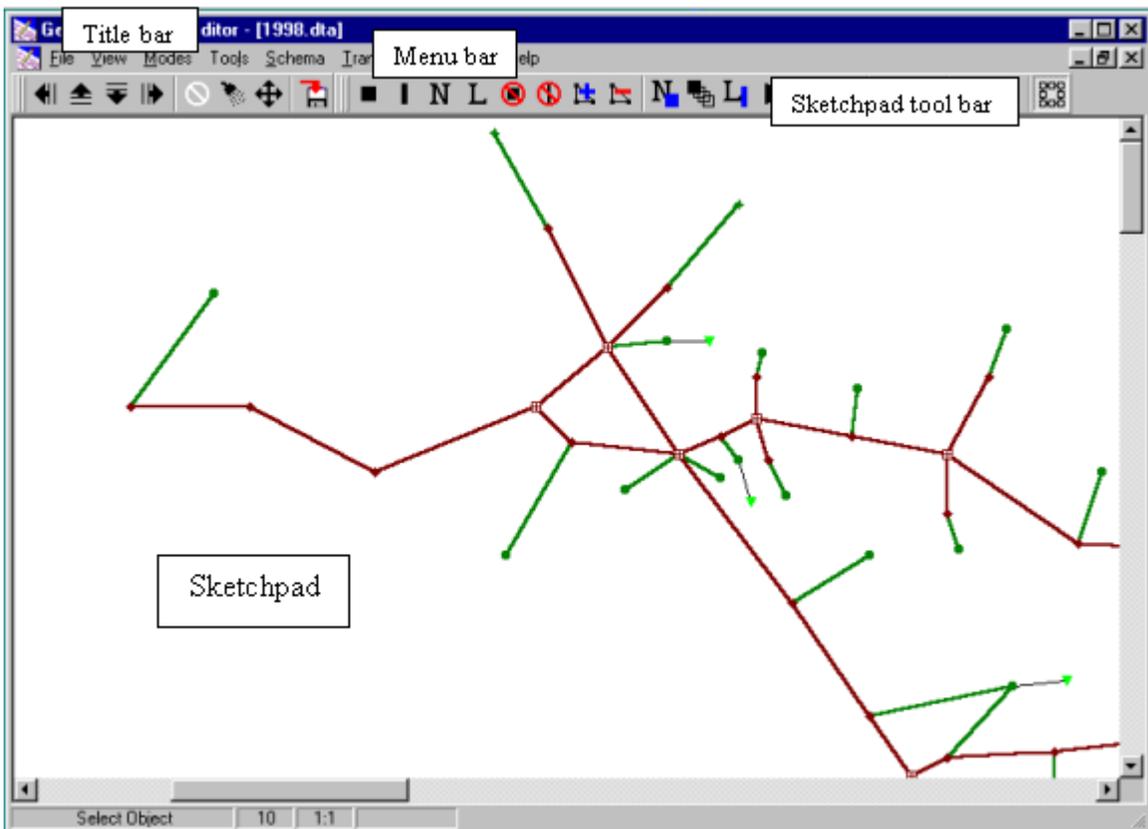


Figure 4.1 GNE's Main Window

The title bar shows the name of the network. The menu bar contains the main menu items. The sketchpad tool bar provides operations that can be performed on sketchpad. The sketchpad is the area in which a network is drawn.

In comparison, EMME/2 also provides a graphic network development tool, but which is different from the QRS II's network development tool. EMME/2' uses a network editor, which is one of its six modules, to develop the network. In order to draw a network, a databank and a scenario must be created first. EMME/2's databank and scenarios will be discussed in 4.1.2 (2).

A sketchpad is called worksheet in EMME/2, in which network will be drawn. A graphic worksheet is subdivided into four areas, which are illustrated in the Figure 4.2.

- Area A is an alphanumeric pad, which is used to display short messages and to input alphanumeric items in the form of an abbreviated dialog.
- Area B is the crosshair cursor command area, which contains an annotated box for each command.
- Area C is the actual plot area for displaying, entering, and modifying the relevant data.
- Area D is the information area, which always contains the date, the module number, the license name, the user initials, the current scenario, and the window coordinates.

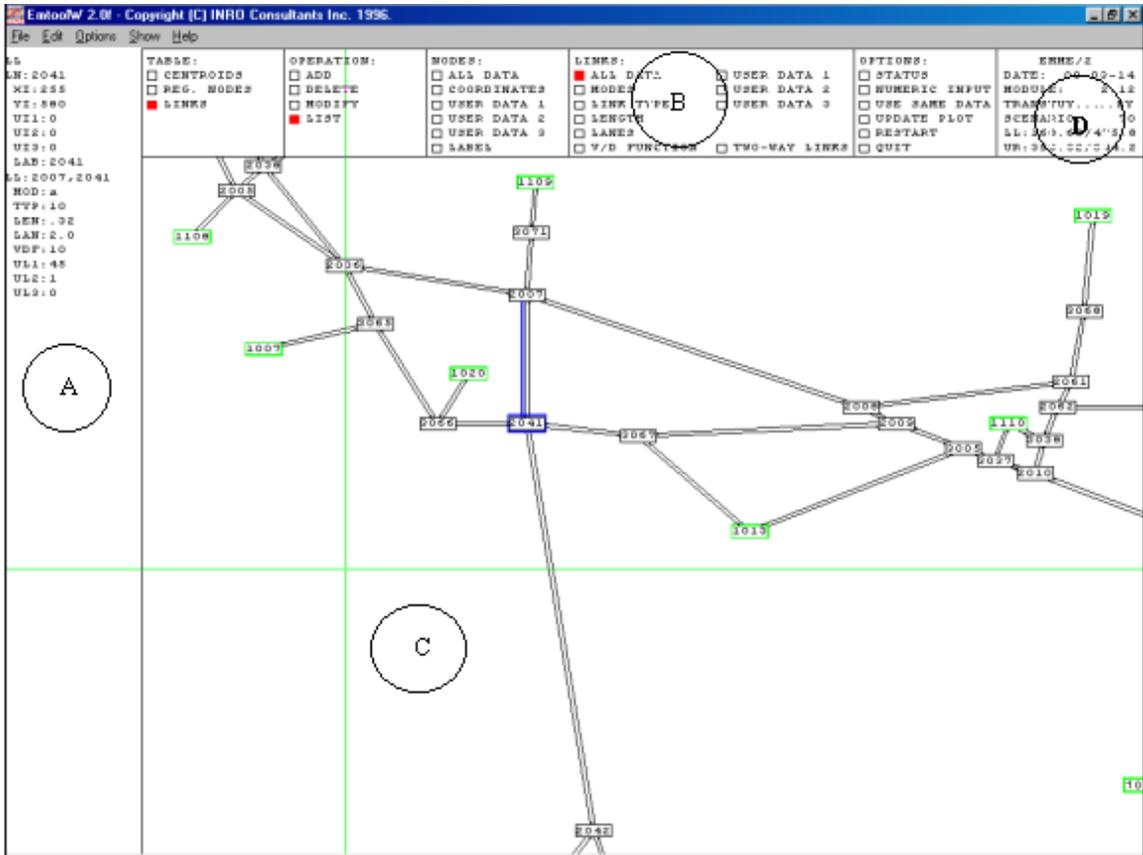


Figure 4.2 EMME/2's Worksheet

(2) Preparations for network development

At the beginning of network development using GNE, users must load an application schema, which tells GNE about definitions of general characteristics of the network to be developed. These characteristics include the types of nodes and links in the network, their colors, their shapes, and their attributes. The application schema for QRS II has been defined and provided for users to use under names of QRS50.dta (for three-purpose network.), QRS50UK.dta (for three-purpose network, UK-style traffic), QRS504.dta (for four-purpose network), QRS504UK.dta (for four-purpose network, UK-style traffic),

QRSTR40.dta (for three-purpose transit network), and QRSTR404.dta (for four-purpose transit network).

After loading a blank application schema, users should setup scale in menu of system attributes. For example, 96 pixels can be set to represent one mile. The scale is very important to network drawing, on which the length of a link will be calculated based.

In comparison, at the beginning of using EMME/2 for travel demand forecasting, users must create a databank, which contains not only the input data for the particular application, but also provides space to accommodate all the resulting output data. That means that network, matrices, functions, and output results are all included in the databank, which is a binary file. To create an EMME/2 databank, Users must execute emme2.exe file with the newbank option. In general, a new databank is created in a new file named emme2bank.dat. Then users should specify databank dimensions, which will determine the disk space that the databank file will occupy, such as maximum number of network scenarios, maximum number of each matrix type, and so on. Users also need to implement the dimensions that apply to each of the network scenarios, such as maximum number of zones/centroids, maximum number of nodes, and so on.

As stated above, when creating a new databank, users have to implement dimensions. These dimensions will decide the file size of databank. It is a challenge to users. If the dimensions set up by users are too small, users may meet some problems to perform some tasks later and thus the dimensions have to be increased. On the other hand, if the

dimensions set up by users are too large, the size of the databank file will be unnecessarily huge.

When a new databank is created, it always contains a single empty scenario. Users can begin to develop a network. EMME/2 provides two methods to draw network. Users can develop a network and complete the attributes of nodes and links either in an interactive graphic way (Module 2.12) or using batch entry (Module 2.11).

(3) Plotting of nodes

A network consists of nodes and links. QRS II defines eight node types: centroid, intersection with delay, intersection without delay, external station, production/attraction tag, special generator centroid, seed tag (for skim trees), and district tag (for district-to-district trip tables).

Internally, GNE references its nodes by their location on the screen in units of pixels. X-coordinate increases as the node plot cursor is moved from left to right. Y-coordinate increases as the node plot cursor is moved from top to bottom. (as shown in Figures 4.3).

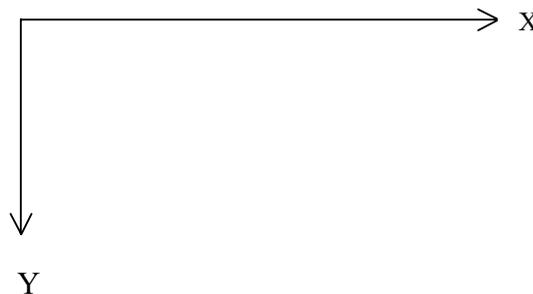


Figure 4.3 Coordination System of Sketchpad in GNE

According to the X-coordinate and Y-coordinate of a node, users can plot this node on sketchpad. Then users should open this node entity, select the type of the node, name the node, and complete the attributes of the node. Figure 4.4 and 4.5 demonstrate an example of small windows for node entity and attributes.

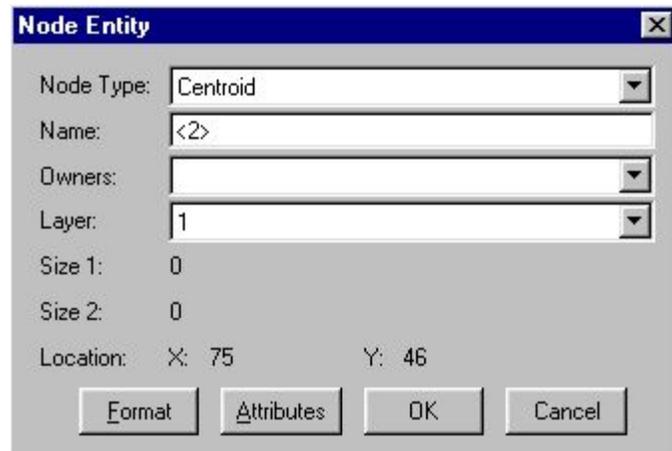


Figure 4.4 An Example of Node Entity in QRS II

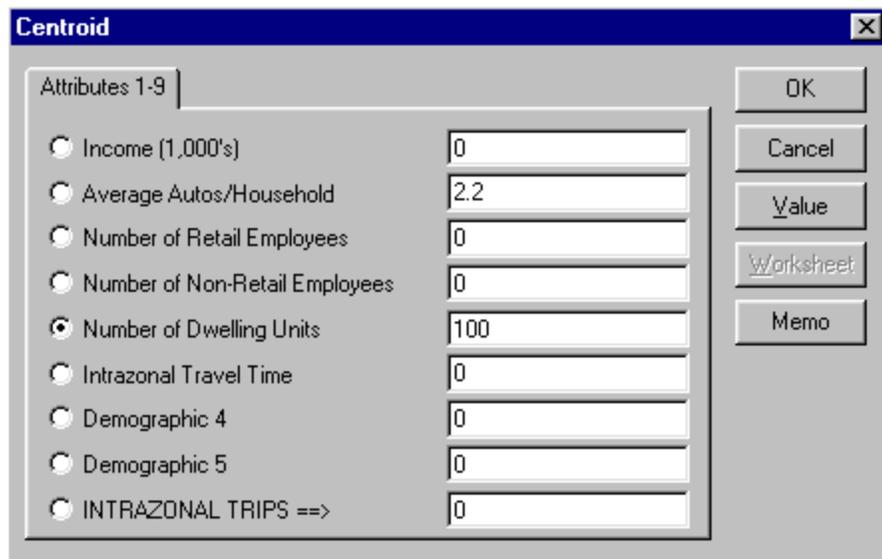


Figure 4.5 An Example of Node Attributes in QRS II

In comparison, EMME/2 defines only two node types: regular node and centroid. EMME/2 also references its nodes by their location on the screen in units of pixels. X-coordinate increases as the node plot cursor is moved from left to right. Y-coordinate increases as the node plot cursor is moved from bottom to top. (as shown in Figures 4.6).



Figure 4.6 Coordination System of Plot Area in EMME/2

When plotting a node, users select commands "CENTROIDS" or "REG. NODES" from "TABLE" and "ADD" from "OPERATION", then complete node attributes in the alphanumeric pad. The attributes are node number (AN), X-coordinate (XI), Y-coordinate (YI), user data 1 (UI1), user data 2 (UI2), user data 3 (UI3), and node label (LAB). Users can leave user data 1, user data 2, and user data 3 blank, unless users will use some data related to nodes. After node attributes are completed, the node will be displayed on plot area. Figure 4.7 is a demonstration. In QRS II, data related to nodes are input as node attributes, while in EMME/2, data related to nodes are input either as node attributes such as UI1 or as values in matrices.

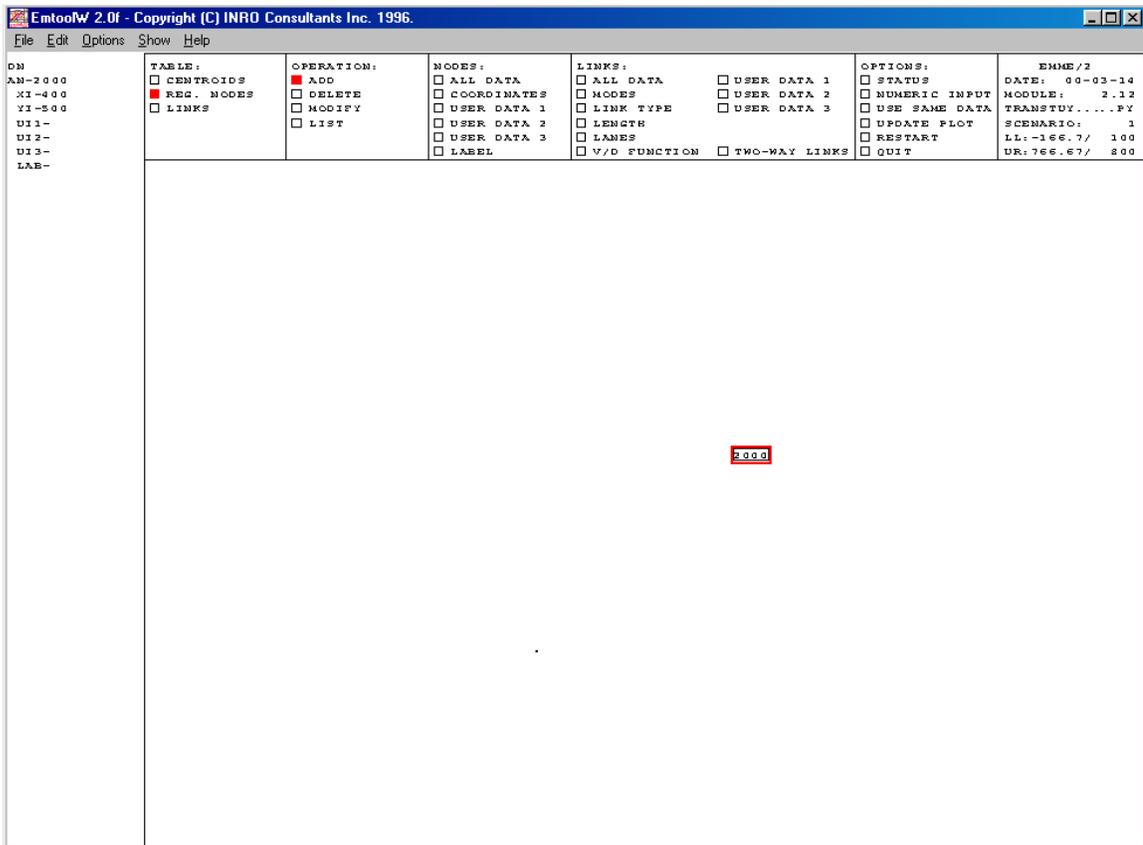


Figure 4.7 An Example of Plotting a Node in EMME/2

As noted previously, users can also develop a network using batch entry in EMME/2. Module 2.11, input/modify base network using batch entry, provides all the operations that are necessary to input and modify the base network using batch entry. This module reads a node and link table file and allows an arbitrary sequence of modifications (add, modify and delete operations) for nodes and links. The following demonstrates plotting a centroid using batch entry.

t nodes

c add a centroid at the coordinations of (75,46), node number is 1002

a* 1002 75 46 0 0 0 1002

(4) Plotting of links

Links are drawn in GNE by simply clicking two nodes respectively. However, users should pay attention to the direction of a link. The first node clicked is called the A-node, and the second node is the B-node. The direction of a link is represented as A to B and B to A. For the uniform direction of links in a network, users had better draw links based on their rules such as from west to east and from north to south. For example, if a link is vertical or approximately vertical, the link is drawn by clicking upper node first and then clicking lower node; if a link is horizontal or approximately horizontal, the link is drawn by clicking left node first and then clicking right node. The benefit to draw links in the uniform direction will be discussed in 4.2.3.

Eight types of links are defined in QRS II: two-way street, one-way street, centroid connector, two-way street (no left turn), two-way street dummy, one-way street dummy, centroid connector dummy, and piece of string. Like drawing a node and entering node data, after drawing a link, users should open the link entity, select link type, name the link, and complete the link attributes. Figure 4.8 and 4.9 illustrate a dialog box for link entity and its attributes respectively.

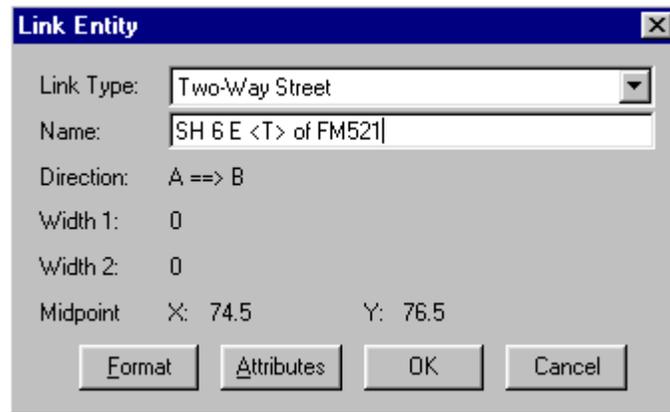


Figure 4.8 An Example of Link Entity in QRS II

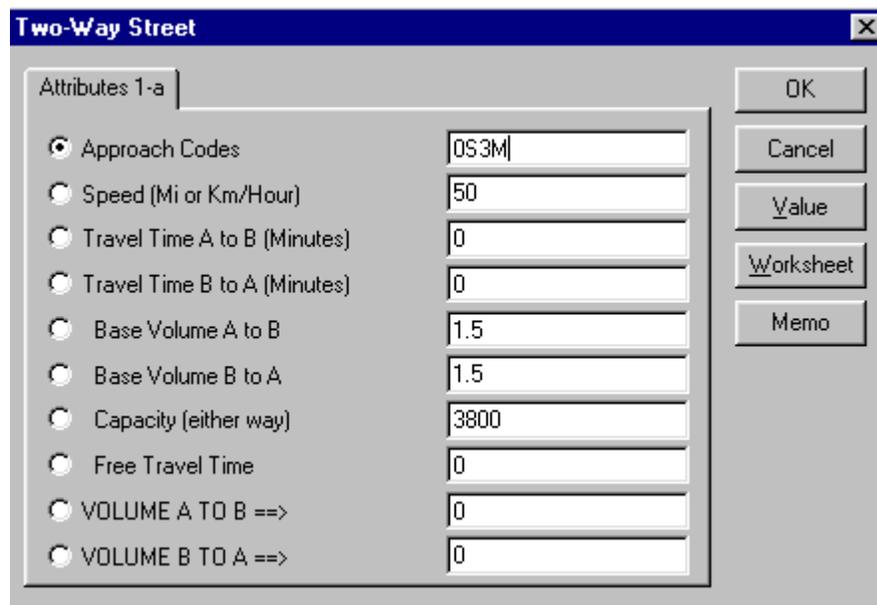


Figure 4.9 An Example of Link Attributes in QRS II

In comparison, EMME/2 does not provide prepared defined link types. However, EMME/2 provides a user-defined classification of links. The classification can be useful for defining a subnetwork. Users can always define link types according to their needs. When plotting a link, users select commands "LINKS" from "TABLE" and "ADD" from "OPERATION", then click the initial node and the terminal node of the link, the link will be displayed on the plot area. Finally, users need to complete link attributes in the

alphanumeric pad. The attributes are I-node (number of initial node of the link), J-node (number of terminal node of the link), link length (defined in units of length, in the range 0.01 to 999.99), modes (the modes are allowed on the link), link type (a positive number in the range 1 to 999), number of lanes (in the range 0.1 to 9.9), index of the volume-delay function (that will applies to this link), user data 1, user data 2, and user data 3. Users can enter the symbol of * to the attribute of link length, in which the link length will be calculated from the straight line distance in coordinate units between I-node and J-node of a link. Users also can leave user data 1, user data 2, and user data 3 blank, unless users will use these data for calculations.

Because the link is identified as the node numbers of I-nod and J-node, users need to plot two links between two nodes if the link stands for two-way roadway. The initial node and terminal node of one link become reversely to be the terminal node and initial node of the other. For example, the link of 2000-2001 and the link of 2001-2000 are reverse in direction. Figure 4.10 illustrates an example of plotting a link in EMME/2.

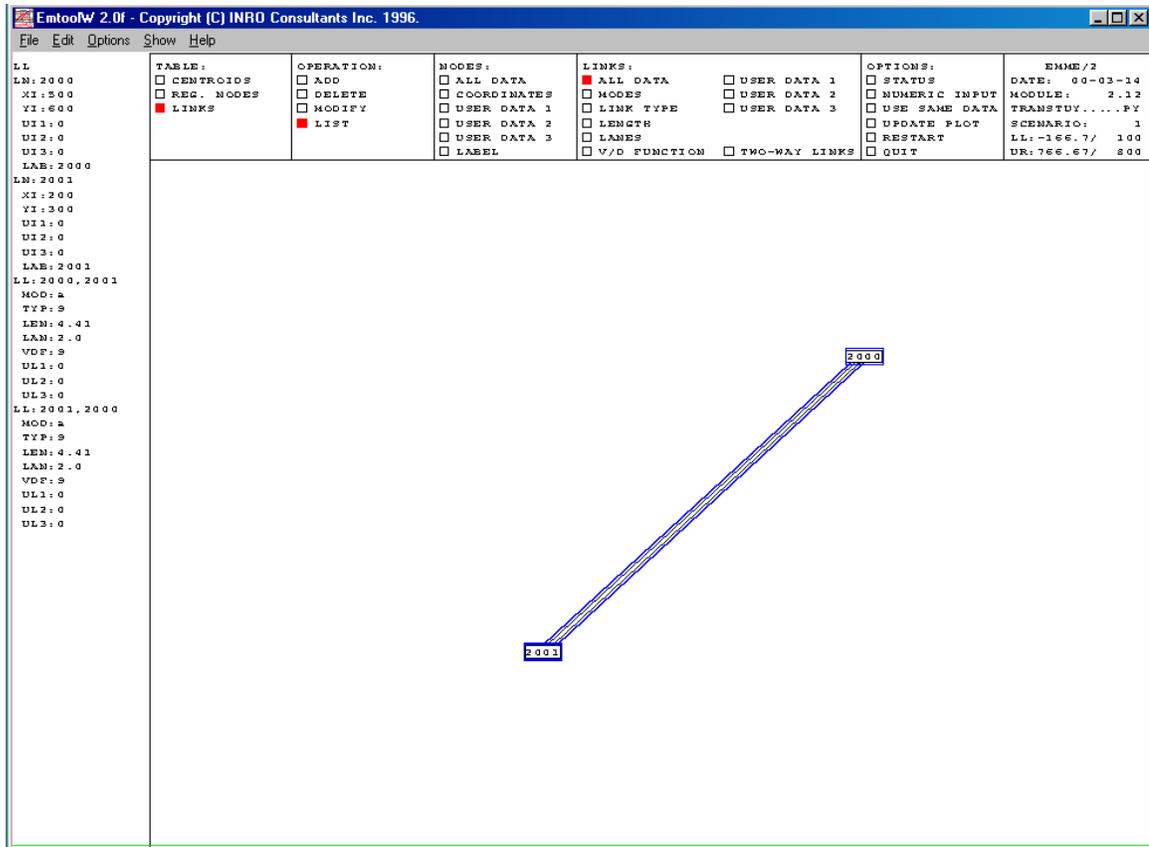


Figure 4.10 An Example of Plotting Links in EMME/2

Similar to plotting nodes, Users can also use batch entry to plot links. Both nodes on a link must be already defined in a node section already input. The following demonstrates an example of plotting a link using batch entry.

t links

c add a link from node 2000 to node 2001, a link from 2001 to 2000, link length calculated based on node coordinations, cb modes, link type 10, 3 lanes, volume delay function number is 10, speed 50 mph as user data 1.

a 2000 2001 * cb 10 3 10 50 0 0

a 2001 2000 * cb 10 3 10 50 0 0

(5) Handling of intersections

In representing a real-world traffic network, there are two kinds of nodes. One represents the intersections controlled by either a signal or a stop sign where delays always occur. The other represents only a point on the road that separates roadway segments with different characteristics. In QRS II, the former is described by the intersection with delay, at which travel time penalties may be added to movements within four categories: turning left, going through, turning to the immediate right, and other right turns. The latter is described by the intersection without delay, through which traffic flows are unimpeded.

In comparison, EMME/2 provides module 2.31 input/modify/display turn table to handle the intersections. Users can input, modify, and output a turn table for an intersection. The turns can be added, deleted, and modified either in the interactive graphic way or using batch entry.

In general, the forecasting of turning volumes at intersections is required for intersection capacity analysis. QRS II can calculate turning volumes at the intersections that are specifically requested to be analyzed. Actually, QRS II reports turning volumes between pairs of links. For this to happen, both links in the pair must have names that contain the three characters: "<T>". For example, in Figure 4.11, the turning volumes at the intersection are requested to be analyzed. Users could name the link just west of this intersection as "SH 6 W <T> of FM521", the link just east as "SH 6 E <T> of FM521", the link just north as "FM521 N <T> of SH 6", and the link just south as "FM521 S <T> of

SH 6". After QRS II calculates the requested turning volumes, they will be placed in the file, TurnMove.txt. If a requested turning volume is zero, QRS II will not list it in the file, TurnMove.txt.

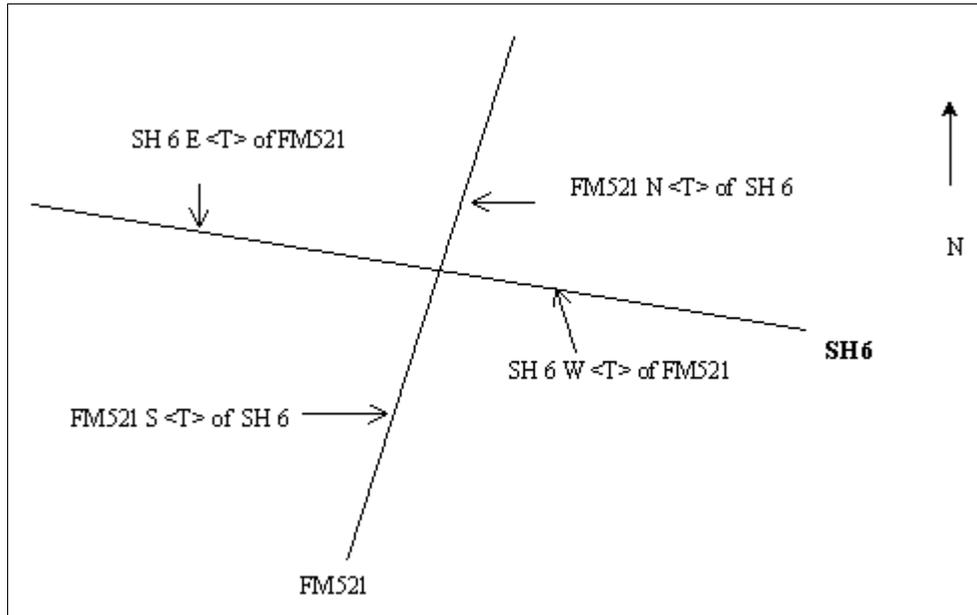


Figure 4.11 An Example of Link Name at an Intersection in QRS II

Because the turn penalty of an intersection is calculated based on the approach code of the link in question, users must input approach codes for all links to the intersection. The approach codes tell QRS II about conflicting and opposing traffic, presence of signs, presence of exclusive lanes, the quality of progression, presence of ramp meters, functional classes, and favorable geometry at right-turn lanes at some-way stop approaches.

There are four approach codes: the through traffic code, the lane geometry and sign code, the progression code, and the functional class code. These codes are single-digit numbers

or upper-case letters. For example, "0S3O" is a general purpose set of approach codes, which would be correct for a majority of approaches in most cities.

The through traffic code is used by QRS II to ascertain opposing and conflicting flows and to apply the proper turn penalties to the various movements at the intersection. At signalized intersections, the through traffic code also determines the number of through/right or left/through/right phases. The through traffic code is a single-digit number, including "0", "1", "2", "3", and "4", placed in the first position.

The lane geometry and sign code tells QRS II about the presence of signs, exclusive lanes, and ramp meters. For example, code 2 is used at an unsignaled intersection, at which the approach has a stop sign and two lanes: One is a left/through lane, and the other is a through/right lane, and code v is used at an intersection, at which the approach has an exclusive right lane, but no stop sign.

The progression code tells QRS II about favorable platoon of traffic at signalized intersections. It should be set according to the "arrival type" as defined in the Highway Capacity Manual (Transportation Research Board, 1997). A progression code varies from "1" (dense platoon arrives at the start of a red interval) to "5" (dense platoon arrives at the start of the green interval). The progression code of "3" represents neutral or random traffic conditions.

Last position of approach code is functional class code, which is used to select the BPR travel time/volume parameters. Permitted values of functional class code are "F" (freeway), "M" (Major Arterial), "m" (Minor Arterial), "c" (Collector), "l" (local), and "O" (other).

If nodes at two terminuses of a link are intersections to be analyzed and if they must have different approach codes to this link, users have to insert a node as an intersection without delay on this link in order to set approach codes correctly. An example is demonstrated in Figure 4.12.

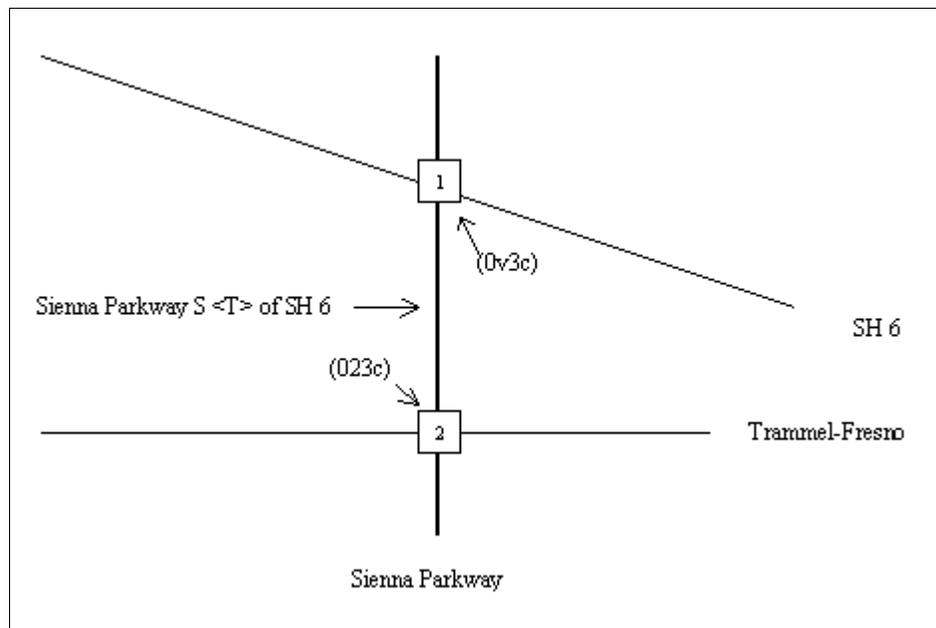


Figure 4.12 An Example of Link Approach Code in QRS II

The approach code to link between intersections 1 and 2, named "Sienna Parkway S <T> of SH 6", is requested to be input. The lane geometry and sign is as follows. Intersection

1 is a signalized intersection. If it is approached from the direction intersection 2, there are two lanes including one exclusive right lane. According to the definition of four codes, this approach code should be "0v3c". However, intersection 2 is an unsignalized intersection, and it is controlled by all-way stop signs. If it is approached from the direction intersection 1, there are two lanes: a left/through lane, and a through/right lane. Therefore, the approach code should be "023c". It is impossible to enter two different approach codes on the same link. The solution is to insert a node of intersection without delay on this link, then enter two different approach codes to these two links respectively. Figure 4.13 illustrates this method.

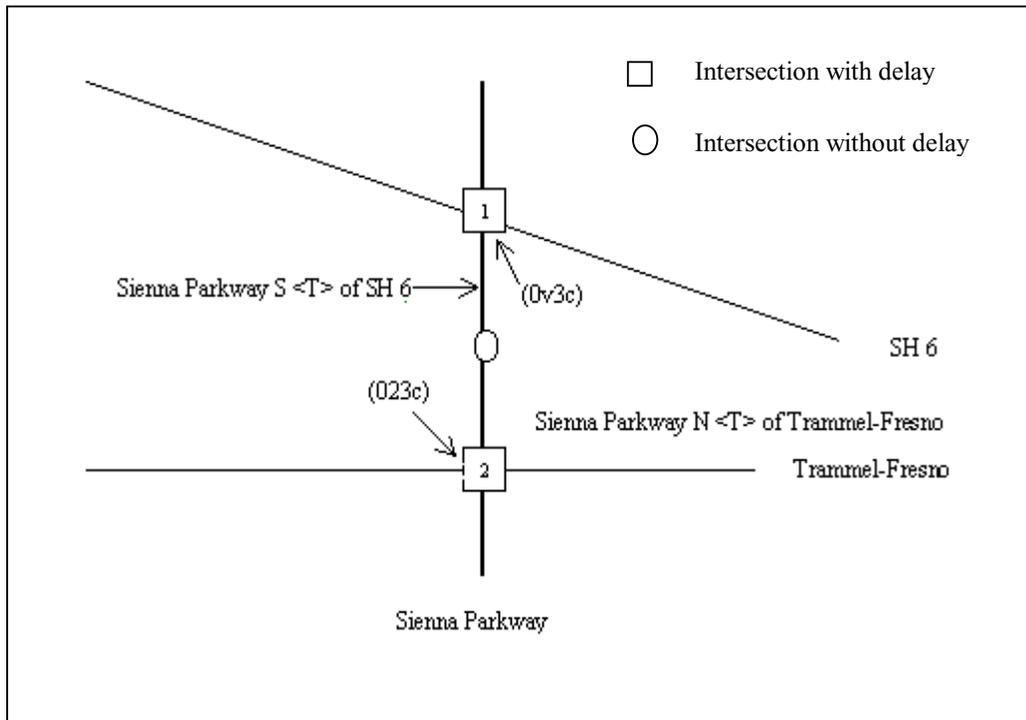


Figure 4.13 An Example of a Link with Two Approach Codes in QRS II

In EMME/2, users use module 2.31 and select interactive graphic method, the worksheet changes to intersection mode. The main plot area of worksheet is divided into three parts,

as demonstrated in Figure 4.14. The area of intersection plot (A) contains the layout of the intersection node. In the layout of turns at an intersection, (1) all turns are displayed, including U-turns; (2) forbidden turns are drawn as dotted lines, and allowed turns are drawn as solid lines; (3) turns are colored according to one of several possible color schemes. The area of turn attribute table (B) lists the turns at the current intersection and their attributes. The from node and to node of the turn are connected by a short vector which is drawn in the same color as the turn in the intersection plot. If selected, the area of network inset (C) displays a small window of the network that surrounds the chosen intersection node. It can also be used to select a neighboring intersection node.

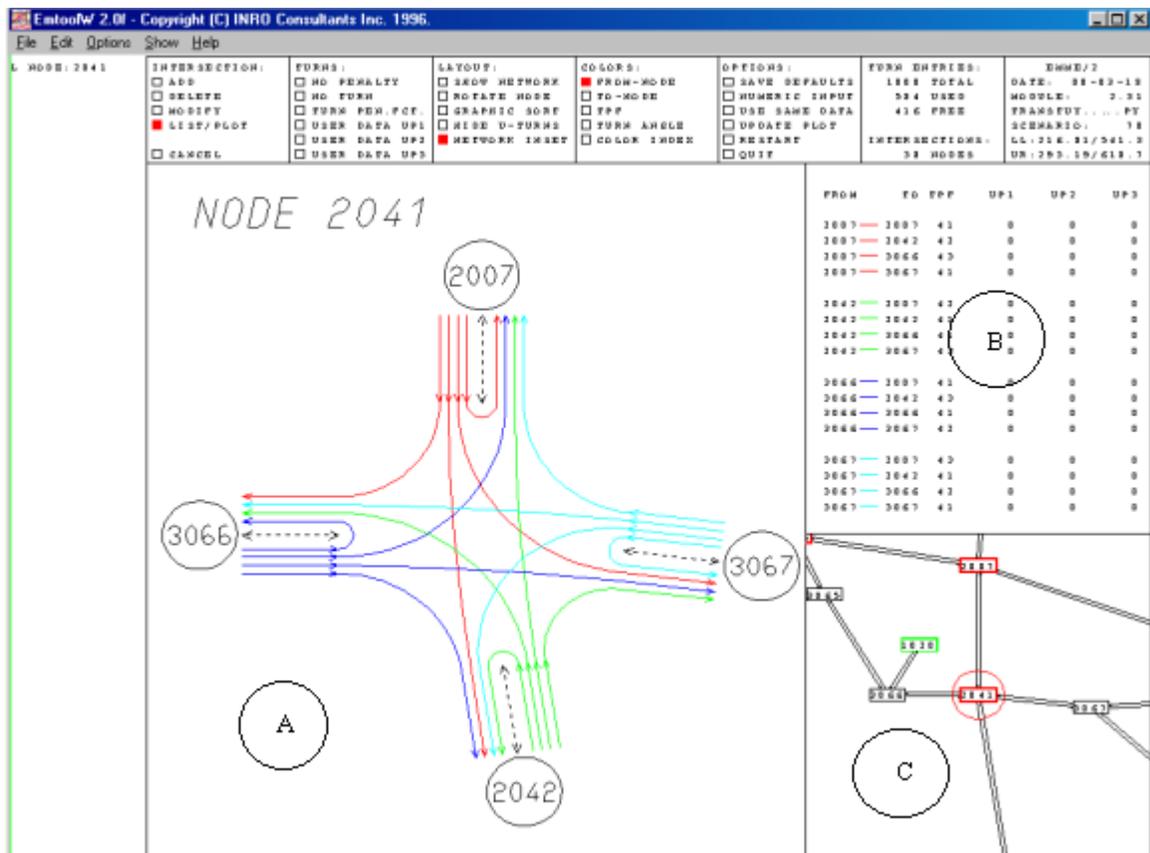


Figure 4.14 EMME/2's Worksheet for Intersection

The attributes of a turn are at-node, from-node, to-node, the number of the turn penalty function, user data up1, user data up2, and user data up3. The three-node number form a triplet JIK , which is used to identify the turn. J is the intersection node where the turn occurs. I is the node from which the vehicles are coming from, and K is the node to which the vehicles are going. The turn penalty function is used to add travel time penalties to the intersection. The number of the turn penalty function must be in the range -1 to the maximum number of functions per class. A zero indicates the turn is not allowed, while -1 indicates the turn is allowed but is not penalized.

Users can add, modify and delete a turn using batch entry. Selection of 2 in module 2.31 performs this task. Following demonstrates a turn table file that adds all turns at the intersection illustrated in Figure 4.14.

```
t turn init
2041 2007 2007 41 0 0 0
2041 2007 2042 42 0 0 0
2041 2007 3066 43 0 0 0
2041 2007 3067 41 0 0 0
2041 2042 2007 42 0 0 0
2041 2042 2042 41 0 0 0
2041 2042 3066 41 0 0 0
2041 2042 3067 43 0 0 0
```

2041 3066 2007 41 0 0 0
2041 3066 2042 43 0 0 0
2041 3066 3066 41 0 0 0
2041 3066 3067 42 0 0 0
2041 3067 2007 43 0 0 0
2041 3067 2042 41 0 0 0
2041 3067 3066 42 0 0 0
2041 3067 3067 41 0 0 0

(6) Transit network development

To perform transit forecasting in QRS II, users first must develop a regular highway network, and then draw a separate transit network showing various transit routes, transfer points, and stops. The only connection between a highway network and a transit network is that centroids in the transit network must also appear in the highway network. There are five types of nodes that may be used in QRS II transit network: stop, transfer point, stop (restricted), transfer point (restricted), and centroid. Six types of links may be used in a transit network: one-way single route, two-way single route, one-way multiple route, two-way multiple route, centroid connector, and piece of string. In a QRS II transit network, transit centroids reflect the highway centroids or external stations. Therefore, every transit centroid must have a corresponding highway centroid or external station on the highway network.

In a comparison, EMME/2 provides two methods to draw a transit network. One is interactive graphics, and the other is batch entry. EMME/2 transit network includes regular nodes, centroids, and links. Different from QRS II, a transit network in EMME/2 is based on the corresponding base network, so nodes and links, which will be included on a transit network, must be on a base network. Because the base network exists, it is easier and faster to draw a transit network using batch entry.

Module 2.22, input/modify transit lines interactively, is used to add, delete, and modify transit lines interactively using a graphic worksheet (Figure 4.15).

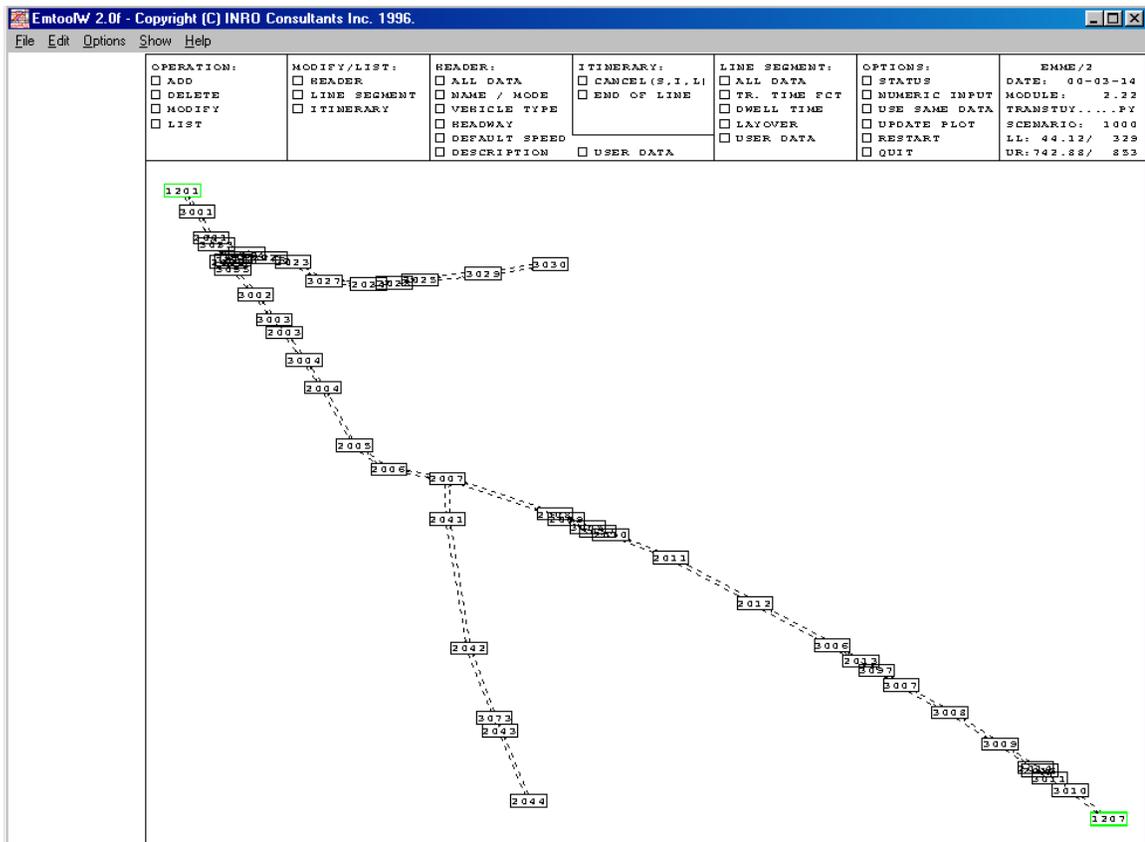


Figure 4.15 EMME/2's Worksheet for Transit Lines

Module 2.21, input transit lines using batch entry, is used to read a transit lines table, i.e. a batch entry file of transit network. This module contains all the operations that are necessary to input and modify the transit lines using batch entry. The batch entry file contains the definition of the transit lines. Each transit line is defined by one header record, which contains the data concerning the transit lines. Following demonstrates a batch entry file.

```
t lines
c add a transit line "downtown express"
a 132 b 2 20.00 30.00 'downtown express' 0 0 0
    path=no ttf=12 dwt.=0.10 2833 2835 2831 2891 2897 2899 2901 lay=5 2903
2905 2907 2908 2909 lay=6
```

(7) Printing of a network

The QRS II network can be printed through either a printer or a plotter. GNE has the scaling feature that permits the expansion and contraction of the network. Although the network can be expanded to a large scale, which makes the plot of network clearer on the screen, users could not print a part of the network they need.

A network in EMME/2 can also be printed through either a printer or a plotter. Printing a network in EMME/2 is more flexible. Users can define network window by using coordinates, using node numbers, centered on a node, using predefined window, and

using same window as before. Therefore, users can select either the entire network or any part of a network for printing.

4.1.2 Travel Demand Forecasting Procedures

To implement the four-step travel demand forecasting process of trip generation, trip distribution, modal choice, and traffic assignment, QRS II and EMME/2 use different methods. This section will discuss and compare the procedures of travel demand forecasting in QRS II and EMME/2.

(1) Basic procedures in travel demand forecasting

To perform travel demand forecasting in QRS II, users first need to load a highway network or a transit network, locate the directories in which the report files and temporary files will be stored, select report file types for highway or transit, and select parameters. Figure 4.16 demonstrates the window of QRS II.

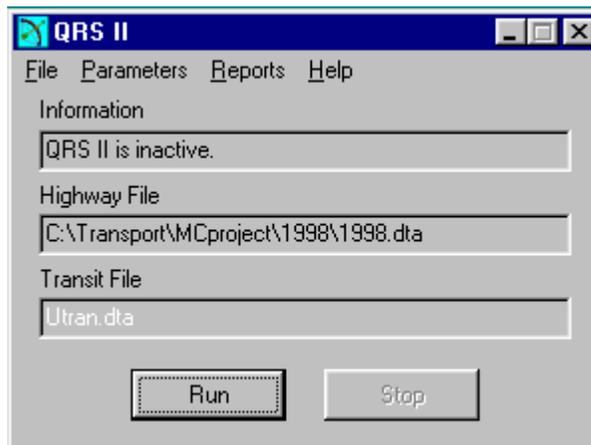


Figure 4.16 QRS II's Main Window

QRS II provides a large number of parameters, which are automatically set when the size of the urban area and the time for modeling are specified. The parameters include trip generation parameters, trip distribution parameters, vehicle occupancy parameters, trip table parameters, fundamental assignment parameters, intersection parameters, transit disutility parameters, and path finding parameters. Users can change the default parameters, which can be done through dialog boxes from the parameter menu. Most parameters are numbers, while some may be set by checking a box, selecting an item from a list, or clicking a radio button. All parameters can be found and setup from parameter menu.

Trip generation parameters are found on the trip attraction parameter dialog box and the trip production parameter dialog box. Trip attraction rates are used to convert demographic characteristics of zones into person-trips. There are four sets of rates. They are retail employment, nonretail employment, dwelling units, and demographic 4 and 5. Each set has four rates for four trip purposes respectively. The trip purposes are home-based work (HBW), home-based nonwork (HBNW), nonhome-based (NHB), and home-based question (HB?). Demographic 4 and 5 are entirely user-defined, which can meet the need of some special trip rates. Figure 4.17 illustrates the dialog box of trip attraction parameters. Trip production uses the average trip production parameter that is the total number of person-trips that a household makes in vehicles. This total encompasses all destinations and all purposes (including return trips to home). QRS II uses these parameters only when the use of average productions parameter box has been checked.

Otherwise, trip productions will be estimated from average income in a zone. Figure 4.18 illustrates the dialog box of trip production parameters.

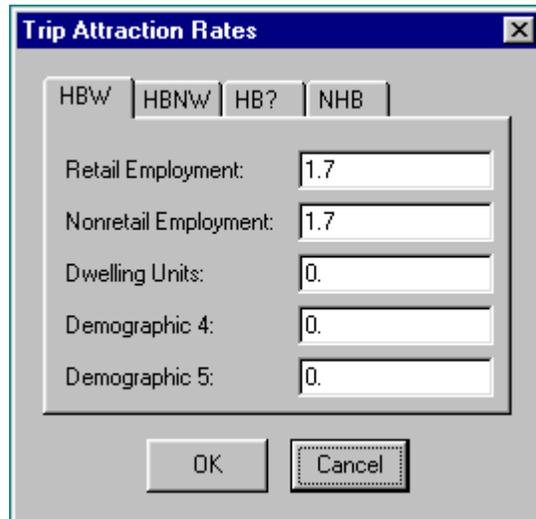


Figure 4.17 A Dialog Box of Trip Attraction Rates

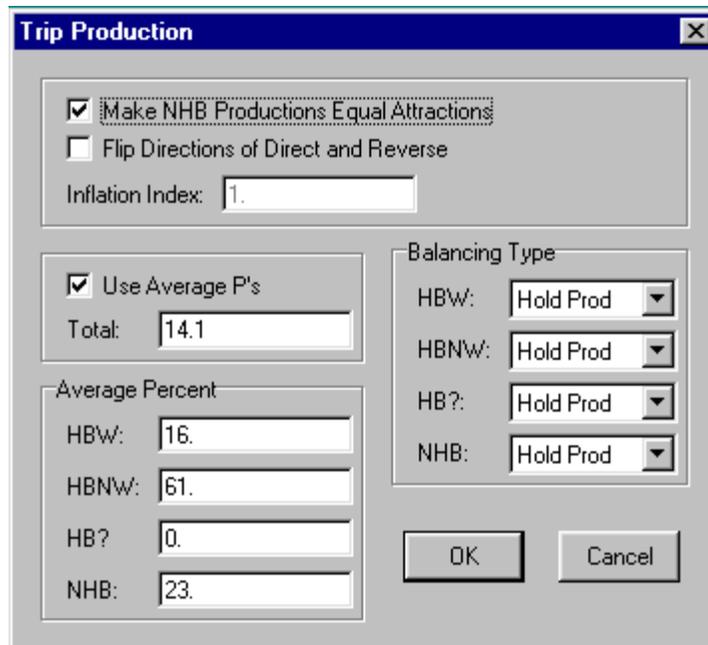


Figure 4.18 A Dialog Box of Trip Production

Like setting up parameters of trip generation, trip distribution parameters and vehicle occupancy parameters are set up similarly. The former is used to perform the trip distribution model, which has a friction factor function. Three kinds of friction factor functions can be selected: power, exponential, and combined. The latter is used to convert person-trips to vehicle-trips.

Different from QRS II, in which users can use default parameters and calculation procedures to perform trip generation and trip distribution, EMME/2 requires users to create calculation matrices and specify all parameters. Matrices in EMME/2 store all data related to zones. They may be used as input (for example a demand matrix for an assignment) and output (for example a matrix used to save the result of a calculation).

There are four types of matrices: full, origin, destination, and scalar. A matrix is denoted by mtn , where m represents matrix, t represents the type of matrix (f for full origin-destination matrix, o for origin matrix, d for destination matrix, and s for scalar matrix), and n is the matrix number, which may be an integer between 1 and the maximum number of matrix of each type that may be stored in the data. For example, $mf1$ is an O-D matrix.

EMME/2 provides a matrix editor to manipulate, display, and calculate matrices. Like drawing or modifying network either in an interactive graphic way or using batch input files, matrices can be input or modified either in an interactive graphic way or using batch input files too. Module 3.12, input/modify matrices interactively, is used to input or

modify a matrix, or to copy one matrix to another interactively. Module 3.11, input matrices using batch entry, is used to input, modify and delete matrices using batch entry. Matrix data can be displayed at the zone locations on a network plot or in the form of a histogram.

In QRS II there are parameters to perform traffic assignment in a variety of ways, depending on the type of forecast and the amount of available data. Assignment techniques in QRS II were discussed in 1.1.4. QRS II bases its calculations on the BPR function and on intersection delay models similar to those in Highway Capacity Manual. The parameters for traffic assignment may be selected from assignment options, BPR global, BPR classes, intersections general, signalized, som-way stop, all-way stop, and meter ramps.

The traffic assignment implemented in EMME/2 is an equilibrium assignment. EMME/2 calculates travel time and intersection delay based on functions that users created. An EMME/2 function is a data structure that is described by an algebraic expression. There are six function classes. Each function is denoted fcn , where f represents function, c represents the function class, and n is a number between 1 and the maximum number of functions per class in the databank. For example, $fd11$ is an auto volume delay function, and $fp2$ is a turn penalty function.

In an EMME/2 databank, the functions are shared by all the scenarios. Specific keywords denote the relevant variables for each function class. EMME/2 also provides a function

editor, by which users can add, delete, and modify functions using batch entry or interactively.

In order to perform travel demand forecasting in QRS II, users need to select the parameters from QRS II's menu, and then just run QRS II. It is relatively simple. To perform travel demand forecasting in EMME/2, users either perform each step separately or run a program that is written using *macro* language for executing travel demand forecasting in one execution. Before carry out last step, traffic assignment, all matrices, functions and network attributes that are to be used for the assignment must be available at the preparation stage (module 5.11). Module 5.11 is used to prepare a scenario for assignment. The main part of preparation consists of specifying the relevant matrices and parameters such as stopping criteria for the auto assignment, time component weights for the transit assignment, and so on. This module also performs certain preliminary tests on the specified data in order to detect possible error conditions that may make an assignment impossible or give invalid results. After the scenario is ready for auto assignment, users can use module 5.21 to perform an auto assignment on the current scenario. An important feature of the EMME/2 assignment modules is that the auto assignment may use data related to the transit network, and the transit assignment may use data that results from the auto assignment.

(2) Transit ridership forecasting

Users can use QRS II to forecast ridership on transit routes in the study area. QRS II can forecast ridership for the whole network, ridership on each route in the network, and

ridership on individual links. It can also forecast transfer volumes between routes at transfer points. In order to perform transit ridership forecasting, users first must develop a QRS II transit network showing the various transit routes, transfer points, and stops. QRS II does not perform transit ridership forecasting unless it is told to do so by checking "Do Mode Split" on the menu (Figure 4.19).

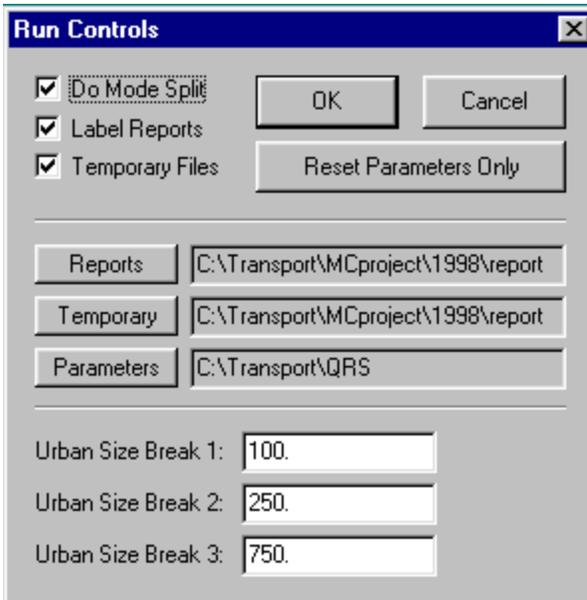


Figure 4.19 A Check Box for Transit Assignment

Users can also use EMME/2 to forecast ridership on transit routes. To do this, the first task is still developing a transit network. Users can develop a transit network using batch entry or interactively. The transit network depends on the base highway network. Different from the QRS II transit network, the EMME/2 transit network is identified as part of the base network that includes transit routes.

Like highway network assignment, QRS II provides a number of default values for parameters to perform transit network assignment. Users can use the default values or set

up their own values for transit network assignment parameters. Using EMME/2, users need to set up matrices and functions to indicate transit network assignment procedures and parameter values.

4.1.3 Model Outputs

Both QRS II and EMME/2 provide numerous reports of results in text files and can plot the results on the network. This chapter describes and compares the main outputs from QRS II and EMME/2 such as link volumes, travel times, and turning volumes at intersections. Table 4.1 is a list of output forms (text file or plot on network) of QRS II and EMME/2 for eleven selected attributes.

Table 4.1 A Comparison of Output Forms of EMME/2 and QRS II

Files	EMME/2		QRS II	
	Plot	Text	Plot	Text
Auto Volumes	Yes	Yes	Yes	Yes
Turning Volumes	Yes	Yes	No	Yes
Travel Time	Yes	Yes	Yes	No
Vehicle Trips	No	Yes	No	Yes
Trip Production/Attraction	No	Yes	No	Yes
Shortest Paths	Yes	No	Yes	Yes
Comparing Auto Volumes	Yes	No	No	No
Transit Volumes	Yes	Yes	Yes	Yes
Transit Time	Yes	Yes	No	Yes
Transfer Volumes	No	Yes	No	Yes
Comparing Transit Volumes	Yes	No	No	No

(1) General outputs

QRS II generates a large number of text files including final and temporary results. Users can select the files that they want to keep from the report menu. The selected reports will be stored as files in the directories that users selected.

QRS II also creates twelve temporary text files that contain intermediate results of a traffic forecast. Sometimes it is useful to inspect these files in order to diagnose problems or to get a better sense of how QRS II does its calculations. All temporary files have the suffix, "tmp". There are twelve temporary files available.

QRS II also creates three binary files: Table.bin, highdis.bin, and trandis.bin. Each file is a $n \times n$ matrix, where n is the number of total centroids and external stations. These files can be converted to ASCII by QRSTOOLS.

As stated in 4.2.1, in EMME/2 all result outputs are included in the databank file but not individual files as in QRS II. EMME/2 provides modules to display results from assignment performed on the current scenario. Various reports and plots are available. Using these modules, users can list and plot link volumes and travel times, list and plot turning volumes and turn times at intersections, plot shortest paths, list and plot transit volumes. Users can compare two scenarios graphically by auto volumes, travel times, auto speeds, and transit volumes. Users can also respectively output link volumes, travel times, turning volumes, turn times, and transit volumes to text files that are stored as individual files.

(2) Link volumes and travel times

Users can view the results of link volumes and travel times either in graphics or in text files in both QRS II and EMME/2. In a QRS II network, a link is defined by the link

name such as FM521 N <T> of SH 6. The link volumes in the text file are shown at directions from A-node to B-node and from B-node to A-node (Figure 4.20). The determination of A-node or B-node of a link depends on how this link was created. In an EMME/2 network, a link is defined by two node numbers: a beginning node and an ending node such as a link from 2001 to 2023 and a link from 2023 to 2001. The link volumes and travel times in the text file are shown at directions from the beginning node to the ending node (Figure 4.21) instead of A to B and B to A. Figure 4.22 and Figure 4.23 are examples of displaying link volumes on networks in QRS II and EMME/2 respectively.

LINK VOLUMES		
Link Label	A ==> B	B ==> A
External Station to SH 6	12750.7	12750.7
SH 6 NW <T> of Murphy Rd.	12750.7	12750.7
External Station to Murphy Rd.	5769.5	5769.5
<1> to Murphy	479.8	479.8
<23> to Creek Club	151.5	151.5
FB Comm. Hosp. to <A1>	0.0	0.0
Murphy Rd. N. <T> of SH 6	5769.5	5769.5
SH 6 SE <T> of Murphy Rd.	11492.1	10455.4
<A1> to SH 6	2950.7	2950.7
<21> to Ridgeview	152.4	152.4
Ridgeview N of Glenn Lakes	152.4	152.4
Creek Club N of Glenn Lakes	151.5	151.5

Figure 4.20 Link Volume File in QRS II

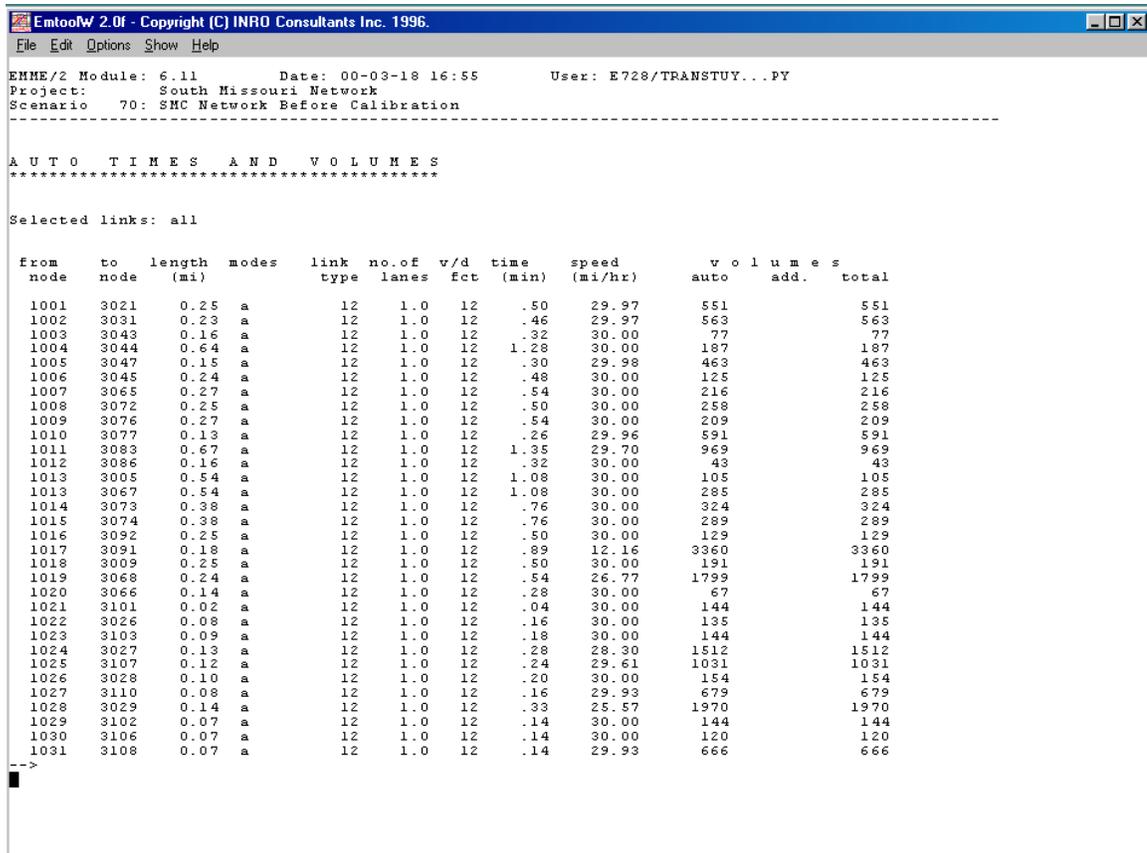


Figure 4.21 Link Volume File in EMME/2

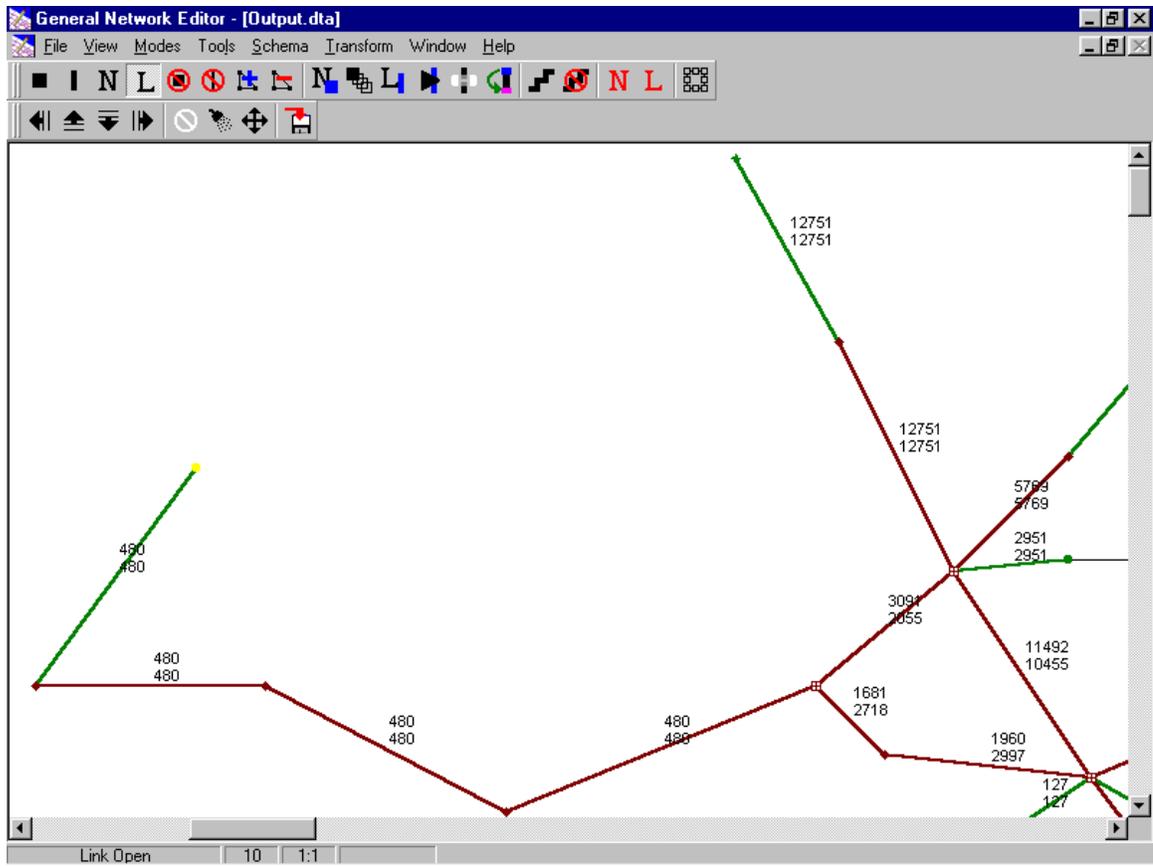


Figure 4.22 Link Volumes Displayed on Network in QRS II

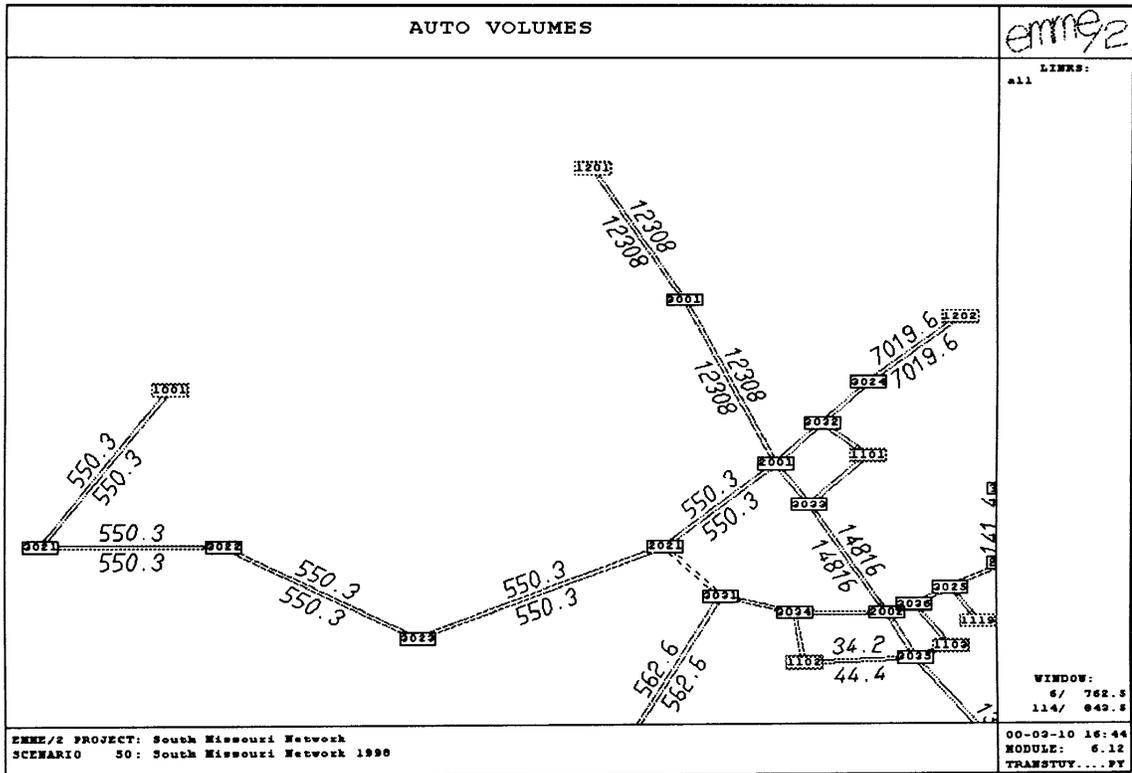


Figure 4.23 Link Volumes Displayed on Network in EMME/2

(3) Turning volumes at intersections

After QRS II calculates the requested turning volumes, it places them in a text file as shown in Figure 4.24. Because turning volumes are presented by a pairs of link names, it is moderate difficult to read and match on the network. Therefore, it is a time consuming process to identify all turning volumes at selected intersections, especially when the modeling network is big and TurnMove.txt becomes large.

TURNING MOVEMENTS		
From Link	To Link	Volume
SH 6 NW <T> of Sienna Parkway	SH 6 SE <T> of Sienna Parkway	4054.0
Thompson Ferry S <T> of Flat B	Flat Bank E <T> of Thompson Fe	86.0
Hillcroft N <T> of SH 6	SH 6 NW <T> of Hillcroft	885.6
Hillcroft N <T> of SH 6	SH 6 SE <T> of Hillcroft	1607.1
Hurricane Alley S <T> of Tramm	Hurricane Alley N <T> of SH 6	3038.1
Hillcroft N <T> of SH 6	Hillcroft S <T> of Trammel-Fre	1301.1
Vicksburg Drive N <T> of SH 6	Hillcroft N <T> of Vicksburg D	0.9
Vicksburg Drive N <T> of SH 6	Hillcroft S <T> of Vicksburg D	5668.5
Manor S <T> of Oilfield	Oilfield Rd W <T> of Manor	12.1

Figure 4.24 Turning Volume File in QRS II

If a requested turning volume is zero, QRS II does not list it in TurnMove.txt. This may bring some problems when a spreadsheet such as EXCEL is used to post-process the turning volume data.

In EMME/2, turning volumes may be output in two different forms: as a report or a plot demonstrated in Figure 4.25 and Figure 4.26. Comparing with QRS II, the output forms of turning volumes in EMME/2 are easier to use for various analyses because it is easier to identify left-turn, through and right-turn volumes between a pair of links by using an intersection plot. In addition, there are no problems to use a spreadsheet to post-process the data because all turning volumes including zero are placed in the output text file.

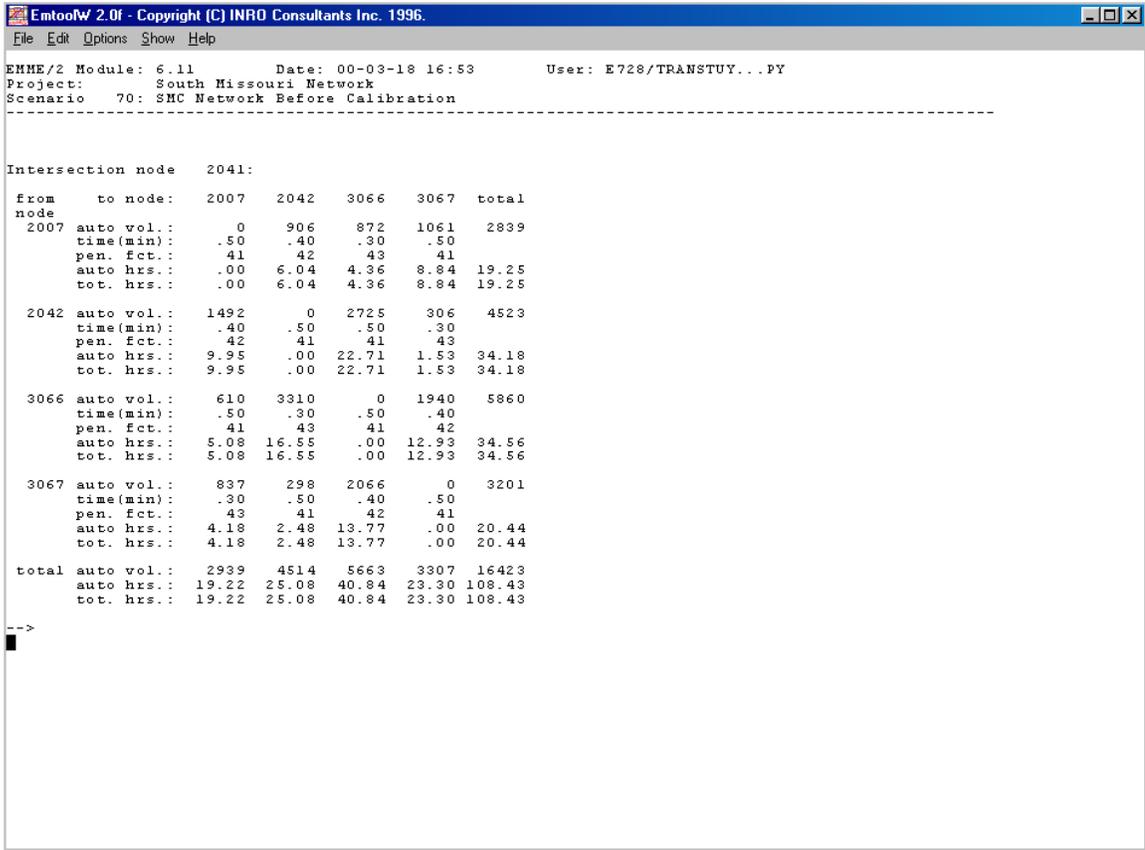


Figure 4.25 Turning Volume File in EMME/2

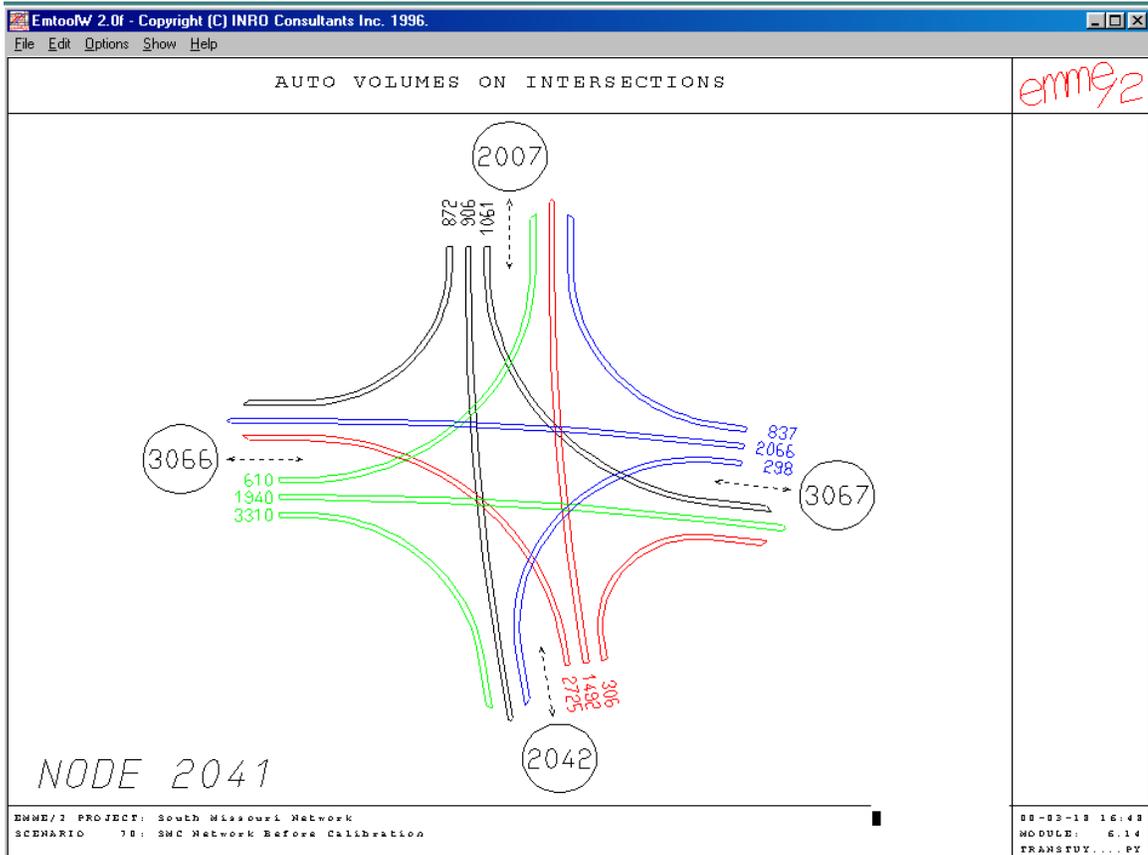


Figure 4.26 Turning Volume Plot in EMME/2

(4) Comparing auto volume and transit volume

As Table 4.1 shows, two of the eleven selected attributes, *Comparing Auto Volumes* and *Comparing Transit Volumes*, are only provided by EMME/2. Two modules in EMME/2 (6.13 and 6.23) can compare traffic volumes and transit volumes between scenarios. Therefore, users can compare traffic volumes and transit volumes of different years in either actual difference form or percentage form. It is always useful for users to compare traffic volumes and transit volumes of a design year with those of the base year or different design years. Figure 4.27 is an example of comparing traffic volumes of two

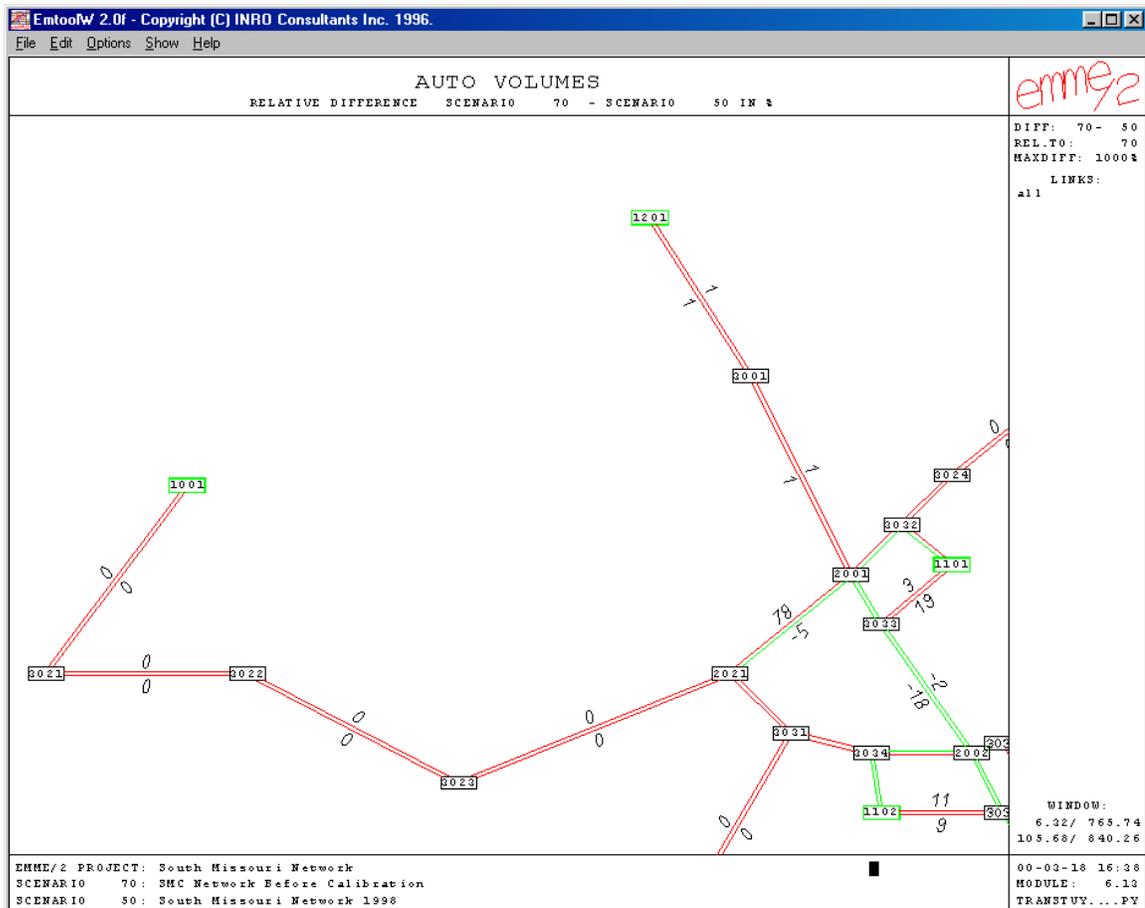


Figure 4.28 An Example of *Comparing Traffic Volumes* of Two Different Years in the Percentage Form

4.2 Modeling a Real-World Network

The comparison of basic features of QRS II and EMME/2 was primarily based on the model manual and the author's own experience with the models. To enhance the comparison effort, QRS II and EMME/2 are used to model a small urban network: South Missouri City (SMC) Network. SMC is located in the suburban of the Greater Houston Metropolitan Area (GHMA) (See Figure 4.29), which is experiencing a rapid growth in both residential and commercial land uses. SMC network was initially developed to

support a traffic impact study for three design years using QRS II (Traffic Engineers, Inc., 1999). In that study, the year 1998 was used as the base year in which the model was calibrated. In this report, the same network is also developed using EMME/2. Based on land uses in this area, forty residential zones and nineteen commercial zones are defined. There are nine external stations, which define the boundaries between this study area and outside areas. The completed networks for the year 1998 drawn by QRS II and EMME/2 are shown in Figure 4.30 and Figure 4.31 respectively.

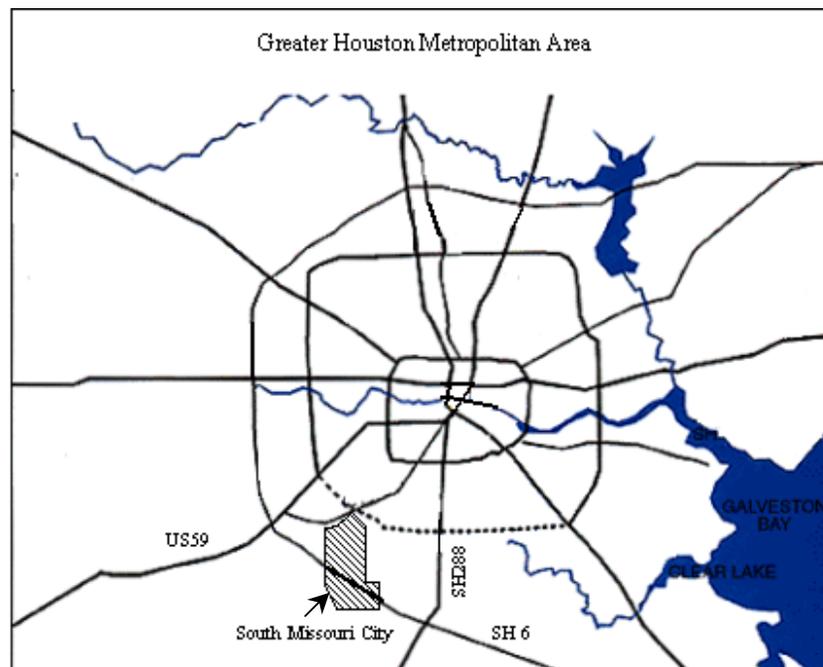


Figure 4.29 Location of South Missouri City in the Greater Houston Metropolitan Area

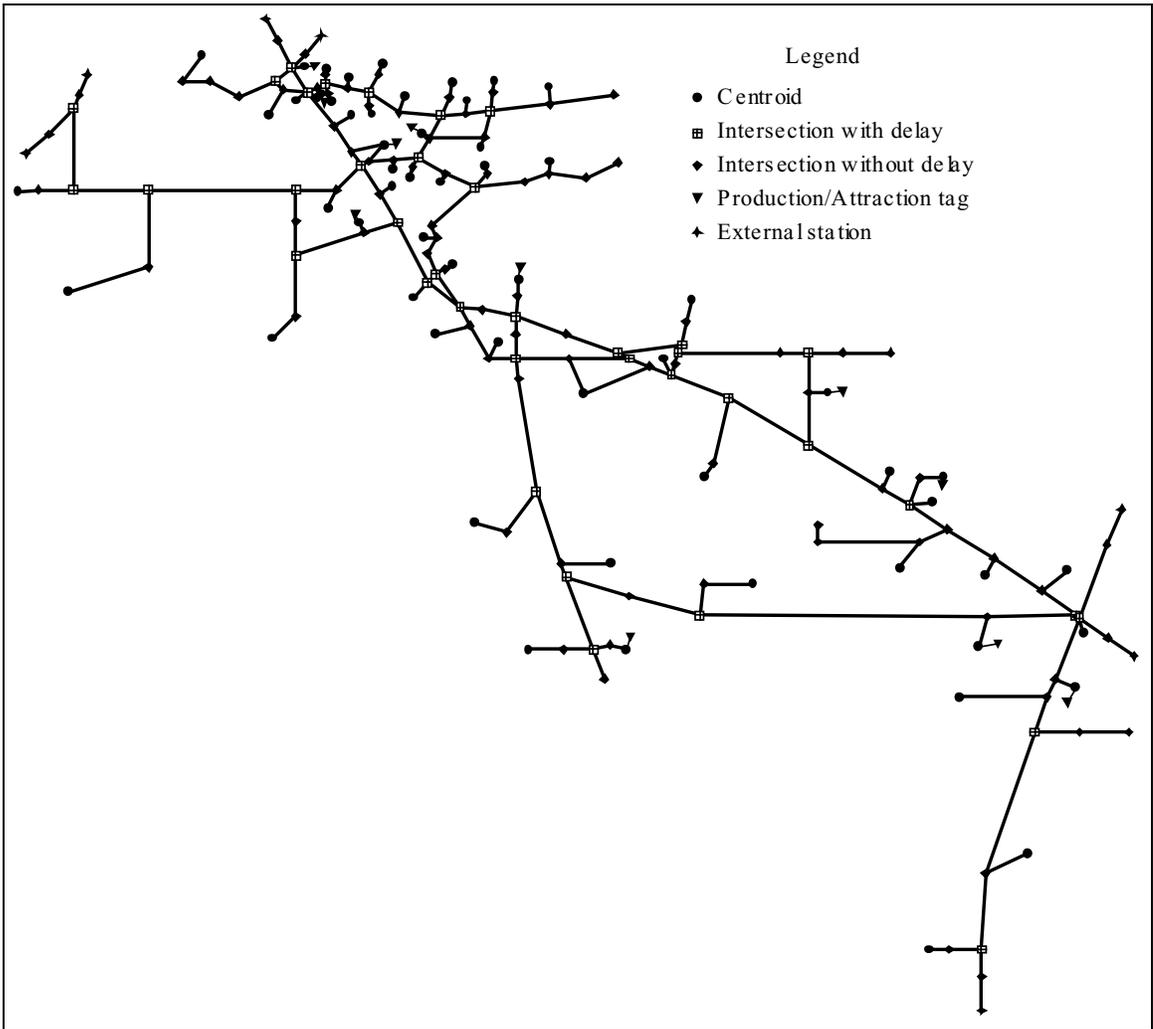


Figure 4.30 South Missouri City Network for the Base Year 1998 by QRS II

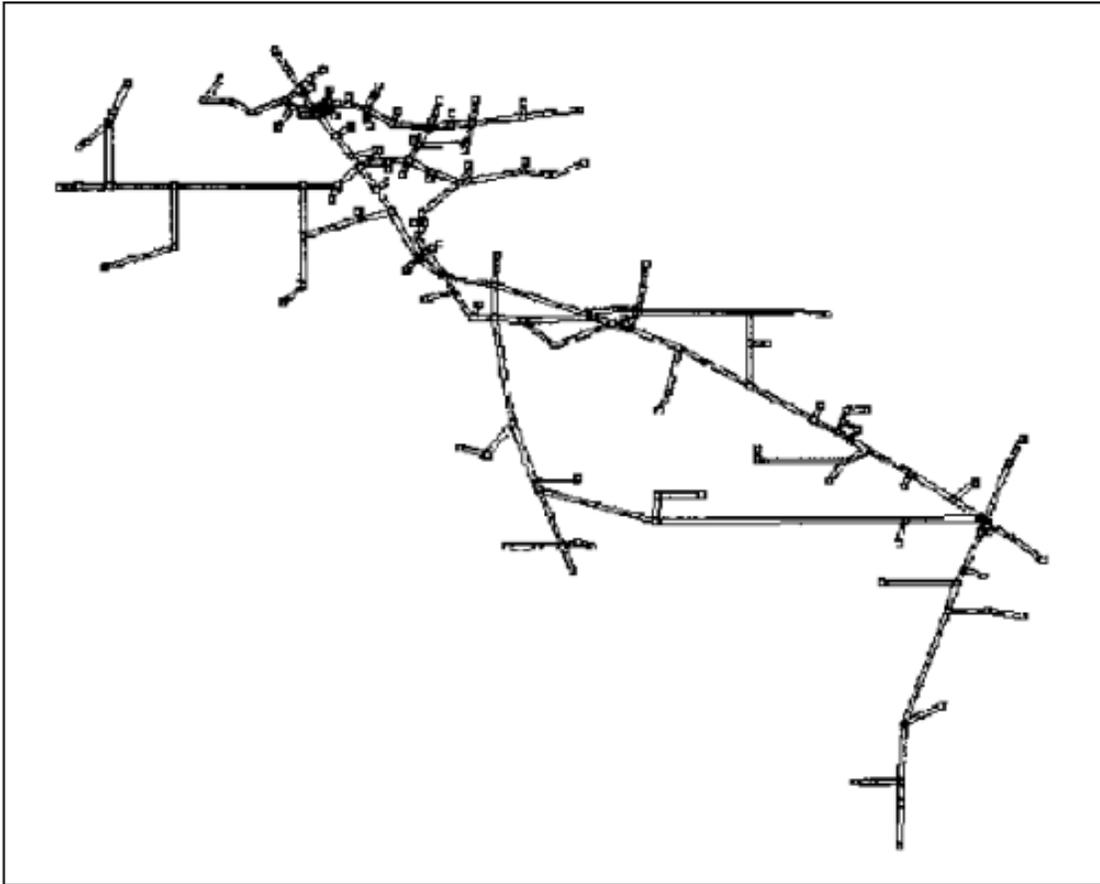


Figure 4.31 South Missouri City Network for the Base Year 1998 by EMME/2

4.2.1 Network Development and Data Input

When developing the QRS II network, data related to zones are input at nodes of centroid, external station, and production/attraction tag. The data input to centroids are average autos per household, number of retail employees, number of non-retail employees, and number of dwelling units. The data input to external stations and production/attraction tags are three purposes of trip production or attraction: home-based work, home-based non-work, and non-home-based, which were derived externally. The

data input at links are approach code, speed, and capacity. The speed uses the post speed limit on road, and the capacity is derived from Chapter 9 of 1997 Highway Capacity Manual (Transportation Research Board, 1997). The capacities of narrow lanes (10 feet), wide lanes (18 or 20 feet), and on-street parking lanes are adjusted according to the real-world conditions. The data at signal controlled intersections include cycle lengths, and at stop sign controlled intersections are minimum unsignalized capacities.

When developing EMME/2 network, no data input at regular nodes and centroids are needed as all needed data are input by using matrices. The data input to links are mode, link type, number of lanes, volume delay function, speed, and capacity adjustment factor. There are three modes defined in EMME/2 for SMC network, which include mode *c* that stands for car, mode *b* that stands for bus, and mode *p* that stands for pedestrian (not used). Four link types are defined: link type 9 represents minor arterial; link type 10 collector; link type 11 major arterial; and link type 12 centroid connector. Accordingly, four volume delay functions are defined. As nineteen (19) intersections that are required to be analyzed are included in the SMC base year traffic network, a turn table for EMME/2 network is created.

QRS II calculates intersection delays using the equations that are specified by HCM. In EMME/2, users have to specify turn penalty functions for all types of intersections. For simplicity, this research has used all constant values for the turn penalty functions, which are fine-tuned at the model calibration stage.

In developing the SMC network, the author has spent relative similar amount of times for QRS II and EMME/2. The only difference is that when the network is completed in QRS II, the data input is also completed simultaneously. By the end of network development, the model is ready for run, as all necessary functions are embedded in QRS II. For EMME/2, however, the model is far from being ready by the end of network development, as all functions and matrices for the calculations except for traffic assignment have to be defined and input by users. This feature of EMME/2 provides flexibility to users who want to set up their own network parameters and functions.

Since EMME/2 can replicate the results of trip generation, trip distribution and modal choice of QRS II, if the relevant matrices and functions are set up in the same logic as those in QRS II, this research will focus on the traffic assignment step of QRS II and EMME/2, as which does not require the manipulation of too many matrices and functions in EMME/2. The origin-destination matrix of traffic demand in EMME/2 for SMC network is derived from QRS II. QRS II creates a binary file (AutoTrip.tmp). It contains the zone to zone vehicle trip table. It has to be converted to a text file using QRSTOOLS. Then it is edited to the batch input format of traffic demand matrix for EMME/2.

4.2.2 Model Calibration

The model calibration is very important in the travel demand forecasting process. The model calibration determines the numerical values of basic parameters used in the base year model, and adjusts network settings in order for the results of link volumes match

24-hour traffic volume counts and for the results of peak-hour turning volumes match the peak-hour turning volume counts. For the SMC network, 24-hour traffic counts were collected from 24 locations and peak-hour turning counts were collected from 19 intersections as detailed in Figure 4.32.

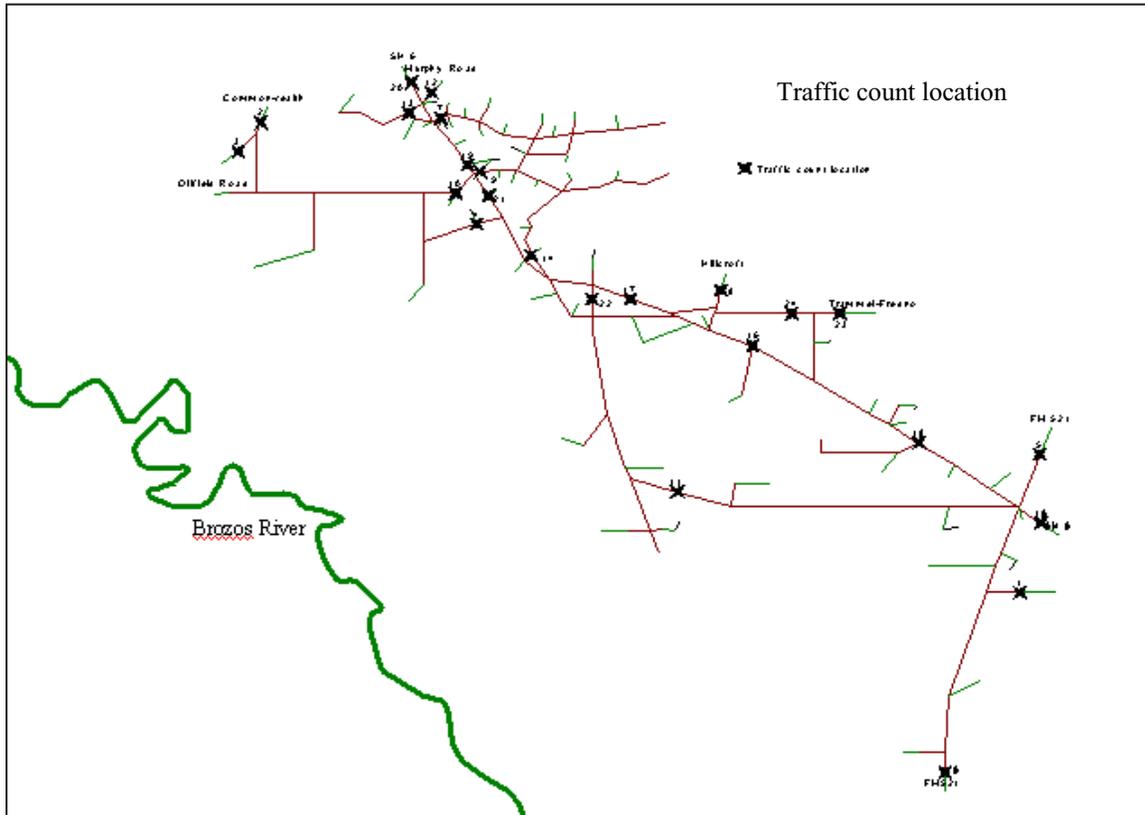


Figure 4.32 24-Hour Traffic Count Collection Locations for SMC Network

As the EMME/2 model for SMC uses the O-D matrix that was produced by QRS II, the only comparable component of two models is traffic assignment.

The link delay functions in EMME/2 are made to use the same ones as used in QRS II: BPR functions. As stated earlier, QRS II uses the procedure of HCM to calculate

intersection delays, while EMME/2 is made to use constant values. In running both QRS II and EMME/2, the assignment results can be fine-tuned by changing free travel times of affected links. The turning penalty values in EMME/2 can also be adjusted to influence the turning volumes at the problem intersections. In this manner, both QRS II and EMME/2 models have demonstrated the ability to produce promising assignment results as shown in the following sections.

(1) Comparison of link volumes

24-hour traffic counts were collected at twenty-four selected locations within the study area including nine external stations. The 24-hour link volumes forecasted by QRS II and EMME/2 from original SMC network as well as traffic counts collected at twenty-four locations for the base year 1998 are shown by Table 4.2 and Figure 4.33. In Table 4.2, Column 3 is the 24-hour traffic counts. Column 4 is the forecasted link volumes by EMME/2, while column 5 is the relative error. Out of twenty-four locations, twelve locations result in errors higher than 10% between link volumes by EMME/2 and traffic counts. Column 6 is the forecasted link volumes by QRS II, while column 7 is the corresponding relative error. Six out of twenty-four locations result in errors higher than 10% between link volumes by QRS II and traffic counts.

Table 4.2: Comparison of 24-hour Link Volumes from Original Network
for the Base Year 1998

1	2	3	4	5	6	7
Loc #	Location Name	Count	EMME/2	EMME/2 Error	QRS II	QRS II Error
1*	Coen Road E of FM521	673	672	0%	682	1%
2*	Commonwealth N of Oilfield Road	3996	3990	0%	3996	0%
3*	Commonwealth S of Oilfield Road	4040	4034	0%	4040	0%
4	Flatbank W of SH 6	3971	3980	0%	3931	-1%
5*	FM521 N of SH 6	7866	7864	0%	7895	0%
6*	FM521 S of Sienna Point Drive	4532	4530	0%	4531	0%
7	Glenn Lake E of SH 6	9815	7858	-20%	5808	-41%
8	Hillcroft N of Vicksburg	3498	3598	3%	3687	5%
9	Lake Olympia E of SH 6	6722	9072	35%	6562	-2%
10	Lake Olympia W of SH 6	2600	2570	-1%	2587	-1%
11	McKeever E of Sienna Parkway	1691	7338	334%	1438	-15%
12*	Murphy Road N of SH 6	14119	13999	-1%	14121	0%
13	Murphy Road W of SH 6	1024	2989	192%	1046	2%
14	Peninsulas N of SH 6	926	13950	1406%	1490	61%
15*	SH 6 SE of FM 521	21249	21217	0%	21228	0%
16	SH 6 SE of Hillcroft	14069	7491	-47%	15941	13%
17	SH 6 SE of Sienna Parkway	19415	8489	-56%	20592	6%
18	SH 6 SE of Teal Bend Blvd.	11789	7477	-37%	12441	6%
19	SH 6 NW of Lake Olympia	27338	21162	-23%	23667	-13%
20*	SH 6 NW of Murphy Road	25000	24890	0%	25187	1%
21	SH 6 SE of Lake Olympia	25154	17995	-28%	25706	2%
22	Sienna Parkway S of SH 6	3232	5778	79%	6867	112%
23*	Trammel-Fresno E of Hurricane	4029	4000	-1%	4103	2%
24	Trammel-Fresno W of Hurricane	3228	5541	72%	3090	-4%

* External Station

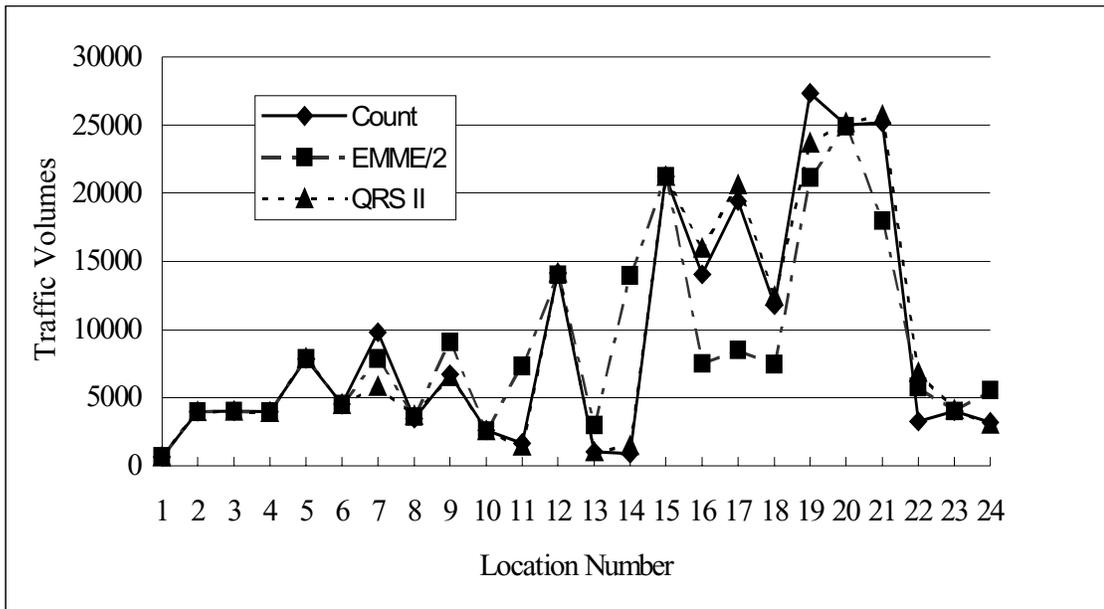


Figure 4.33 Comparison of 24-hour Link Volumes from Original SMC Network at 24 Locations for the Base Year 1998

Each location with an error higher than 10% is analyzed. Most errors in QRS II are caused by the wrong selection of minimum paths in the traffic assignment module. By manually adjusting the free travel times of affected links in QRS II as well as EMME/2 networks, the path travel times can be affected and thus the traffic volumes on the affected links can be altered. Table 4.3 is a comparison of 24-hour link volumes forecasted by QRS II and EMME/2 after several iterations of free travel time adjustments. Except for the error at location 19, all locations have shown an error less than 10% between link volumes by EMME/2 and traffic counts. For QRS II, all errors between link volumes and traffic counts are below 10%. Figure 4.34 illustrates the comparison of traffic counts, and the results from calibrated networks by EMME/2 and QRS II at 24 locations.

It is shown from Table 4.3 and Figure 4.34 that both QRS II and EMME/2 can be calibrated to assign traffic that match the real-world 24-hour traffic counts after careful adjustment of network parameters.

Table 4.3: Comparison of 24-hour Link Volumes from Calibrated Network for the Base Year 1998

1	2	3	4	5	6	7
Loc #	Location Name	Count	EMME/2	EMME/2 Error	QRS II	QRS II Error
1*	Coen Road E of FM521	673	672	0%	682	1%
2*	Commonwealth N of Oilfield Road	3996	3990	0%	3997	0%
3*	Commonwealth S of Oilfield Road	4040	4034	0%	4040	0%
4	Flatbank W of SH 6	3971	3875	-2%	3929	-1%
5*	FM521 N of SH 6	7866	7864	0%	7895	0%
6*	FM521 S of Sienna Point Drive	4532	4530	0%	4531	0%
7	Glenn Lake E of SH 6	9815	9261	-6%	10016	2%
8	Hillcroft N of Vicksburg	3498	3598	3%	3659	5%
9	Lake Olympia E of SH 6	6722	7175	7%	6269	-7%
10	Lake Olympia W of SH 6	2600	2644	2%	2569	-1%
11	McKeever E of Sienna Parkway	1691	1813	7%	1838	9%
12*	Murphy Road N of SH 6	14119	14239	1%	14134	0%
13	Murphy Road W of SH 6	1024	1102	8%	1055	3%
14	Peninsulas N of SH 6	926	930	0%	898	-3%
15*	SH 6 SE of FM 521	21249	21217	0%	21218	0%
16	SH 6 SE of Hillcroft	14069	15465	10%	14771	5%
17	SH 6 SE of Sienna Parkway	19415	20205	4%	19303	-1%
18	SH 6 SE of Teal Bend Blvd.	11789	11915	1%	11993	2%
19	SH 6 NW of Lake Olympia	27338	23818	-13%	24851	-9%
20*	SH 6 NW of Murphy Road	25000	24890	0%	25206	1%
21	SH 6 SE of Lake Olympia	25154	24796	-1%	24281	-3%
22	Sienna Parkway S of SH 6	3232	3155	-2%	3165	-2%
23*	Trammel-Fresno E of Hurricane	4029	4000	-1%	4095	2%
24	Trammel-Fresno W of Hurricane	3228	3093	-4%	3027	-6%

* External Satation

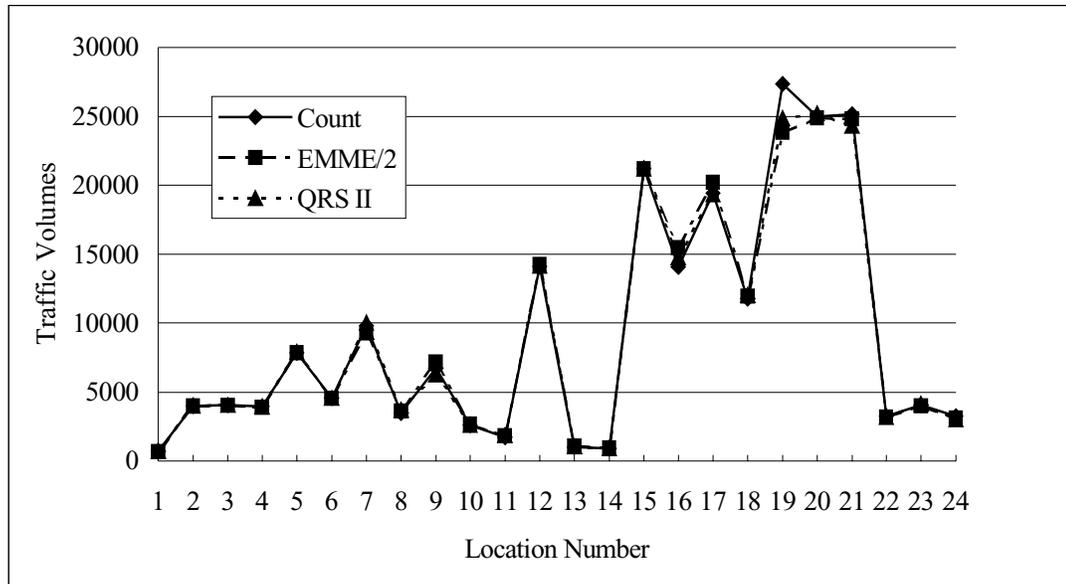


Figure 4.34 Comparison of 24-hour Link Volumes from Calibrated SMC Network at 24 Locations for the Base Year 1998

(2) Comparison of turning volumes

The morning peak-hour is run for both QRS II and EMME/2. Turning volumes at nineteen intersections are output from the two models. Nine of these intersections are controlled by signals, and others by stop signs. QRS II outputs turning volumes in a text file (see Figure 4.24). There are three columns in the file. The first column shows the link name from which the turning volume comes; the second column shows the link name to which the turning volume goes; and the third column shows the turning volume. EMME/2 can output tuning volumes in a text file too (see Figure 4.25). EMME/2 also provides a plot with turning volume for each turn of the selected intersections as illustrated in Figure 4.26. Figure 4.35 is an example of a turning volume comparison of QRS II and EMME/2 at the same intersection from calibrated SMC network for the base

year 1998. Although turn penalty functions use constant values in EMME/2, users can still get turning volumes that match the traffic counts by fine-tuning the turn penalties.

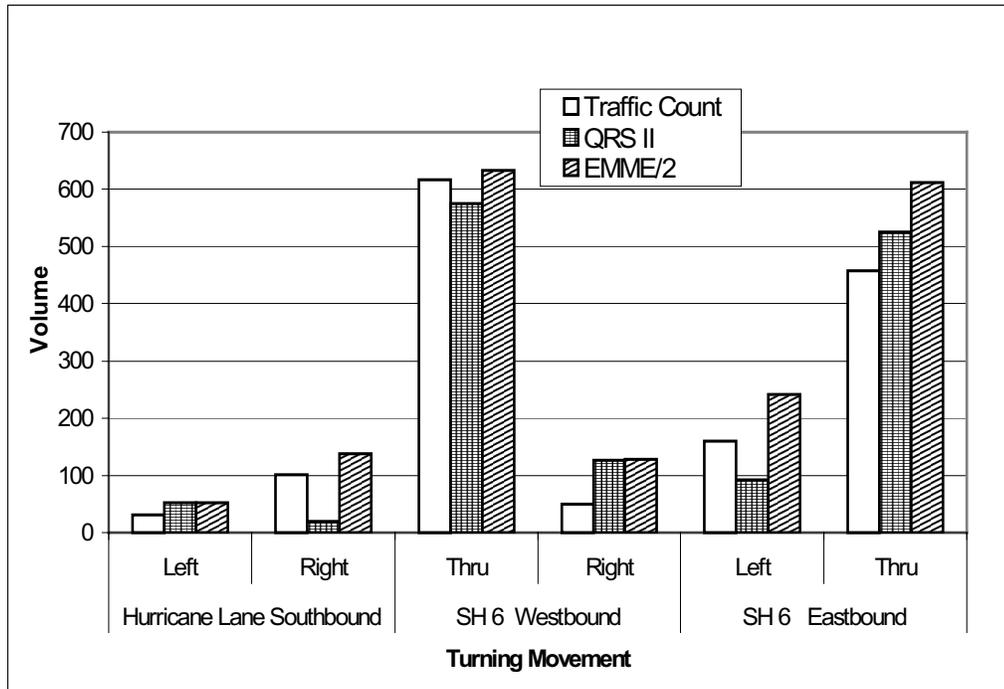


Figure 4.35 Comparison of Turning Volumes at Intersection Hurricane Alley and SH 6 From SMC Calibrated Network for the Base Year 1998

(3) Comparison of transit network

Two artificial transit routes are incorporated into and tested in the QRS II and EMME/2 networks. QRS II transit network is drawn graphically using GNE, which is independent from the original highway network. On the other hand, EMME/2 transit network is drawn using the batch entry method based on the base highway network. QRS II transit network can only consist of the centroids and nodes that are related to the routes and the transit stops, while all other nodes that appear on the base highway network should not be included. Differently, EMME/2 transit network can consists of not only the nodes and

centroids that are related to routes and stops, but also the other nodes on the routes that appear on the base highway network. As mentioned earlier, default functions and parameters are used to execute ridership forecasting in QRS II, while a transit demand matrix and transit time functions need to be defined to perform ridership forecasting in EMME/2 transit network. Both QRS II and EMME/2 are shown to produce similar results of transit volumes, ridership boarding and alighting at stops, and transit transfer volumes. Figure 4.36 and Figure 4.37 show the transit network developed in QRS II and EMME/2 respectively.

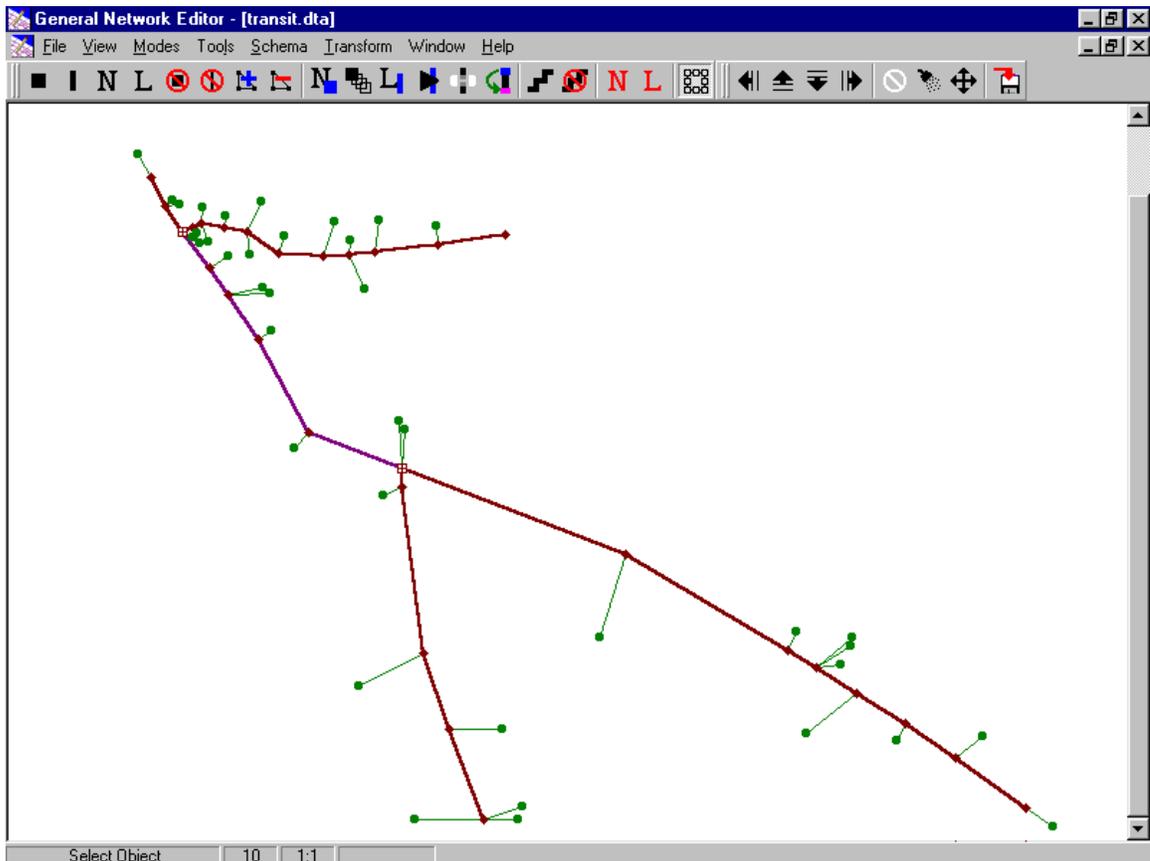


Figure 4.36 An Artificial Transit Network in GNE

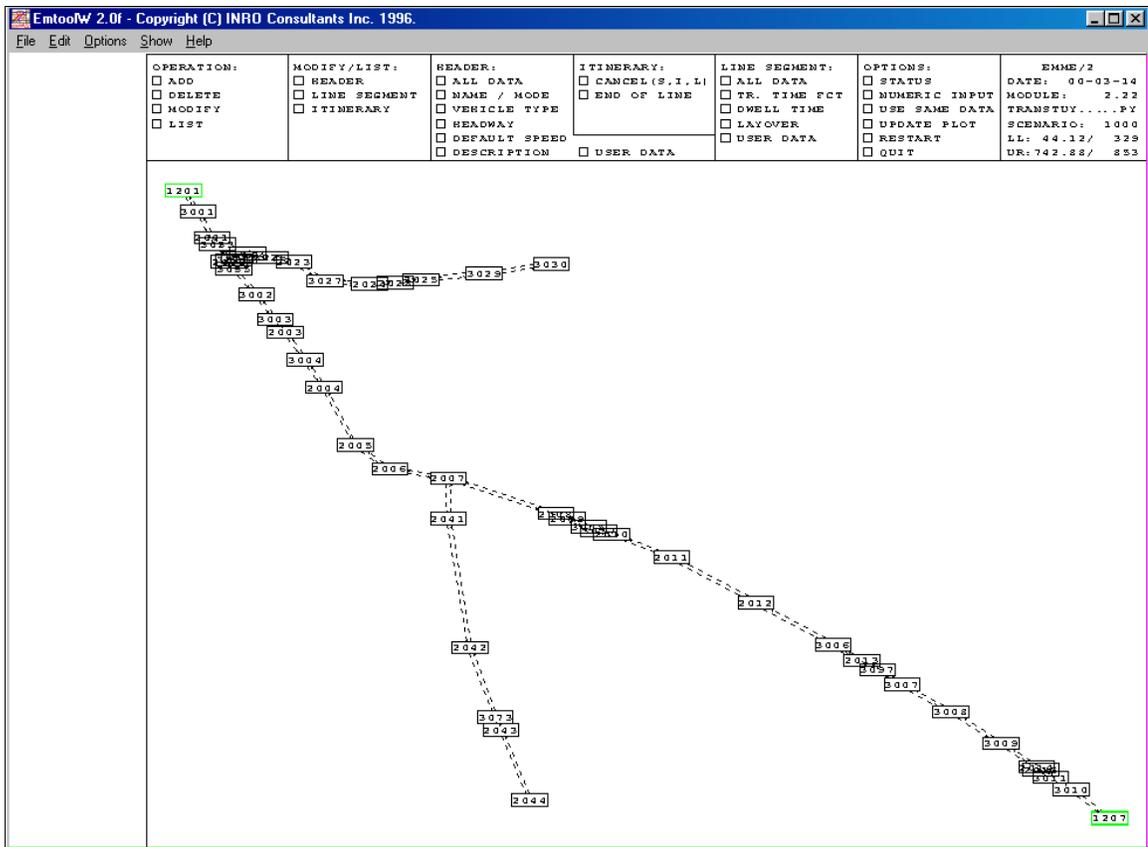


Figure 4.37 An Artificial Transit Network in EMME/2

The procedure of performing transit ridership forecasting is similar to that of performing highway network both in QRS II and EMME/2. Many result reports are created after the procedure is completed. Figure 4.38 and Figure 4.39 demonstrate transit volumes on links in QRS II and EMME/2 respectively.

Link Label	Route	Load		Factor	
		A => B	B => A	A => B	B => A
SH 6 NW <T> of Murphy Rd.	10	0.0	0.0	0.000	0.000
SH 6 SE <T> of Murphy Rd.	10	59.9	59.9	0.019	0.019
Glenn Lakes E of Ridgeview	20	100.6	100.7	0.063	0.063
Glenn Lakes W of Ridgeview	20	105.2	105.3	0.066	0.066
Glenn Lakes W of Creek Club	20	98.7	98.9	0.062	0.062
SH 6 SE <T> of Glenn Lakes	10	52.9	52.1	0.017	0.016
Glenn Lakes E <T> of SH 6	20	108.5	108.6	0.068	0.068
Glenn Lakes E of Creek Club	20	95.1	95.3	0.059	0.060
Glenn Lakes W of Crow Valley	20	74.5	74.6	0.047	0.047
SH 6 NW of Transportation Cent	10	53.6	53.6	0.017	0.017

Figure 4.38 Transit Ridership Report in QRS II

EMME/2 Module: 6.21 Date: 00-05-09 17:46 User: E728/TRANSTUY...PY
Project: South Missouri Network
Scenario 1000: SMC Transit Network 1998-24

Transit line: 20 (Glenn Lakes to Sienn)

mode:	b (bus)	vehicle type:	1 (bus)	no. of passengers:	136
headway:	30.00 min	no. of vehicles:	24	avg. pass. speed:	1.27 mi/hr
line length:	17.80 mi	avg. veh. speed:	1.55 mi/hr	pass. hours:	274.1
line time:	690.38 min	max-load factor:	.39	pass. mi:	349.3
capacity/hr(s/t):	100/ 100	operating costs:	.00 \$ /hr	op.cost / pass.:	.00 \$
user data:	0/ 0/ 0	energy consumpt:	.00 mj/hr	energy/pass-mi:	0 mj

---segment---	length	time	speed	load	volume	stop	exits	boardings	seat- prob.
from to	(mi)	(min)	(mi/hr)	fact					
3030 3029	0.49	2.98	9.87	0.00	0	3030	-	-	-
3029 2025	0.46	3.00	9.19	0.19	19	3029	-	19	1.00
2025 3028	0.19	2.48	4.60	0.24	24	2025	2	6	1.00
3028 2024	0.19	2.50	4.56	0.26	26	3028	1	3	1.00
2024 3027	0.32	2.99	6.41	0.31	31	2024	3	9	1.00
3027 2023	0.28	3.42	4.91	0.37	37	3027	6	11	1.00
2023 3026	0.17	2.97	3.44	0.37	37	2023	1	2	1.00
3026 2022	0.17	3.03	3.37	0.38	38	3026	1	1	1.00
2022 3025	0.07	2.49	1.69	0.39	39	2022	1	2	1.00
3025 3036	0.05	0.51	5.86	0.35	35	3025	9	5	1.00
3036 2002	0.03	3.31	0.54	0.35	35				
2002 3035	0.06	0.43	8.29	0.26	26	2002	10	0	1.00
3035 3002	0.26	3.90	4.00	0.26	26				
3002 3003	0.24	1.75	8.24	0.24	24	3002	1	0	1.00
3003 2003	0.13	2.66	2.93	0.24	24				
2003 3004	0.26	3.34	4.67	0.24	24	2003	-	-	-
3004 2004	0.26	1.33	11.71	0.24	24	3004	1	0	1.00
2004 2005	1.15	25.47	2.71	0.24	24				
2005 2006	0.31	81.63	0.23	0.24	24	2005	0	0	1.00
2006 2007	1.18	178.69	0.40	0.24	24				
2007 2041	0.32	4.14	4.64	0.11	11	2007	21	9	1.00
2041 2042	1.03	3.39	18.25	0.10	10	2041	1	0	1.00
2042 3073	0.58	0.78	44.71	0.07	7	2042	3	0	1.00
3073 2043	0.11	2.15	3.07	0.07	7				

Figure 4.39 Transit Ridership Report in EMME/2

(4) *Comparing Features* in EMME/2

EMME/2 has a useful *comparing* feature, in which users can compare graphically the results of traffic assignments of two different scenarios using module 6.13 (module 6.23 for comparing transit volume). The difference between any two scenarios is displayed either in actual difference or in percentage on the EMME/2 network. An example of this feature was shown in Figure 4.27 and 4.28, which show the actual difference and difference percentage of traffic volumes between calibrated network and pre-calibrated network.

4.3 Discussion of Advanced Features

Advanced features of both QRS II and EMME/2 are extensive and it is impossible to discuss all of them in this report. Also many advanced features of travel demand forecasting models are not comparable because they were developed for different purposes. In order to demonstrate the strengths of QRS II and EMME/2, this report discusses two advanced features: *Calculate* function in GNE (QRS II's network editor) and *macro* language in EMME/2. Users can use these features to perform specific tasks.

4.3.1 *Calculate* in GNE

Using *Calculate* in GNE, users can manipulate network attributes with a program. The *Calculate* is a series dialog boxes for writing program lines. The program is specific to an

application schema. Therefore, the proper application schema, either with or without a network, must first have been loaded.

Following is an example of using *Calculate*. A common use of program in GNE is finding properties of a network, such as numbers of various nodes and links. The following program counts the number of centroid, intersection with delay, intersection without delay, external station, and production/attraction tag in QRS II's SMC network (Figure 4.40).

The program relations dialog box consists of program lines that tells GNE what to do. Figure 4.40 illustrates the GNE program that looks like a simple BASIC program. Most statements assign a value. All assignment statements must be in the following form.

$$\textit{Variable name} = \textit{Expression}$$

All statements as shown in Figure 4.40 are simple statements to count the number of nodes and links. The variables used are defined in the network wide variables dialog as demonstrated in Figure 4.41. After running the program, the results will be stored in the box. Users must indicate node, link, and system ranges in corresponding dialog box as shown in Figure 4.42, Figure 4.43, and Figure 4.44. These dialog boxes tell GNE which program lines pertain which entity types. For example, in Figure 4.42, the range of centroid begins 1 and end 1. That means only program line 1 in Figure 4.40 executes to the nodes of centroids. Because the total number of nodes is the sum of number of each type node, variable *v6* is calculated after *v1* through *v5* are calculated. Therefore, the range of after nodes before links begins 6 and ends 6 in system range dialog box, and that

means program line 6 executes after node calculations are finished and before link calculations begin.

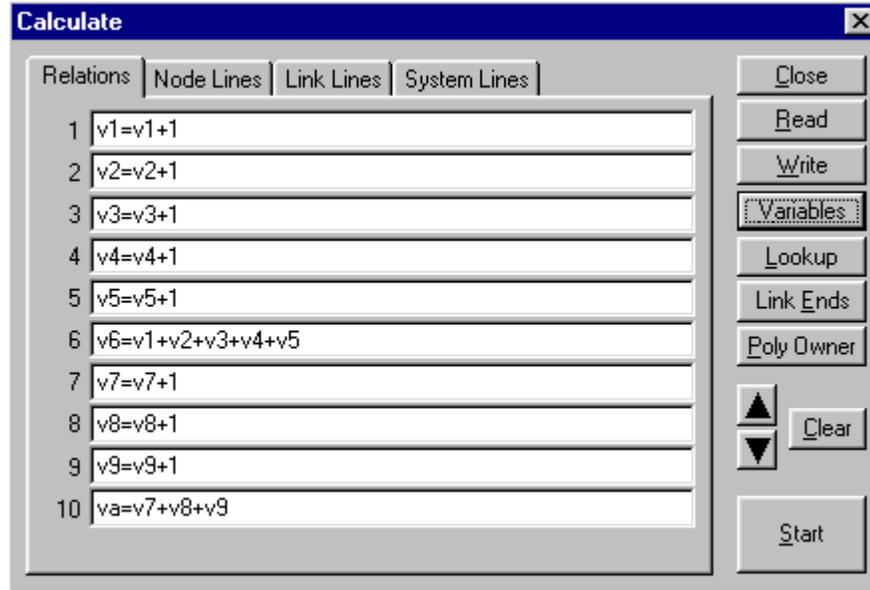


Figure 4.40 Program Relations of *Calculate* in GNE

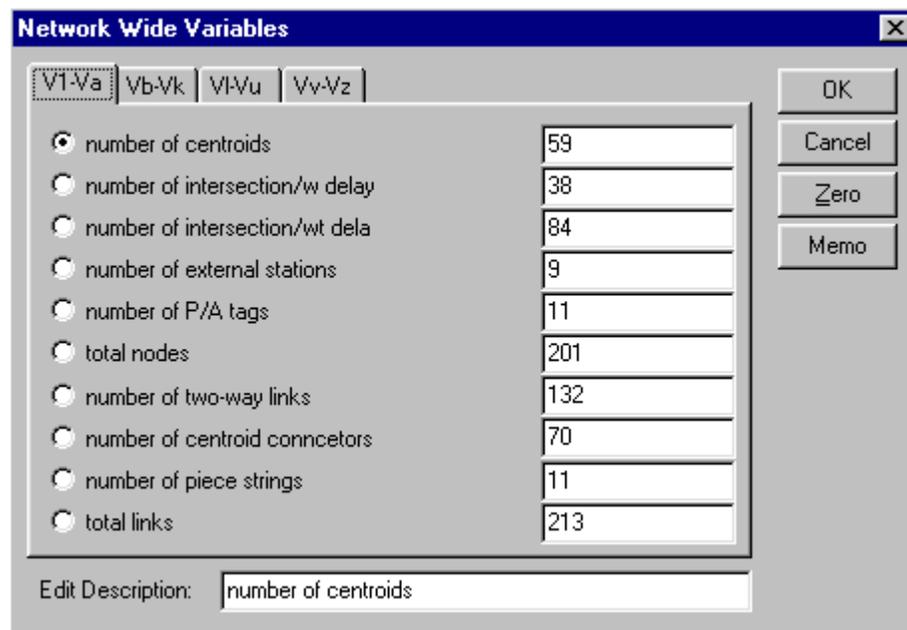


Figure 4.41 Defining Variables in Network Wide Variables Dialog Box

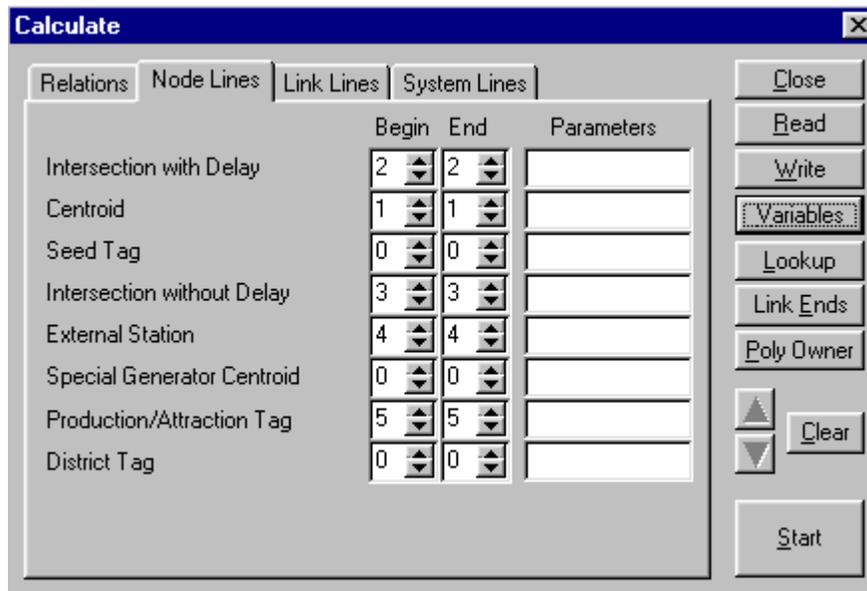


Figure 4.42 Node Line Ranges Dialog Box

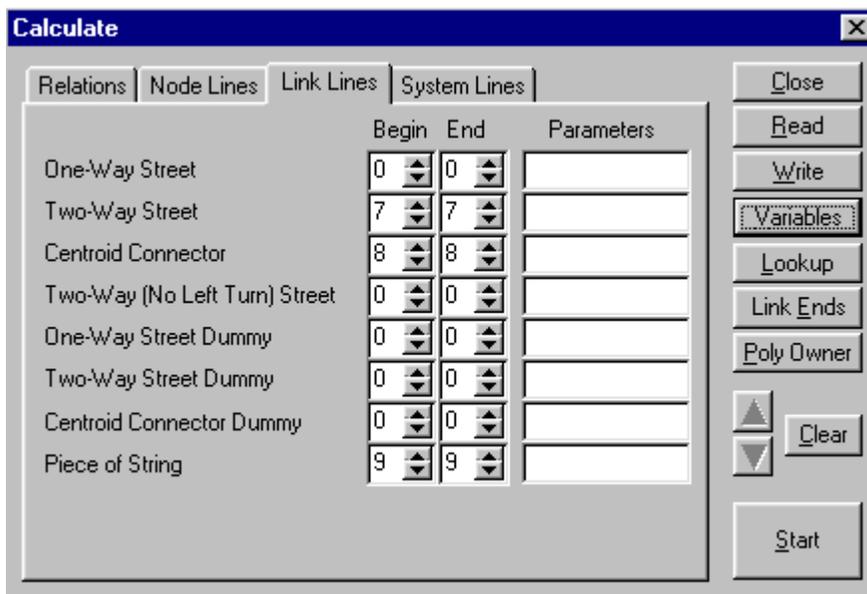


Figure 4.43 Link Line Ranges Dialog Box

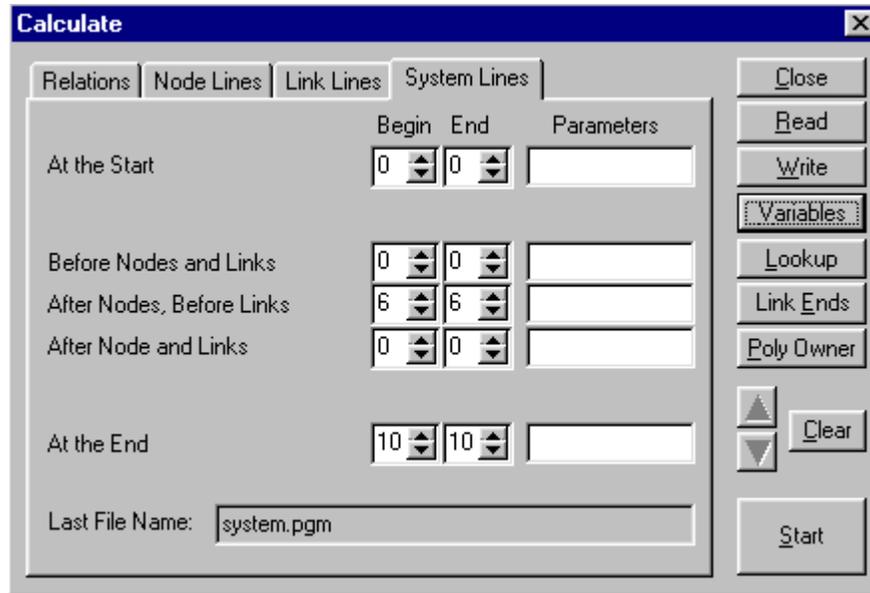


Figure 4.44 System Line Ranges Dialog Box

One of functions of *Calculate* in GNE is to manipulate network. For example, users can use *calculate* to enter or modify values of attributes of nodes and links. Figure 4.45 and Figure 4.46 illustrate a program of calculating link free travel time. In Figure 4.45, a_8 stand for the eighth attribute of two-way street (free travel time), and a_2 for the second attribute (speed). In Figure 4.46, L is a parameter code that is the length of link in pixel, and it is stored in parameter $p1$. Because the scale in SMC network is 96 pixels per mile, the length of link in mile is L divided by 96. After running this program, the result is assigned to the attribute of free travel time as by Figure 4.47.

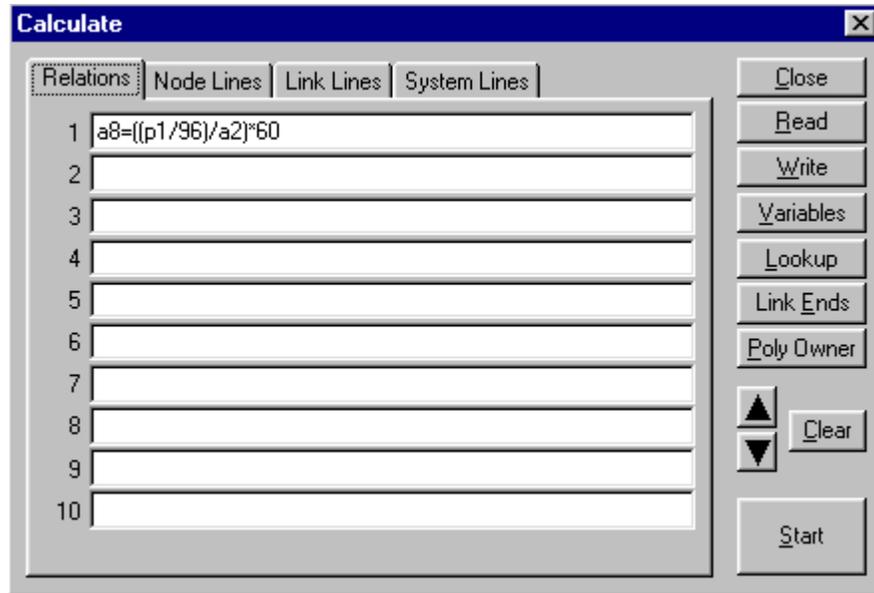


Figure 4.45 Calculating Free Flow Travel Time Using *Calculate* in GNE

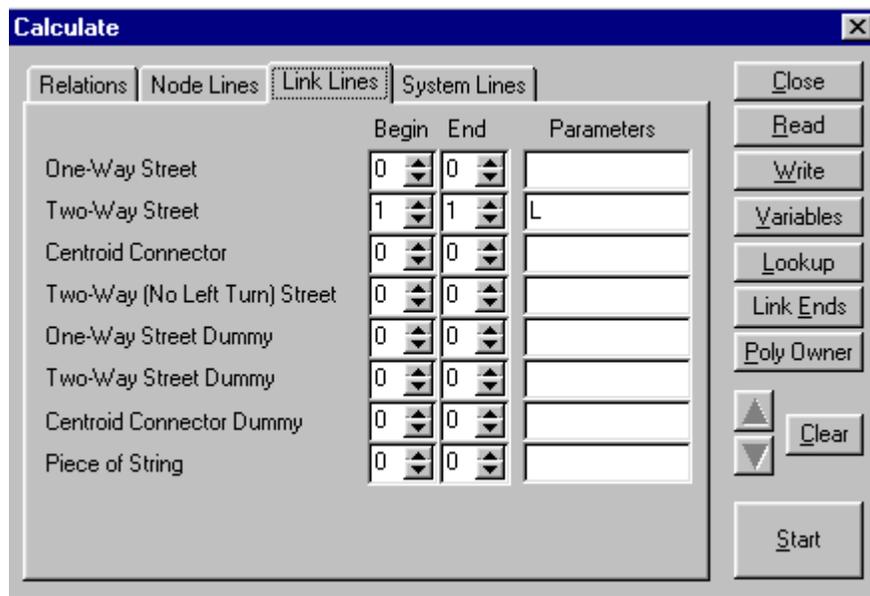


Figure 4.46 Parameter and Link Line Range

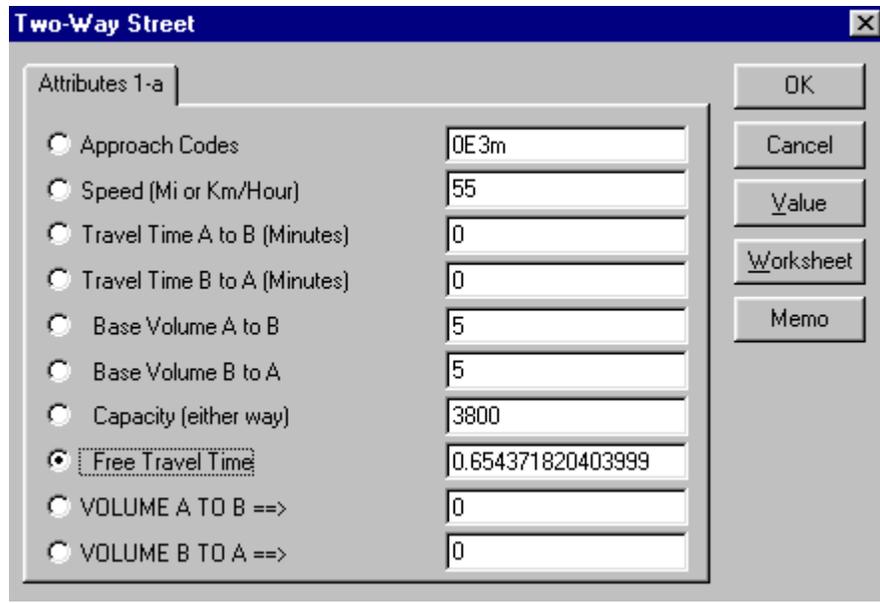


Figure 4.47 Assigning Value of Attributes Using *Calculate* in GNE

It can be seen that *Calculate* is a very strong feature for GNE. Many lengthy tasks can be accomplished with the assistance of *Calculate*.

4.3.2 Macro Language in EMME/2

When performing travel demand forecasting using EMME/2, users must frequently answer some questions with dialog. In order to automate complex repetitive procedures, EMME/2 provides a powerful *macro* language. A *macro* is a sequence of answers to the questions posed in an EMME/2 dialog. A *macro* file can be created while entering the answers for a dialog the first time, and then recalled it when it is needed again. Users also can create and modify a *macro* using a text editor such as Windows Notepad.

In its simplest form, a *macro* consists of a sequence of pre-defined answers. A simple *macro*, "save and recall", can be created and recalled only using the *macro* save (~>) and *macro* recall (~<) commands. Following is an example of a simple *macro*. The *macro* *plotfun* specifies the volume delay function to be plotted together with the values for the different variables (Figure 4.48 and Figure 4.49).

```

EmtoolW 2.0f - Copyright (C) INRO Consultants Inc. 1996.
File Edit Options Show Help
4.13 PLOT FUNCTIONS

Select: 1= plot functions
        2= change module parameters
        3= end
        1
Enter: Function=~>plotfun fd11 1 1 1
%1%
fd11 = (length / ull) * 60 * (1 + .15 * ((volau) / (lanes * 1900)) ^ 4)
Enter: Variable to plot on horizontal axis=volau
Enter: Range of volau      (  0.00, 100.00)=
Set of curves for a variable?n
Enter: lanes=%2%
Enter: length=%3%
Enter: ull=%4%

Other functions on the same plot?~>

```

Figure 4.48 An Example of Creating a *Macro* in EMME/2

```

EmtoolW 2.0f - Copyright (C) INRO Consultants Inc. 1996.
File Edit Options Show Help
4.13 PLOT FUNCTIONS

Select: 1= plot functions
        2= change module parameters
        3= end
        1
Enter: Function=~<plotfun fd12 2 2 1
< fd12
fd12 = (length / ull) * 60 * (1 + .15 * ((volau) / (lanes * 1900)) ^ 4)
Enter: Variable to plot on horizontal axis=< volau
Enter: Range of volau ( 0.00, 100.00)=<
Set of curves for a variable?< n
Enter: lanes=< 2
Enter: length=< 2
Enter: ull=< 1

Other functions on the same plot?<~<

```

Figure 4.49 An Example of Recalling a *Macro* in EMME/2

In a powerful set of *macro*, which is used by the users who need to implement complex repetitive procedures, a *macro* may consists of substitution mechanism, conditional and branching commands, register arithmetic and feedback of *macro* result values through scalars. Like other computer language, a *macro* file may consist of commands, variables, and parameters.

As part of EMME/2 system, the EMME/2 package contains some prepared *macros* in the directory of *macros* in EMME/2. Users can use these *macros* directly. For example, the *macro* modifydb modifies the dimensions of an EMME/2 databank. Following is an example of using *macro* modifydb to increase maximum number of scenarios.

```

EmtoolW 2.0f - Copyright (C) INRO Consultants Inc. 1996.
File Edit Options Show Help
4.  F U N C T I O N   E D I T O R
5.  A S S I G N M E N T   P R O C E D U R E S
6.  R E S U L T S
9.  E N D   O F   S E S S I O N
Enter: Next module=~<modifydb morescen 55 58
*****MODIFYDB:  MODIFY DIMENSIONS OF AN EMME/2 DATA BANK (8.4)*****
*** Copyright (C) INRO Consultants Inc. 1996. All rights reserved. ***
*****MORESCEN:  INCREASE NUMBER OF SCENARIOS IN A DATA BANK*****
***
*** This EMME/2 macro can be used to increase the maximum no.
*** of scenarios that can be stored in an existing data bank.
*** This is done using module 1.11 for modifying the dimensions
*** of all applicable internal files. Depending on the size
*** of the data bank, this operation can be quite lengthy.
*** It is of utmost importance that the procedure is not inter-
*** rupted, since this would leave the data bank in an unusable
*** state. Also, it is up to the user to make sure before
*** running this macro that enough disk space is available to
*** hold the additional scenarios. THUS, ALWAYS MAKE A COMPLETE
*** BACKUP OF THE EMME2BANK FILE BEFORE RUNNING THIS MACRO!!!!
*****
About to increase number of scenarios from 55 to 58. This operation
will increase the size of the data bank by approximately 855000 bytes.
Do you really want to proceed?

```

Figure 4.50 An Example of Prepared *Macro* in EMME/2

Comparing to *Calculate* in QRS II as stated above, *macro* language in EMME/2 is more powerful and more complex. Using both of them, users can write program that they need to perform specific travel demand forecasting tasks. The *Calculate* in QRS II must execute to a network. However, a *macro* in EMME/2 plays a role of automating travel demand forecasting procedures.

4.4 Discussions

The following discussion points can be drawn from Section 4.1 through Section 4.3:

- (1) QRS II provides a tool of network editor, GNE, for network development, which is an individual program. EMME/2 provides a network editor, which is an integral module of EMME/2. QRS II uses GNE to develop a network and enter data in an interactive graphic manner. EMME/2 provides two methods to develop a network: using an interactive graphic worksheet or using batch entry. Not all data related to nodes and links are entered when developing a network in EMME/2.

- (2) The first task for developing a network in QRS II is loading an application schema, which pre-defines network characteristics. In order to use EMME/2, the first task is creating a databank and implement dimensions.

- (3) QRS II defines eight node types and eight link types; however, EMME/2 provides only two node types and user-defined link types. In QRS II, users can name nodes and links based on the real-world road names, so users can easily match the results with a real world network. In EMME/2, users name nodes and links using numbers, so users cannot match the results with a real world network so easily as they do in QRS II. A link is defined using the node numbers at the two terminuses of the link.

- (4) In order to analyze the turning volume in QRS II, users must name the links using "<T>" and define the approach code to a link. Sometimes users have to split a link to set different approach codes for one link. However, EMME/2 provides a turn table for defining all turns at an intersection. Each intersection can be plotted in an

interactive graphic way, and the layout of an intersection includes all turns at the intersection. Therefore, it is easier to read turning volumes at intersections in EMME/2 than in QRS II.

- (5) In estimating transit ridership in QRS II, users first must develop a regular highway network, and then develop a separate transit network. Every transit centroid must have a corresponding centroid or external station on the highway network. In EMME/2, users develop a transit network based on a base highway network. Nodes and links on a transit network must be on the base network.
- (6) Although both QRS II and EMME/2 can zoom in and zoom out a network, QRS II prints only entire network, while EMME/2 can print either an entire network or selected part of the network.
- (7) Both QRS II and EMME/2 can perform the four-step travel demand forecasting process. QRS II provides a large number of default parameters and default calculation formulas and procedures. However, in EMME/2, users must create matrices and define functions that are needed to perform calculations, especially for steps other than traffic assignment.
- (8) QRS II performs highway and transit network assignments separately. However, EMME/2 can perform highway and transit network assignments either separately or simultaneously, which reflects a real world transportation system.

(9) Both QRS II and EMME/2 can be calibrated to match the forecasted results with real-world collected traffic counts. Therefore, both are reliable models for application in practice.

(10) QRS II provides *Calculate* for users to write program for specific tasks. The program is simple and specific to an application schema. EMME/2 provides *macro* language for users to write program. It is more complex, but more powerful. It is used to implement complex repetitive procedures.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter will present conclusions, which are drawn from preceding chapters, and provide some recommendations for future research.

5.1 Conclusions

The research in this report conducted a comparative study of two widely used computer-based travel demand forecasting models: QRS II and EMME/2. First, the basic features including network development, travel demand forecasting procedure, and model outputs were compared. In order to enhance the comparison process, QRS II and EMME/2 were used to model a small urban network: South Missouri City (SMC) Network. Finally, the advanced features, *Calculate* function in QRS II and *Macro* language in EMME/2, were discussed.

In order to use QRS II and EMME/2, users first need to prepare a file: an application schema in QRS II and a databank in EMME/2. EMME/2 provides one more method than QRS II for developing a network. QRS II defines more node types than EMME/2; however, EMME/2 permits users to define more link types than QRS II. Users can name nodes and links using real-world road names in QRS II, but cannot in EMME/2. Therefore, users can match the result with a real-world network more easily in QRS II than in EMME/2. In regards to analyzing turning volumes at intersections, EMME/2

provides results in the form of graphics and text file, so it is easier to read turning volumes in EMME/2 than in QRS II. In terms of the relations of a transit network to a highway network, both QRS II and EMME/2 can perform the four-step travel demand forecasting process. Modeling a real-world network by QRS II and EMME/2 has indicated that both models are reliable to model real-world scenarios. Comparatively, QRS II is easy to use for inexperienced users because of the availability of default parameters, calculation formulas, and procedures. EMME/2 is more flexible for users to perform more complex tasks. The outputs in QRS II and EMME/2 are provided in the form of text files and some of them can be displayed on networks.

QRS II provides *Calculate* for users to write programs, which are simple and only specific to networks. Although EMME/2 also provides *macro* language for users to write programs, the *macros* are not only specific to networks, but also used to automate complex repetitive procedures. A *macro* is either as simple as the saving and recalling *macro* or as complex as a set of commands, variables, and parameters. EMME/2 provides some prepared *macros* to be used, but QRS II does not.

5.2 Recommendations

In order to improve and complete the comparative study of computer-based travel demand forecasting models, two recommendations are provided for future research:

1. Future research should continue to systematically explore more features of QRS II and EMME/2 for their applications in various traffic network scenarios.
2. Future research should compare QRS II and EMME/2 with other existing computer-based travel demand forecasting models.

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