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# **DEVELOPMENT OF MULTIPLE GROWTH STRATEGIES FOR USE IN DEVELOPING TRAFFIC FORECASTS: A ROBUSTNESS APPROACH**

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<b>16 Abstract</b> <p>Decisions that may be based on misleading forecasts may lead to a misallocation of funds and to under-performing projects during construction and operation. Poor projections of demographic and socioeconomic data are usually cited as the major source of poor traffic assignment projections and hence, unfavorably conceived planning and construction of street and highway infrastructure facilities.</p> <p>This report evaluated the accuracy of long range projections by using a transportation study done the in 1970s, projecting transportation demand 20 years into the future. The projected travel model inputs were compared with what actually happened after the horizon year had been reached and also compared the projected traffic volumes versus the actual ground counts at the same horizon year. The results of this study show that there is a poor correlation between what was forecasted and what actually happened in terms of socioeconomic and demographic data, which are the major inputs used by travel demand models to forecast future traffic volumes on road links. The projected traffic volumes were poorly correlated with the actual ground traffic counts for the same road links in the network. However, the end results of these projections, the estimated number of lanes required to accommodate the resulting traffic, were not adversely affected. It was found that 98 percent of the major streets had the number of lanes correctly estimated based on the 1994 Highway Capacity Manual (HCM) planning level of service (LOS) criteria.</p> <p>Robustness analysis is a technique with the potential in aiding decision makers in choosing transportation investment projects that more closely correlate to actual future development. In this report it has been demonstrated that robustness analysis can be successfully used in urban transportation planning in conjunction with urban travel demand software. The robustness analysis procedure emphasizes the need, under conditions of uncertainty, to make early decisions in a time-phased sequence, while preserving many future options until the choices are more definitive. The results of the robustness analysis indicate that the method is simple to understand, easy to use, minimizes future surprises in terms of expected future events not happening, and provides the flexibility required in typical urban planning problems where decision making has to be done under conditions of uncertainties. A general framework to be used in such cases is proposed.</p>					
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## **PREFACE**

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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## **ABSTRACT**

Decisions that may be based on misleading forecasts may lead to a misallocation of funds and to under-performing projects during construction and operation. Poor projections of demographic and socioeconomic data are usually cited as the major source of poor traffic assignment projections and hence, unfavorably conceived planning and construction of street and highway infrastructure facilities.

This report evaluated the accuracy of long range projections by using a transportation study done in the 1970s, projecting transportation demand 20 years into the future. The projected travel model inputs were compared with what actually happened after the horizon year had been reached and also compared the projected traffic volumes versus the actual ground counts at the same horizon year. The results of this study show that there is a poor correlation between what was forecasted and what actually happened in terms of socioeconomic and demographic data, which are the major inputs used by travel demand models to forecast future traffic volumes on road links. The projected traffic volumes were poorly correlated with the actual ground traffic counts for the same road links in the network. However, the end results of these projections, the estimated number of lanes required to accommodate the resulting traffic, were not adversely affected. It was found that 98% of the major streets had the number of lanes correctly estimated based on the 1994 Highway Capacity Manual (HCM) planning level of service (LOS) criteria.

Robustness analysis is a technique with the potential in aiding decision makers in choosing transportation investment projects that more closely correlate to actual future development. In this report it has been demonstrated that robustness analysis can be successfully used in urban transportation planning in conjunction with urban travel demand software. The

robustness analysis procedure emphasizes the need, under conditions of uncertainty, to make early decisions in a time-phased sequence, while preserving many future options until the choices are more definitive. The results of the robustness analysis indicate that the method is simple to understand, easy to use, minimizes future surprises in terms of expected future events not happening, and provides the flexibility required in typical urban planning problems where decision making has to be done under conditions of uncertainties. A general framework to be used in such cases is proposed.

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# Chapter 1

## Introduction

### 1.1 Introduction

Travel demand modeling remains a cornerstone of the transportation planning process (Marshment, 2001). Although current transportation planning procedures are mostly performed by an interdisciplinary team approach, there are still a number of institutional issues which may hinder the process from providing the best results. According to Marshment (2001), the most notable setback is a lack of coordination between land use and transportation planning. Most of the time, land use plans do not reflect the influence of the accessibility to the alternative transportation facilities.

The lack of interaction between land use and transportation planning may play a major role in using unrealistic and unattainable land use and socioeconomic and demographic assumptions in the projection of future traffic levels with travel demand models. Unreliable travel demand model inputs, coupled with well-known travel demand model weaknesses, have compounded and amplified the uncertainty of future travel projections. Robustness analysis can provide an approach to the structuring of transportation problems where uncertainty is high and where sequential, time-phased decision making is necessary. According to Khisty and Sriraj (1999), the robustness analysis technique emphasizes the need, under conditions of uncertainty, to make early decisions in a time-phased sequence that will preserve future options that seem attractive. The strength of robustness analysis is in exploiting flexibility in phased transportation project planning. The basis of robustness decision analysis comes from the operational research tradition (Rosenhead, 1989a). Rosenhead states (1989a):

“The robustness analysis is concerned with situations where an individual, group or organization needs to make commitments now under conditions of uncertainty, and where these decisions will be followed at intervals by other commitments”.

With the robustness perspective, the focus will be on the immediate commitments that can be made, and that will be compared in terms of the range of possible future commitments with which they appear to be compatible.

Since transportation forecasting is full of uncertainties, the robustness technique emphasizes the need to leave open all alternatives considered viable, minimize the possibility of surprises, and make early decisions in a time-phased sequence while keeping open all other future options that seem attractive. Robustness analysis, unlike traditional optimization techniques, can increase flexibility and minimize the uncertainties of the planning process, which can lead into a better and more reliable decision making.

## **1.2 Problem Statement**

It has long been a concern of management that traffic forecasts are based on assumptions that may not be realized. For example, traffic forecasts made for projects in the western part of Topeka, Kansas, before the West Ridge Shopping Center was conceived, were grossly understated. The governing body selected the proposal of one developer over another and totally changed the land use and travel patterns of the area. Even though the best information available at the time is used in making a forecast such as this, the results could be either a costly over or under design. In the Topeka West Ridge Mall case, the result was a vastly under statement of the needs in the area. If a projected development results in a traffic forecast that is on the borderline

between a modest and expensive design solution, management should know the probability (or risk) of the actual development being higher or lower than forecasted.

The professional transportation community has been quite concerned about the quality of traffic forecasting data which is used as a basis for multi-million dollar investment decisions.

If a range of possible assumptions was made and the resulting forecasts were prepared, along with their respective possibilities (not probabilities), management would be able to better assess the risk of development occurring or not occurring, or development occurring at one location rather than another. Due to uncertainties in forecasting future transportation facilities, procedures employed should be flexible enough to accommodate changing outcomes as they develop. Under conditions of uncertainty, it would be advantageous to make early decisions in a sequence in such a way as to preserve many future options which initially seem attractive, instead of the current practice of deciding on the one option which seems to be optimal now, based on assumptions that may never materialize, and pursuing it as if it were deterministic.

### **1.3 Research Objectives**

Developing a procedure to accommodate multiple growth strategies or assumptions will require greater time and resources than predicting only one. Intuitively, one would think that a wider range of possibilities should be considered when there is greater uncertainty about the factors used to develop model output that determines a proposed highway improvement. Research has been conducted for urban areas that examine multiple projects to determine which ones will be feasible under any future alternative and which ones are feasible only if certain things happen (e.g., Boyce, et al., 1970; Binkley, 1995; Steiss, 1995). This approach provides little information about the planning risk, i.e., where assumptions and resulting forecasts are uncertain, by putting the emphasis on a prediction assuming certainty and neglecting the problems which may result

from uncertainties (Caplin and Kornbluth, 1975). This research will attempt to take the next step to formulate a process that increases the flexibility and minimizes the uncertainties of the transportation planning process and thus should reduce the risk level of poorly planned roadway systems. Specifically, this research involved:

- developing “future” street networks for time periods already past as shown in previous planning documents using one of the available transportation planning software packages,
- assessing the differences between past “future” projections and what actually occurred,
- using robustness analysis techniques to develop a procedure to aid in making the urban transportation planning process more flexible to accommodate possible future surprises and minimize the uncertainties of using travel demand models,
- developing generalized guidelines based on the principle of robustness analysis for developing a procedure for better transportation planning decisions.

#### **1.4 Selection of Study Area**

The Topeka Metropolitan area in Kansas was selected as the study area. The authors were confident about being able to obtain sufficient data for the study from both the Kansas Department of Transportation (KDOT) and Topeka city authorities.

Current information (Topeka, 2001) shows that the city of Topeka has a population of 123,993 and the Metropolitan Statistical Area (MSA) has a population of 165,400 (Topeka, 2001). Topeka is the capital of the state of Kansas. Two major interstates, I-70, a west-east highway, and I-335, come together at Topeka and with I-470, form a ring around the city.

## **1.5 Outline of Report**

The rest of this report is organized as follows. Chapter Two presents a literature review. It describes the application of geographic information systems (GIS) technology in transportation planning, the four-step modeling process, uncertainties, and problems of forecasting future travel demands. It also describes the use of robustness analysis and how it can be used in planning process.

Chapter Three outlines the study methodology. Procedures used to manipulate the socioeconomic, demographic and land use data and traffic analysis zone (TAZ) delineation using GIS are described in detail. Also, Chapter three describes how highway network alternatives and the development of six scenarios were used to simulate 1990 traffic assignments with travel demand model software. The data used was the data developed in the early 1970s for projecting travel demand for 1990 horizon year and the 1990 centennial census data. This chapter also outlines the procedure used to formulate the robustness scores and how to interpret their results.

Chapter Four covers the analysis and discussion of results. Results of the comparison between what was projected in the original planning documents with what actually happened after the projected horizon year arrived. The results of the traffic assignments from the travel demand modeling, and the determination of the links' priorities by using robustness analysis to develop robustness scores, are described in detail. Chapter Five presents recommendations, conclusions and contribution of the research.



## Chapter 2

### Literature Review

#### 2.1 GIS Application in Transportation Planning

It has been determined that within geographic information system (GIS) environments, different traffic growth strategies can be easily developed and their impact on land use can be analyzed.

According to Azar and Ferreira (1995), there is an increasing need to have systematic and robust capabilities for integrating and managing large sets of geo-referenced data and computing spatial overlays (i.e., combining several layers of information together based on geographic location). This is especially true for analytic tools aimed at providing interactive exploratory capabilities.

In the GIS approach to transportation planning, most of the data transfer can be done automatically. GIS can be used to combine data on different levels of aggregation and to combine different types of data, which creates possibilities for more comprehensive analyses (Nielsen, 1995).

Nielsen (1995) reports that alternative projects can easily be entered into GIS, by drawing on the base map, by using a scanned raster image as background or by using a digitizing tablet. Several projects can be considered simultaneously by separating them using different topographic codes. Nielsen notes further that by this approach, all the relevant roads in a specific feasibility study can be selected by a single command making it easy to handle and analyze multiple alternatives.

There are several advantages to implementing traffic models in GIS, since handling of data is more rational and the presentation and quality control of results can be done more easily

(Nielsen, 1995). For this reason, traffic modeling may be the field in transportation planning that has made the most use of GIS (Simkowitz, 1990; Nielsen, 1995).

The GIS software package TransCAD, developed by Caliper Corporation, has been designed primarily for traffic modeling (Nielsen, 1995). TransCAD is an extension of Maptitude GIS software created by adding traffic assignment capabilities which normally cannot be handled by GIS software. Numerous studies have used GIS-Transportation software to take advantage of GIS capabilities for displaying and matching data, for defining zone structures and for linking zones with nodes on the traffic network. Applications have been developed which utilize a full GIS package with partial transportation modeling capabilities (Hans and Souleyrette, 1995). However, they note that Caliper Corporation's TransCAD software is such a GIS package, possessing numerous transportation modeling capabilities and that it has been used in several research efforts. According to Nielsen (1995), TransCAD has been used extensively for traffic modeling in Denmark.

An advantage of GIS-based, urban transportation models is a greatly enhanced capability to modify traffic analysis zone (TAZ) boundaries (Hans and Souleyrette, 1995). GIS-based models allow for zone specification or redesign at any stage in the model development process. It enables overlaying proposed TAZ boundaries on socioeconomic, demographic or commercial databases (such as TIGER census, parcel coverages, and zip code areas) to quickly check the validity of the boundaries and create new ones, if necessary (Hans and Souleyrette, 1995).

## **2.2 UTP Software Application in Transportation Planning**

### **2.2.1 The Four-Step Modeling Process**

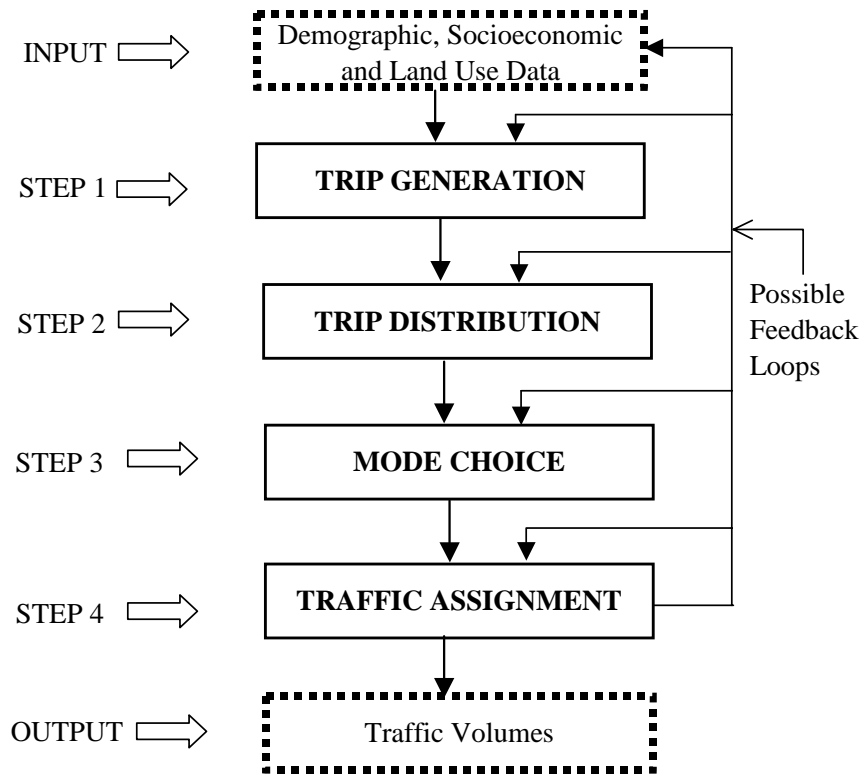
According to Chang and Meyers (1999), transportation models are an integral part of the transportation planning process, serving as analysis tool for transportation planners and as an aid

to decision-makers in evaluating alternative proposals. Almost all transportation planning models have been implemented into computer-based urban transportation planning (UTP) software packages and thus travel demand modeling has been made simple, quick and more reliable, as long as adequate data is available and appropriate parameters are used.

Models are continually being adapted, changed, and improved as new research efforts are undertaken, as well as the demands placed upon them. The steps that are generally considered to be part of the traditional four-step, sequential process include (Chang and Meyers, 1999):

1. Trip generation—predicts the number of person trip ends that are generated by and attracted to each defined zone in a study area.
2. Trip distribution—connects trip ends (productions and attractions) estimated in the trip generation model to determine trip interchanges between each zonal pair.
3. Mode choice—determines the modes that will be used to travel on each zonal interchange.
4. Trip (traffic) assignment —assigns trips to specific highway or transit routes.

This traditional four-step sequential process which makes up a travel demand model can be easily explained by a flowchart diagram shown in Figure 2.1 as envisioned by authors. Reliable inputs are required to initiate the first step in the sequence, i.e., the trip generation model, are also shown in the figure.



**FIGURE 2.1: Travel Demand Model Flowchart**

To quantify the transportation implications of new land use development, a travel demand forecasting model is often used to estimate traffic volumes on the roads (Yue and Yu, 1999). According to Yue and Yu, the modern micro- computer-based travel demand forecasting model is an automatic version of the traditional four-step, sequential travel demand forecasting process. The advent of computer models has speeded computations and allowed planners to perform more sophisticated analyses. In the foreword of the Microcomputer Applications within the Urban Transportation Environment Conference Proceedings, (American Society of Civil Engineers, 1985), the editor states that the advent of microcomputer systems has created an

opportunity to enhance the productivity and efficiency of transportation operations through improved decision-making capability. Of course, the “output” is only as good as the “input”.

Martin and McGuckin (1998) note that the practice of travel-demand forecasting started some 40 years ago with the areawide transportation studies in Chicago and Detroit it was the advent of large computers that made these studies possible. But since then, the transformation to micro-computer has dramatically changed the environment in which such analyses are carried out.

### 2.2.2 Shortcomings of the Process

As is widely accepted, almost all procedures implemented in commercially available travel demand software packages are essentially based on the four-step travel forecasting procedures (Horowitz, 2000; INRO, 1998). The four-step travel forecasting procedure evolved during the Chicago Area Transportation Study (CATS) in the 1950s (Boyce, 1998). This procedure has been highly criticized by some as not fully being able to simulate the current urban traffic situations. As stated by one author in the field of travel demand forecasting (Boyce, 1998):

“The four-step, sequential approach to travel forecasting was institutionalized into a professional practice well before a more integrated approach was fully understood. Once computer software became available for implementing this procedure, it was widely adopted and not much effort was instituted to adopt a new approach”.

Samdahl and Pedersen (1984) reported that for some time now the transportation professional community has been quite concerned about the quality of traffic forecasting data which is used as a basis for multi-million dollar investment decisions. They argue that although

the widespread use of computerized urban transportation planning packages for traffic forecasting has increased the level of sophistication of the forecasting process, the outputs still leave much to be desired in terms of accuracy and the degree of confidence which can be placed in the results.

Anderson et al. (1998) acknowledge that limitations of conventional sequential network modeling are often cited in literature. They argue that because most travel demand models are continuously updated, researchers rarely examine the original constructs for accuracy after horizon years have come and gone. Most of the shortcomings identified in literature are accepted on a theoretical basis.

Yue and Yu (1999) argue that despite the existence of so many travel demand forecasting packages, it is widely recognized that none of them is perfect for all application scenarios. Since all software packages are commercial products, the developers will advertise all kinds of good things their software can do in predicting future travel demand.

### **2.3 Problems and Uncertainties in Transportation Planning and Forecasting**

Projected growth in vehicular traffic is a controversial issue for transportation planners. Forecasts are used to make strategic decisions including; whether and where to build new highways, how best to allocate resources for maintenance, and how to develop effective transit and freight transportation policies, among others (Souleyrette et al., 1995).

Goetz and Szyliowicz (1997) note:

“Planning is a critical element in the development and implementation of sound transportation projects, yet existing practices have resulted in numerous problems and, in some cases, outright disasters. Indeed, one has to consider recent major transportation projects and the degree to which these have not met their original objectives to realize that this issue has profound significance”.

Skamris and Flyvbjerg (1996), when studying the accuracy of traffic forecasts and cost estimates on large transportation projects, noted that little research has been carried out on before-and-after studies of traffic flows in large transportation infrastructure projects. They found, too, that the few studies that do exist show that past forecasts of traffic tended to be overestimated. In that study, it was also found traffic forecasts that were off by 20 to 60 percent are common.

Mierzejewski (1995) presented some good examples where predicted transportation planning data, e.g, land use, socioeconomic activities and transportation demand, greatly differed from the actual data for a certain time horizon under study. One example is the case of Tampa, Florida. A comparison of the actual 1985 traffic volumes with the 1985 forecasts made in 1970, revealed that the error ranged from -78% to +281%, with an average absolute link error of 57%. This was largely due to the fact that in the early 1980s, employment was forecasted for Tampa's central business district (CBD) to be in the range of 75,000 to 80,000. In reality, the employment in the CBD has been very stable in the range of 26,000 to 28,000. Thus Mierzejewski points out that these highly erroneous employment forecasts were the basis for major capital facility planning in the city for a period of more than a decade.

Anderson et al. (1998) also observed that most of the travel demand model error derives from the poor estimates of horizon-year demographic and socioeconomic data. In their study of Iowa's Travel Model Performance, they report that the population projections clearly overestimated growth in the northwestern sections of the city of Ames, Iowa which, at the end of the 20-year projection period remained relatively undeveloped. The overall population over-estimation was as high as 117% for Ames and 153% for Marshalltown, Iowa. They noted a

similar situation with total employment projections, whereby lower estimates were made in some areas of the town. Anderson et al. (1998) concluded by writing:

“Examining the Ames model, improvements in the forecasts could have been attained from better estimates of the demographic and socioeconomic data”.

McDowell (1972) pointed out that traffic forecasting models have been unjustly criticized because of poor plans that were developed, poor evaluation techniques that were used, or poor judgements as to which routes were committed. McDowell further states that such criticism should be directed to the scope of the planning process underway, not to the model. It takes knowledgeable planners to develop and evaluate the alternative concepts, using the traffic estimates obtained through the models.

Skamris and Flyvbjerg (1996) conclude their study by writing:

“Decisions based on misleading forecasts, which are often presented to policymakers and to the general public, may lead to a misallocation of funds and to under performing projects during construction and operation”.

However, pressure from politicians and policymakers can lead to “misleading” forecasts because they want to assume that their communities are growing even if they are not.

The significance of uncertainty associated with a decision depends on the cost of reversing a commitment once made. In transportation projects, the cost can be in the order of millions of dollars and thus, when a decision is made, it is difficult to reverse because of the high costs involved (Khisty and Sriraj, 1999). They conclude that uncertainty is embedded in most long-range planning processes where planners have addressed such problems by using



conventional techniques that do not consider uncertainty. Mierzejewski (1995) quoting the 2020 Florida Transportation Plan report states:

“It is tough to forecast the future; analyzing historical and current trends to forecast conditions 20 or more years into the future has been compared to throwing darts at a moving board under a strobe light”.

These opening remarks by Mierzejewski are very strong. He continues to note that in spite of the recognition of uncertainty, the methods and practices mostly ignore its implications in the planning of future transportation facilities.

A serious criticism by Mierzejewski of the current methods of forecasting travel (in the context of urban transportation planning) is centered on the fact that in reality the models used are not very precise, the inputs to the model are equally very uncertain, and hence, the predicted results are not likely to occur. But how are the unreliable predicted results used? These results are used to develop a master plan intended to optimally serve the forecasted future conditions as if there were no elements of uncertainty in the whole process.

Rosenhead (1989a) notes that:

“Most often the future is captured by means of a forecast which is based on the projection of current trends. Sometimes this certain future is merely assumed, in which case the assumption is that tomorrow will be essentially the same as today. There are good reasons for believing that forecasts of any importance are inherently fallible, and that this will be compounded by the succession of natural disasters, new discoveries, accidental conjunctures and conscious interventions which will lay their train across the future”.

Future uncertainty is a reality. In a future that holds unanticipated surprises there is a need to place a high value on retaining future options.

However Rosenhead (1989a) states that a more limited task of identifying a range of scenarios that might happen would be a modest and supportable basis for planning analysis. He also points out that one key to planning under uncertainty is the acknowledgment of multiple futures.

Rosenhead (1980a) points out that the most influential methodology of planning is rational comprehensive planning. In this approach a decision maker establishes an agreed upon set of values, lists all the opportunities for action open to him or her, identifies the consequences which would follow from each action, and selects the action whose set of consequences rates highest on the agreed upon values. Rosenhead (1980a) writes:

“The pure rational comprehensive methodology puts its emphasis on prediction and certainty, and neglects the problems which may result from uncertainties or from human fallibility”.

Therefore, rational comprehensive planning does not express well the issue of future uncertainty. Sensitivity analysis is a partial exception to this. However, Rosenhead (1980a) argues that in rational comprehensive planning sensitivity analysis is normally taken as an extra option, not part of the prescribed methodology and it is taken as a secondary test, carried out on decisions already singled out as “optimal” only.

## **2.4 Decision Theories and Future Predictions (Forecasting)**

### **2.4.1 Uncertainties and Scenarios**

According to Van Zuylen et al. (1999), decision making and prediction have always been linked together; predicting the impacts of different alternatives makes it possible to choose the

best decision. On the other hand, predicting the future makes it possible to anticipate upcoming events. They further note that such predictions are a prerequisite for decision making. Predictions make sense only if one has the possibility to make decisions and take actions.

The poor predictability of the future and of the impact of actions is very general and common (Van Zuylen et al., 1999). Van Zuylen, et al., note that there are many causes for the fact that future traffic is often difficult to predict.

According to Van Zuylen et al. (1999), it is unrealistic to think of the future without taking into account the fact that people will shape the future with their decisions, which are based on their expectations of the future, their preferences and their choices. This makes the future uncertain, for a great deal is influenced by their actions and is only partly predictable. Van Zuylen et al. argue further that developing scenarios is a way to obtain a set of possible futures, with each scenario being based on assumptions about future developments. Within the scenarios, all features that can be derived from the basic assumptions or from predictable trends are covered, resulting in consistent, rather complete descriptions of possible futures.

Scenario studies are especially useful in situations in which there is low predictability of essential features of the future and the possibility to shape them. Decision making and strategy development using scenarios for an ill-predictable future can be done by looking for the least-regret options—options that do reasonably well in all scenarios (Van Zuylen et al., 1999). This approach is useful if there is a fair amount of certainty that the different scenarios used cover the entire range of possible futures.

Souleyrette et al. (1995) note that regionally, a mathematical model is needed for travel estimation; the most appropriate and effective model may be an area's existing calibrated, network-based UTP travel model. They further note that potential uses of a UTP model includes

calculation of growth factors using base and forecast year data, simulation of travel growth, and analysis of the effects of travel growth. In their study, they used one of the network-based UTP packages, TRANPLAN, for Des Moines, Iowa, to simulate various scenarios of travel growth. They then tested the sensitivity of delay to this growth. Four different traffic growth scenarios were developed with the aim of testing their effects on vehicle kilometers traveled (VKT) and vehicle-hours traveled (VHT).

The main suggestion given by the above researchers was that trip generation models should be modified to be more sensitive to underlying trends affecting travel growth. Their conclusion was that nowadays, much-improved information systems might well allow tying land-use forecasting to VKT policy as well as to the ways markets are evolving, as evidenced by such things as building and subdivision permits (Souleyrette et al., 1995).

A similar approach is to look for a strategy that reduces the maximum risk for all scenarios, e.g., the robustness of a decision can be tested with the help of scenarios (van Zuylen et al., 1999). An inherent and major variable in any planning effort is uncertainty about the future. Developing scenarios is a way to address such uncertainty in an explicit and structured manner (Munoz-Loustaunau and Sussman, 1999).

Van Zuylen et al. (1999) give five functions of scenarios as follows:

1. to stimulate creative thinking and communication in organizations, (by generating more alternatives, decision makers are challenged to make their assumptions and mental models more explicit and to make them adaptable to changing circumstances),
2. to identify and clarify the driving forces behind certain developments and distinguish them from other unpredictables,

3. to let decision makers learn to understand complex, unstructured, and threatening situations, (they learn the possible causal relations and consequences of certain decisions),
4. to help decision makers to integrate future events and developments in consistent, broad pictures of the future, and
5. to simulate the future by comparing and evaluating various alternative strategies, (decision makers gain insight into, and can compare the consequences of, various strategies).

Munoz-Loustaunau and Sussman (1999) say a common meaning attributed to “scenario” is that of “alternative”. The role of scenarios is to broaden the decision makers’ strategy and perspective about the future so that they make sounder decisions. A crucial outcome of scenario-based planning is robust decisions, i.e., decisions that will perform adequately across a range of envisioned scenarios (Munoz-Loustaunau and Sussman, 1999). Strategies in this context are considered to be a form of decisions, i.e., a high-order determination on how to better address the elements present in the external and internal environment (Munoz-Loustaunau and Sussman, 1999).

Munoz-Loustaunau and Sussman (1999) argue that in their forecasting role, scenarios are primarily a quantitative tool that can be programmed for a computer and most likely will yield a numerical value. Then it is up to the decision makers to use that figure to make a resolution. They conclude by saying that this approach shares many of the limitations of other forecasting techniques.

Quoting Van der Heijden, Munoz-Loustaunau and Sussman (1999) identify three basic components in any scenario exercise:

1. the characterization of internal issues or strategies about which an organization is seeking insight,
2. a set of scenarios describing alternate and possible futures of the organization's environment that will affect these issues, and
3. a component for which scenarios can prove most productive—as a testbed for the organization's strategies and concerns.

In the context of regional transportation strategic planning, Munoz-Loustaunau and Sussman (1999) have found that scenarios can accomplish the following:

- identify the link between transportation and the key economic, social, environmental, and political issues faced by the region,
- provide strategic direction to the regional transportation system by: (a) generating strategic options for the regional transportation system—in the face of different alternative futures, a region that wants to achieve a set of objectives can identify new options that were not considered previously, (b) serving as a tool for sound transportation decision and strategy making, and
- provide flexibility in the regional strategic transportation planning—the broadening of perspective and the testing of strategic options across alternative futures are also a source of flexibility in the planning process.

## **2.4.2 Decision Making for Flexible Future Forecasting**

### ***2.4.2.1 Introduction***

Decision theory, or decision analysis, can be used to determine optimal strategies when a decision maker is faced with several decision alternatives and an uncertain or risk-filled pattern of future events. Traffic forecasting is prone to future uncertainties. The road planning

process is long-termed, sequential, faced with many conflicting objectives and subject to great uncertainty as to outcomes and preferences.

Van Zuylen et al. (1999) mention five specific methods of decision making which they believe provide a specific way to deal with predictability and uncertainty. These methods are listed as follows:

- developing and planning scenarios,
- developing robust strategy,
- using more open, flexible strategies,
- involving important people in the decision-making process to reduce uncertainty about their attitude afterwards, and
- developing and using better forecasting models.

#### ***2.4.2.2 Flexibility as an Objective***

According to O'Sullivan et al. (1979), as descriptive theorizing on decision-making unfolded through the 1950s and 1960s, accompanied by the elaboration of operational optimizing techniques, general analytic approaches to uncertainty were also translated and applied into solving transportation investment problems. Decisions are most frequently made in a continuing sequence and this is certainly the case in transportation planning. That is why the metropolitan or regional comprehensive transportation plans are normally termed a "3C Planning Process" which means a plan is Comprehensive, Cooperative, and Continuing. One expects feedback to be incorporated in the planning process as new evidence or data becomes available and is flexible enough to accommodate it. In building up a road network over time the potential exists for modifying the original planning priorities as new information comes to light and new attitudes form which were not originally perceived at the planning stage (O'Sullivan et al., 1979).

There are several useful decision criteria which can be used to aide decision makers in the absence of probabilities, but most of them have been found to have serious theoretical limitations. For example, the Laplace Criterion, which assigns equal probabilities of occurrence for each future scenario, has been criticized, especially the assumption that several possible futures have an equal probability of occurrence has no basis (O’Sullivan et al., 1979, Khisty and Sriraj, 1999).

Rosenhead (1980b) argues that a planning process should be bottom-up in structure and facilitate participation; it should be non-optimizing, and be based on establishing a set of feasible solutions. He continues to add that it should accept the uncertainty of future states, attempt to keep options open, and aim at a loose fit on the planned for activities.

Robustness analysis is a technique which has potential in aiding decision makers in choosing investment projects and is discussed in detail in the following section.

#### ***2.4.2.3 Robustness Analysis***

“Robustness,” and the analysis based on it, embodies a particular perspective on flexibility (Khisty and Sriraj, 1999; Rosenhead, 1980b; O’Sullivan et al., 1979; and Rosenhead, 1989a). It is concerned with situations where an individual, group or organization needs to make commitments now under conditions of uncertainty, and where these decisions will be followed at intervals by other commitments (Khisty and Sriraj, 1999; Rosenhead, 1989a).

With a robustness perspective, the focus is on the alternative immediate commitments which could be made, and they will be compared in terms of the possible future commitments with which they appear to be compatible (Rosenhead, 1989a).

The idea of robustness as a decision criterion was first applied to an industrial plant location by Gupta and Rosenhead (1968) and Rosenhead et al. (1972). Immediately after this



first application of the concept, Friend and Jessop (1969) applied the criterion to local government finance and planning, where road investment was a subset of the whole problem. O'Sullivan et al. (1979) illustrated the usefulness of a robustness criterion to incorporate a measure of flexibility in the road network choice processes as opposed to comparing a selection of possible solutions. It has also been applied in personal education planning (Rosenhead, 1978; Rosenhead, 1989b). The most recent application of robustness analysis was in transportation project selection by Khisty and Sriraj (1999). Other several applications are reported elsewhere in Best, Parston and Rosenhead (1986) for health systems; Caplin and Kornbluth (1975) for chemical plants.

Rosenhead (1980b) observes that applications of robustness methodology can easily be incorporated in such areas as planning the locations and facilities for health clinics, and more generally in regional planning; in the development of transportation networks; in research and development; and in the funding activities of international agencies.

O'Sullivan et al. (1979) note that:

“Rather than assuming a single demand scenario for some horizon year, it is clearly necessary to conceive of a bounded set of possible environments within which the transport system could be operating in the future. Attention is shifted from the selection and staging of a single horizon year plan to the selection of initial investment choices which are elements of sets of long-range plans which can provide reasonable returns under any eventuality”.

For each horizon year socioeconomic configuration, it is necessary to determine which network investment projects are elements of satisfactory network structures according to the whole range of criteria dimensions identified as pertinent.

According to O’Sullivan, et al. (1979), the robustness of a project is a measure of its chances of being a good, though not necessarily optimal, initial decision. They further note that the analysis of robustness of a project is made in relation to a set or family of good transportation plans and not merely the single optimal plan for any future.

Rosenhead (1980b) argues that planning should be non-optimizing, and be based on establishing a set of feasible solutions and it should accept the uncertainty of future states while attempting to keep options open, and aim at a “loose fit” on the planned-for activities. Rosenhead (1980b) notes further that there is no single, unique methodology for flexible planning, or even for robust planning.

As stated by Rosenhead (1980b):

“... We have moved slowly from the era of the blueprint or the master plan into the phase of continuous review—a period when flexibility and adaptability are emphasized. What is happening is that we are coming round to recognizing that uncertainty is the future, that no matter how glossy we make our plans, we cannot be sure what will happen”.

Robustness analysis assesses the flexibility achieved or denied by particular acts of commitments (Khisty and Sriraj, 1999). Robustness of any initial decision is the number of acceptable options at the planning horizon with which it is compatible, expressed as a ratio of the total number of acceptable options at the planning horizon (Khisty and Sriraj, 1999; Rosenhead, 1989a; Rosenhead et al., 1972).

The robustness of an initial decision  $d_i$  can then be defined as shown in equation 2.1 (Khisty and Sriraj, 1999; Rosenhead, 1989a; O’Sullivan et al., 1979; and Rosenhead et al., 1972):

$$r(d_i) = \frac{n(S_i)}{n(S)} \dots\dots\dots \text{(Equation 2.1)}$$

where:

$r(d_i)$  = robustness of initial decision,  $d_i$ ,

$n(S_i)$  = number of acceptable options at the planning horizon with which it is compatible, and

$n(S)$  = total number of options at the planning horizon

Goetz and Szyliowicz (1997) describe the robustness and flexibility as follows:

“Robustness is the degree to which an organization is prepared to function after having been subjected to unanticipated events. Flexibility represents the ability to make continuous adjustments in constantly changing conditions”.

Robustness analysis provides an approach to the structuring of transportation problems where uncertainty is high and where sequential, time-phased decision making is necessary. Faced with the possibility that any of the formulated possible future paths (scenarios) of growth may actually occur, what initial link improvement project appears to be the best investment alternative? Such a question is what the robustness method tries to address. The method is intended for use in planning problems where probabilities cannot be assigned to the outcomes (Khisty and Sriraj, 1999; Rosenhead, 1989a). If one cannot assign probabilities and can only specify a certain number of possible outcomes, then the planners should be in a position to accommodate these changing outcomes in their plans as they occur. This is made possible with the help of robustness analysis (Khisty and Sriraj, 1999).

Robustness analysis is a technique that emphasizes the need, under conditions of uncertainty, to make early decisions in a sequence in such a way as to preserve many future options that currently seem attractive (Khisty and Sriraj, 1999; Rosenhead, 1989a).

A simple algorithm for conducting a robustness analysis for a planning process involving sequential decision-making (as suggested by Khisty and Sriraj, 1999) is as shown below:

- set a budget,
- list all proposed projects and their capital and operating costs,
- generate scenarios of demand,
- draw up a set of plans for each scenario,
- find the number of times a particular project appears as part of a plan,
- calculate the Robustness Score for a project; the ratio of number of times a project repeats to the total number of plans, and
- select the project that is the most robust, subject to budget constraints being met.

Khisty and Sriraj (1999) list the following advantages of robustness analysis:

- it is technically very simple,
- it is easier to adopt and apply to any situation, because of its simplicity and generality of the procedure, and
- it provides insight into how to tackle daunting problems, based purely on common sense and without any complex procedural analysis.

Khisty and Sriraj (1999) also note that there are some concerns about the robustness analysis which they listed as follows:

- the process is simple enough to be taken for granted and not taken seriously, and

- the robustness score indicates the flexibility and other factors need to be considered before deciding on what plan to implement.

## **2.5 Summary of Literature Review**

The capability of GIS technology in simplifying and efficiently manipulating the socioeconomic, demographic, and land use data to suit various needs of travel demand models has been discussed and various studies which have managed to utilize this capability at various levels have been cited. The literature review covered the problems facing projections in travel demand planning and the uncertainties surrounding the results of the projections. Major causes of projection uncertainties in travel demand modeling usually cited include poor estimates of horizon-year demographic and socioeconomic data, models used not being precise enough to model the real world and poor planning processes and poor evaluation techniques used.

The method of robustness analysis is discussed and its advantages over rational comprehensive planning methodologies, which aim at optimizing the results, are deliberated. The major criticism of the current optimization methodologies used in rational comprehensive planning is on the lack of acknowledging the uncertainties involved in the whole procedure. The issue of formulating scenarios in transportation planning is stressed in the literature and their advantages to such type of planning where uncertainties are high. The application of robustness analysis procedure that encompasses all scenarios, as opposed to the well known procedures of selecting the best scenario on the basis of optimizing preselected certain measures of effectiveness, is cited in details.

In this report, GIS has been used to manipulate the socioeconomic data and TAZs from one format to another and these data are the ones which were used into the travel demand model

software. The concept of formulating possible growth scenarios and street networks has been utilized in this report. Also, the robustness analysis, which forms the core of this research, has been used to evaluate the better way of making decision based on the results/outputs from the urban transportation planning (travel demand) software.

## Chapter 3

### Study Methodology

#### 3.1 Selection of Platforms

Several commercial GIS and UTP model software packages are available. There are many factors to consider when choosing one software over another. Among these are reliability of software in providing reliable outputs, level of sophistication and its user-friendliness, cost of software acquisition, input data demand and availability, etc.

In this study, Maptitude was chosen as a GIS platform. According to Calipers (2001):  
“Maptitude is a powerful combination of software and geographic data that provides everything you need to realize the benefits of desktop mapping and spatial analysis with a single, easy-to-use package”.

Maptitude version 4.1 was used in this study. For the UTP modeling, the Quick Response Software (QRS II version 6) was chosen. QRS II is one of the widely known travel demand models mostly developed for small and medium sized cities for quick analysis and easy transferability of data. QRS II, which was developed in the late 70s, has been widely used in the United States.

In this study, a GIS platform was used for socioeconomic data manipulation, analysis and preparation for input to QRS II's trip analysis stage. QRS II was mainly used for the four-step process. Also, GIS can be used for graphical presentations and summarization of outputs from QRS II. This provides easy display and visualization.

## **3.2 Development of Socioeconomic Data in Maptitude**

### **3.2.1 Data Requirements: Main Sources of Data**

Three major planning studies done at different periods for the Topeka-Shawnee County Metropolitan Area were available and were furnished by the Kansas Department of Transportation (KDOT). The first planning study was completed in 1964 by the State Highway Commission of Kansas (1964) and will be referred to as "Report 64". Report 64 used 1958 as the base year and projected for the year 1980. The second planning study was published in 1974 by Johnson, Brickell, and Mulcahy (1974) and this report will be referred to as "Report 74." Report 74 used 1965 as base year and projected for the year 1990. The most recent planning report was published in 1989 by the Topeka-Shawnee County Metropolitan Planning Agency (1989). This report, which will be referred to as "Report 89", was mainly a statistical report of socioeconomic projection. In Report 89, projections for 1980, 1985, 1987, 1990, 1995, 2000, 2005, and 2010 were contained in Report 89. Only Report 64 and Report 74 have a transportation planning component. The new, 2000 TAZs' geographic files and maps were furnished by KDOT.

In the first part of the analysis in this report, all "past future" projections made in previous studies were supposed to be compared with what actually took place. For example, projected population was to be compared to the actual population for the projected year. The street network used with QRS II was developed using the current (2000) traffic analysis zone (TAZ) boundaries (2000 TAZs). One of the most time consuming parts of this research was to translate all of the different years' socioeconomic data into one common zoning scheme. The TAZ boundaries used in Report 64 are not compatible with census tracts nor with the current traffic analysis zone boundaries. In Report 74, data is presented by districts and 1974 traffic



analysis zones. These TAZs are not the same as the 2000 TAZs. However, these district boundaries defined in Report 74 are the same as the current census tracts. It is also important to note that the census tracts' boundaries for the developed area have not changed for many years, probably since the 1950s.

Data in Report 89 are presented both in census tracts and 1990 TAZ boundaries. The census tract boundaries are compatible with both the 1990 and 2000 TAZ boundaries, i.e., several TAZs will fit exactly in one census tract. However, the 1974, 1990 and 2000 TAZs are not compatible, i.e., they are delineated differently and therefore, they are not compatible to each other.

Report 64 does not include the necessary socioeconomic data on which the 1980 traffic projections were based. Since Report 89 was not meant to be used for transportation planning, the report does not include some data required by QRS II. The missing data is the average household income and number of autos per household. Report 74 has all the required QRS II socioeconomic inputs. Therefore, it was decided to use only Report 74 data for further analysis. Since Report 74's TAZ boundaries were not totally compatible with the 2000 TAZs, some data manipulations were required. These are explained below.

### **3.2.2 Defining Traffic Analysis Zones (TAZs)**

The first task was to create a geographic file or layer for the zones used in Report 74 by using the GIS's spatial analysis and manipulation capabilities and were easy to interactively delineate. A geographic file of current TAZs that was supplied by KDOT, was loaded into Maptitude. The 1990 TAZs and census tract geographic files were generated from TIGER files. The 2000 traffic analysis zone layer, the census tract layer and the street network layer, were combined in one map view.

Socioeconomic data from Report 74 was uploaded into a dataview table associated with the new traffic analysis zones (i.e., the redefined ones for Report 74). An advantage of using GIS is that when one modifies zone boundaries, it automatically updates and calculates the area of each zone that changes.

Only one basic network was used for all the analysis in order to reduce variations that might have been caused by differential centroid ties and network configurations. Since KDOT was in the process of developing a new network to be used with QRS II for the year 2000, that network was chosen as the starting point for all the years as well. As a result, there was a need to convert all data from the Report 74 layer into the 2000 TAZs format. The capability of GIS made this conversion relatively simple to accomplish.

### **3.2.3 Using Overlays in Maptitude for Data Manipulation**

#### ***3.2.3.1 Rules for Estimating Attributes in a Working Layer***

Maptitude estimates the attributes of area features by adding together the attribute values from features in the reference layer, based on the percentages that they overlap. Some types of data have to be averaged instead of using the sum. For example, when two areas are joined together, Maptitude adds the population of the two areas to get the population of the new, combined area. However, data on income should be averaged rather than added together. Therefore, some data fields should be added, while others should be averaged or handled in some other way (Caliper, 1999).

When you split a zone into two unequal parts, Maptitude divides the population proportional to the size of each area. When averaging values, let's say income, Maptitude performs what we call weighted averages. The average income of the new zone in the working

layer has to take into account not only of the average incomes of each zone in the reference layer, but also the number of persons who live in each zone.

Maptitude has a default aggregation method that is used whenever you combine attribute data. Whenever you perform overlays or use geographic editing, Maptitude uses this aggregation method automatically. Maptitude can join, merge or split areas (zones). When creating a dataview table, the user can choose the aggregation method that he/she thinks is appropriate for each existing data field. Whenever overlays are created, Maptitude uses the default aggregation method for every data field. Table 3.1 summarizes the default aggregation methods and how they work. It is up to the software user to change the method according to the data field requirements.

**TABLE 3.1: Default Aggregation Methods in Maptitude**

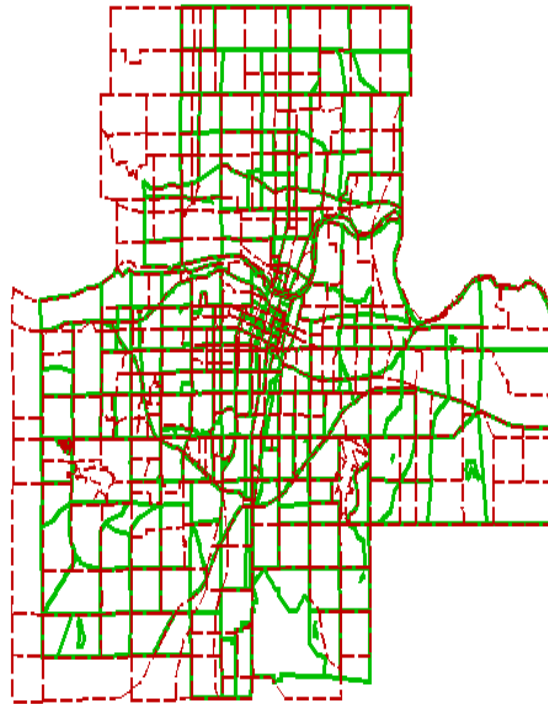
(Caliper 1999, pp. 293)

Method	Joining/Merging Areas	Splitting Area
None (blank)	Leaves the field blank	Leaves the field blank
Copy	Uses the value for one of the features (whichever one encounters first) for the combined feature	Copies the value for the feature to all of the pieces
Add	Adds the values for individual features or the proportional values for parts of the individual features	Splits the values into parts based on the area of parts
Lowest	Uses the lowest of the values of the individual features	Copies the value for the feature to all of the pieces
Highest	Uses the highest of the values of the individual features	Copies the value of the feature to all of the pieces
Average	Computes a weighted average of the values from the individual features	Copies the value for the feature to all of the pieces

***3.2.3.2 Overlaying of Report 74 TAZs into 2000 TAZs' Format***



The two layers of traffic analysis zones, i.e., the TAZs of Report 74 and the 2000 TAZs were opened into one view. The “Tools-Overlay” command in Maptitude was used to overlay the two features and distribute the socioeconomic data (attributes) of Report 74's TAZs into 2000 TAZs' format. For this operation, Report 74 features formed the working layer and 2000 TAZs' features formed the reference layer. Data was aggregated or disaggregated to new zonal levels by performing weighted averages by area and summing the values and associating

them with appropriate zones. Figure 3.1 shows the 1974 TAZs (Report 74) superimposed with the current system of TAZs.



**FIGURE 3.1: Topeka Urban Area Map Showing Report 74 TAZs Superimposed on 2000 TAZs**

**Key:**

-  Report 74 TAZs boundaries
-  2000 TAZs boundaries

### **3.3 Traffic Networks Development in QRS II**

#### **3.3.1 Overview**

The highway system is a network consisting of computerized representations of streets and intersections. Streets are represented by links while intersections are represented by nodes. The urban area is described by a set of zones (traffic analysis zones). These zones are represented by centroids, which are special types of nodes. Centroids are connected to the network by a special type of link called a centroid connector and the activity within the zone is assumed to be concentrated in the centroids. Urban activity information is loaded at the centroid as centroid attributes. In QRS II, the default centroid attribute variables include income, average vehicles/household, number of retail employees and non-retail employees, number of dwelling units and intrazonal travel time. The default attribute variables for street links are approach codes, speed, travel time and capacity. The link length is computed from the coordinates of the end-points and travel time is computed using link length and the coded speed.

A traffic network map of the Topeka Urbanized Area, developed in QRS II software by use of the General Network Editor (GNE) and depicting the year 2000 existing system, was created by personnel in the KDOT Planning Bureau. As usual for most UTP models, this is an abstract network whereby only major streets and highways are included in the network and centroid connectors that represent local streets accessing the TAZs.

It was decided that five network alternatives should be tested in this study. This includes three major network alternatives that were developed and tested in Report 74 and the two other networks that actually existed, i.e., the existing 1990 network and the existing 2000 network. These alternatives are explained as follows:

1. the existing 1974 network alternative with minimum development (in Report 74 was termed as Existing + Committed),
2. the network alternative that was tested in Report 74 with highway US-75 bypass connected to I-470 in the vicinity of Gage Street (in Report 74 was termed as 1990.L),
3. the network alternative that was recommended and selected in Report 74 projecting for 1990 (in this case, highway US-75 bypass was connected to I-470 in the vicinity of Burlingame Road and was termed as 1990.R),
4. the actual 2000 existing network as supplied by KDOT, and
5. the actual network as it existed in 1990.

Also, two scenarios (sets) of socioeconomic data were selected for loading onto the three network alternatives mentioned above:

1. socioeconomic assumptions from Report 74 on land use, socioeconomic and demographic data projections for 1990, and
2. socioeconomic data from 1990 census data extracted from a Bureau of Transportation Statistic (BTS) CD-ROM “1990 census transportation package”.

Therefore, combinations of various network alternatives and socioeconomic data alternatives, as outlined above, resulted into ten feasible and reasonable development plans. In this report, the ten development plans (scenarios) will be abbreviated as follows:

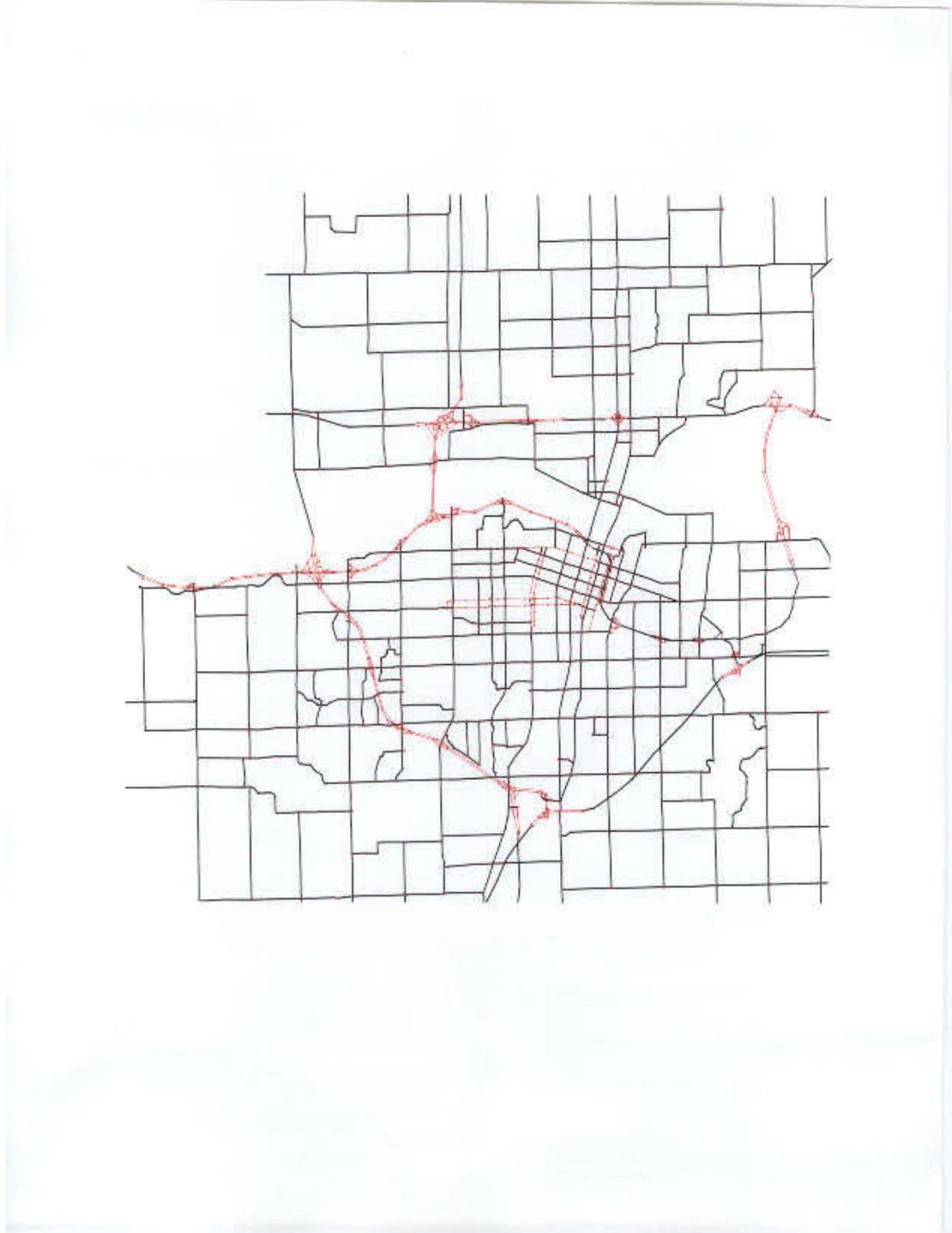
1. “*Net 74EC-74*”: Report 74 Existing + Committed network loaded with Report 74 data,
2. “*Net 74EC-Census*”: Report 74 Existing + Committed network loaded with census data,
3. “*Net 74L-74*”: Report 74 1990.L network loaded with Report 74 data,
4. “*Net 74L-Census*” Report 74 1990.L network loaded with census data,

5. “*Net 74R-74*”: Report 74 1990.R network loaded with Report 74 data,
6. “*Net 74R-Census*” Report 74 1990.R network loaded with census data,
7. “*Net 90-74*”: Actual 1990 existing network loaded with Report 74 data,
8. “*Net 90-Census*”: Actual 1990 existing network loaded with census data,
9. “*Net 00-74*”: Actual 2000 existing network loaded with Report 74 data,  
and
10. “*Net 00-Census*”: Actual 2000 existing network loaded with census data.

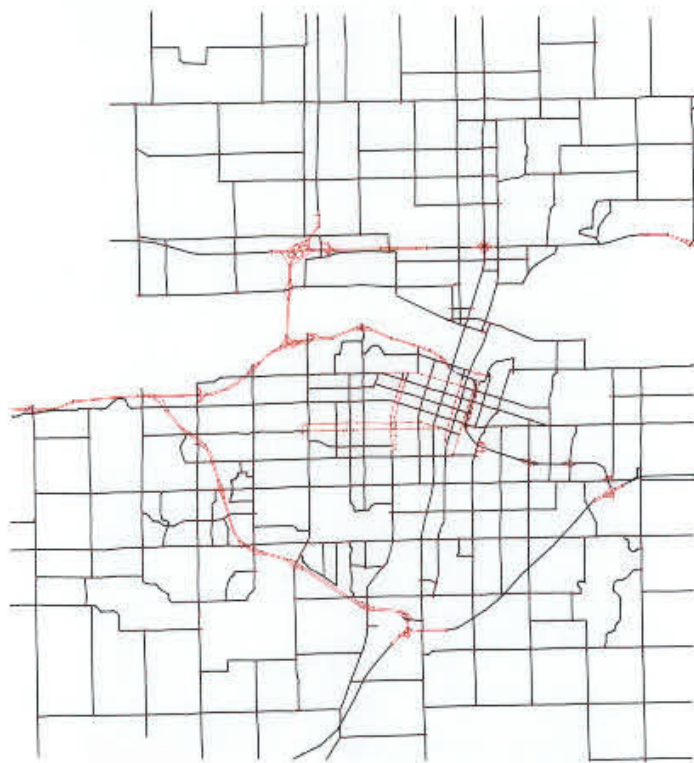
Figure 3.2 shows a plot of the coded base highway network, including all link types except centroid connectors, recommended in Report 74 (1990.R). The plot of the same base highway network depicting the network that existed in 1990 is depicted in Figure 3.3 while the one that existed in 2000 is shown in Figure 3.4.

The 2000 Topeka traffic network that was supplied by KDOT was modified so as to obtain the other two alternative networks. Some of the road segments and connectors were either removed from the network or added to the original network in order to better represent the actual road systems as described above.

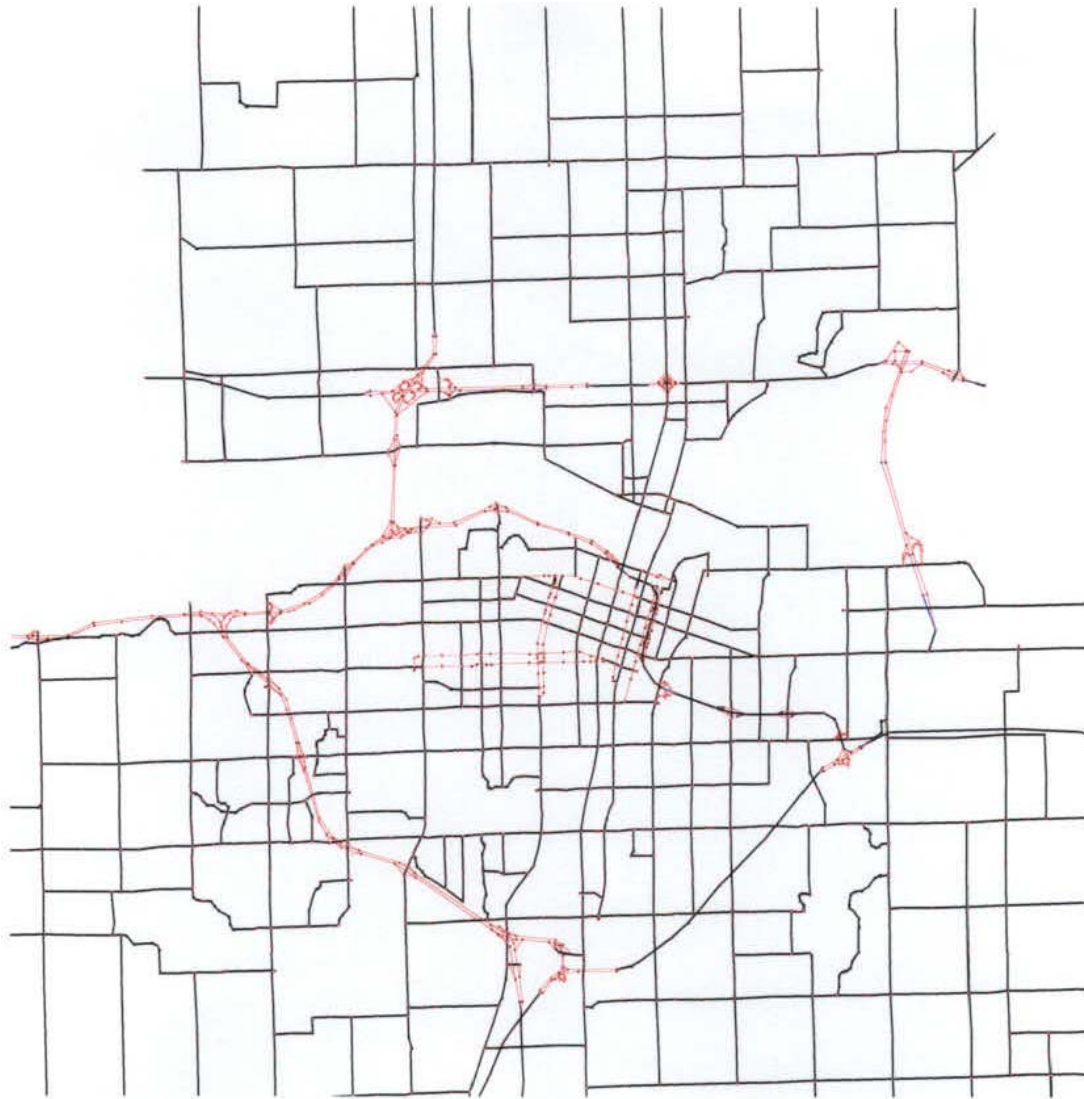




**FIGURE 3.2: Base Highway Network Recommended in Report 74**



**FIGURE 3.3: Base Highway Network as Existed in 1990**



**FIGURE 3.4: Base Highway Network as Existed in 2000**

**3.3.2 Development of Alternate Traffic Assignments in ORS II**

Report 74 does not describe in detail the models used in assigning traffic to the respective street networks. For example, Report 74 simply mentions that a computer program was developed which was capable of determining the shortest time or distance path through a

highway network. For traffic assignment, it only mentions that a modified all or nothing method was used and that the gravity model was used for trip distribution.

QRS II is capable of performing both all-or-nothing traffic assignment and capacity-restrained, equilibrium assignment. Usually, the best method is the capacity-restrained equilibrium assignment as it reflects and incorporates both congestion effects and intersection control effects. The capacity-restrained, equilibrium method in QRS II is the one that was used in this study to assign traffic volumes for the different network scenarios considered.

Traffic assignment for each network scenario was performed separately as QRS II can handle only one run at a time (although QRS II 6 can make one run initiate another run by using the “Cascade” command). NCHRP Report 365, “Travel Estimation Techniques for Urban Planning” (Martin and McGuckin, 1998), which is an update of the NCHRP Report 187, was used for some of the default data suggested for urban areas with a population less than 200,000. These parameters include average trip production parameters, vehicle occupancy parameters and trip distribution parameters. However, the new version of QRS II, version 6, uses the same default values and it has been modified to accommodate the new findings stipulated in NCHRP Report 365.

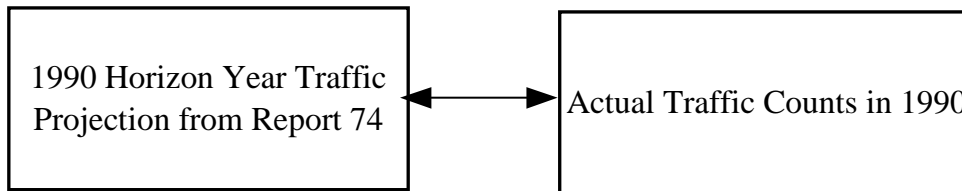
### **3.4 Analysis of Projected Demographic and Socioeconomic Data**

As mentioned earlier in Chapter Two, poor projections of demographic and socioeconomic data are usually cited as one of the major source of poor traffic assignment projections, and hence, ill conceived comprehensive plans and construction programs. Report 74 has projections for 1975, 1980, 1990 and 2000. However, the only projections that could be compared with actual data extracted from census reports are for 1980 and 1990 since the 2000 census data at the census tract level was not yet available at the time this study was done.

These comparisons provide an opportunity to compare what was predicted to what actually happened after the horizon year had occurred. This is rarely done, especially for small and medium sized cities (Anderson et al., 1998), such as Topeka. Most of the time, the current planning staff is busy developing new long range plans rather than taking the time to compare what was predicted to what actually happened.

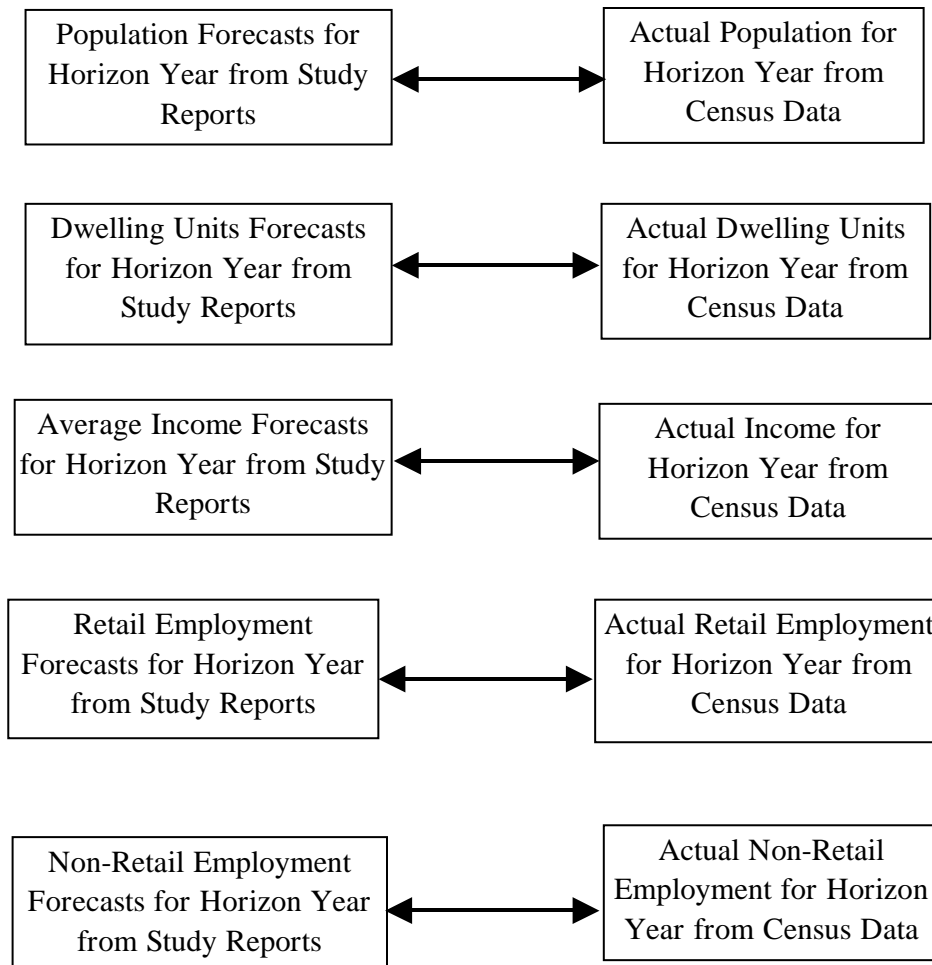
The 1990 traffic volumes that had been projected in Report 74 were compared with actual 1990 traffic counts on some important major roadways as illustrated in Figure 3.5. The key data that was compared (i.e., extracted from the report data vs. the census data) is:

1. population,
2. number of dwelling units (DUs),
3. retail employment,
4. non-retail employment, and
5. average household income.



**FIGURE 3.5: Symbolic Comparison of Projected Traffic Volumes Versus Actual Ground Traffic Counts**

The comparisons are illustrated in Figure 3.6.



**FIGURE 3.6: Symbolic Comparison of Projected Socioeconomic and Demographic Data Versus Actual Data**

### **3.5 The Use of Robustness Analysis to Develop a Decision Criteria**

#### **3.5.1 General**

Ten development plan scenarios consisting of various traffic networks and socioeconomic assumptions of land use, demographic and other socioeconomic growths were

developed as described in Section 3.3.1. In Report 74 there were highway links/corridors that were proposed to be constructed, improved or developed to handle the expected future 1990 growth of population and vehicular traffic volumes for the network alternatives that were developed.

Robustness analysis is used to test the decision made on which highway links should have been given priority early in the sequence for development, expansion or construction of highway networks. The general robustness score formula represented by equation 2.1 was used in this study. The basis for a robustness score for any particular link selected in this study is the number of times it appears as part of the plans.

### **3.5.2 Procedure**

A set of links to be included in the project (i.e., expansion, construction, etc.) for each scenario being considered was prepared during the study documented in Report 74. These are road sections that were considered in the original study (Report 74) that came up after a one year analysis done by the Topeka Area Planning Study (TAPS) Committee (Johnson et al., 1974). After traffic assignment was performed in QRS II for this research study, traffic volumes projected for each scenario were generated as the output of the assignment model. From traffic assignment results, links that showed to have high volume-capacity ratios (V/C ratios), in this case, the minimum was taken to be  $V/C = 0.95$ , were selected for each scenario as the candidate to be tested by the robustness analysis procedure. In other words, a particular link was counted for a given scenario if it has a V/C ratio  $\geq 0.95$ .

Using equation 2.1, the robustness score for a particular link “i” is determined as shown in equation 3.1.

$$\text{Robustness score for (Link } i) = \frac{\# \text{ of times link " } i \text{ " is chosen as part of plans}}{\sum (\text{Number of all plan scenarios})} \dots\dots\dots \text{(Equation 3.1)}$$

About 115 links that were selected from Report 74 were tested in this study. Due to the criterion described above of screening candidate road links for robustness analysis, only 43 road links managed to at least be part of one scenario plan.

### **3.5.3 Usage of Robustness Scores**

The robustness scores were used to assess the road links that should be given priority for construction, expansion or upgrading to higher standards. Therefore, the higher the robustness score for a particular link in the network the more important the link is, thus, the higher its priority should be.

The robustness procedure does not choose a scenario that seems to be optimum, but simply keeps open all scenarios that seem to be possible candidates. All links that were proposed in Report 74 for construction or improvement or widening have been included for testing in order to determine the viable options (robust links) that needed future improvements as demanded by most of the network-socioeconomic combination scenarios that were considered.

From the foregoing discussion, the viability of a link to be given a priority in terms of improvement does not depend on which network scenario it belongs to. In practice, under optimization methodologies, long range planning just chooses one network scenario that is thought to be optimum or best and discards the other candidate scenarios. In robustness analysis, the assumption is that, as long as all candidate scenarios were based on realistic assumptions based on the best knowledge of the planners concerned, any of the scenarios can actually happen



and so none have to be discarded altogether. It allows keeping all options open at the beginning and also for any future changes should the need arises.

The robustness score of a certain link under consideration is how many times it has been part of the ten viable alternative plans formulated and described earlier in this chapter. A particular link is considered to be “part” of a certain plan scenario if its V/C-ratio is at least 0.95.

## **Chapter 4**

### **Analysis and Discussion of Results**

#### **4.1 Introduction**

This chapter is divided into three main parts. The first part compares the projected 20-year forecast of socioeconomic and demographic inputs and traffic volumes for major highways (20-year forecast) from Report 74 against the actual census data and ground traffic counts after the horizon year, 1990, had come and gone. The second part evaluates the results from travel demand modeling using QRS II, obtained from using various combinations of assumptions on socioeconomic, land use, and demographic inputs, loaded onto various highway network scenarios. The third part applies robustness methodology early in transportation planning sequence to aid in making decisions on which highway links should be given priority.

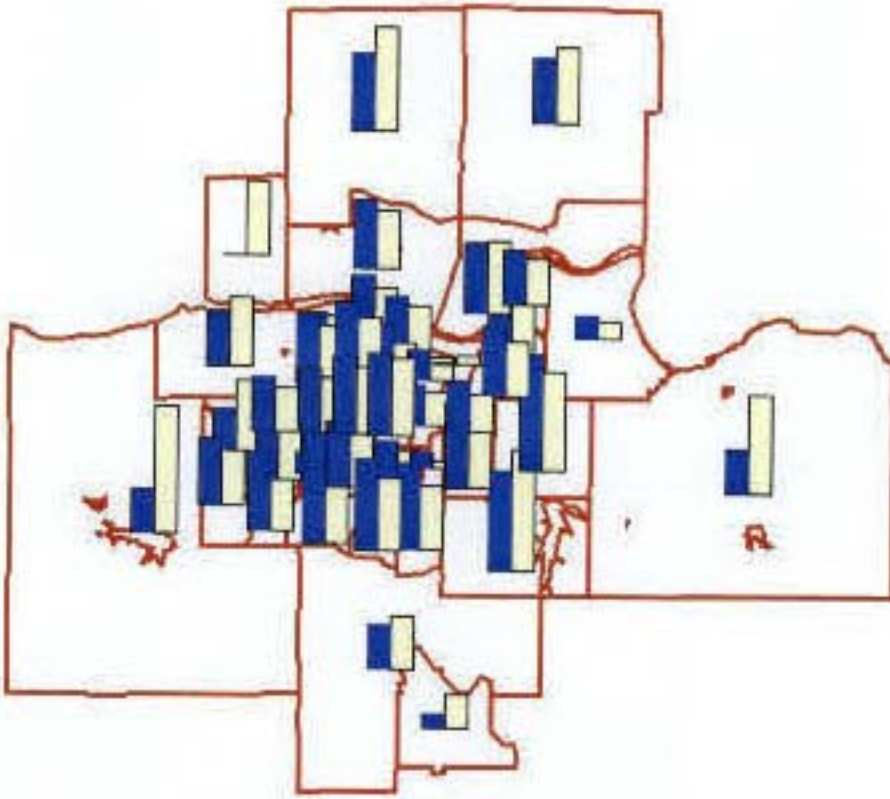
#### **4.2 Summary of Projected Socioeconomic Data and Traffic Volumes**

In the original report (Report 74), socioeconomic and demographic data, was summarized both for census tracts and traffic analysis zones (TAZs). Since the census data is summarized at the census tracts level, the census tract level data formed the basis for comparison of projected values against actual values. Table 1 summarizes the  $R^2$  values produced by regression analysis of the socioeconomic projections made in 1974 versus actual 1980 and 1990 census tract totals (i.e., how good the projected data estimated the actual data in the horizon year).

**TABLE 4.1: R<sup>2</sup> Values of Projected Versus Actual Values  
for Socioeconomic Input Variables**

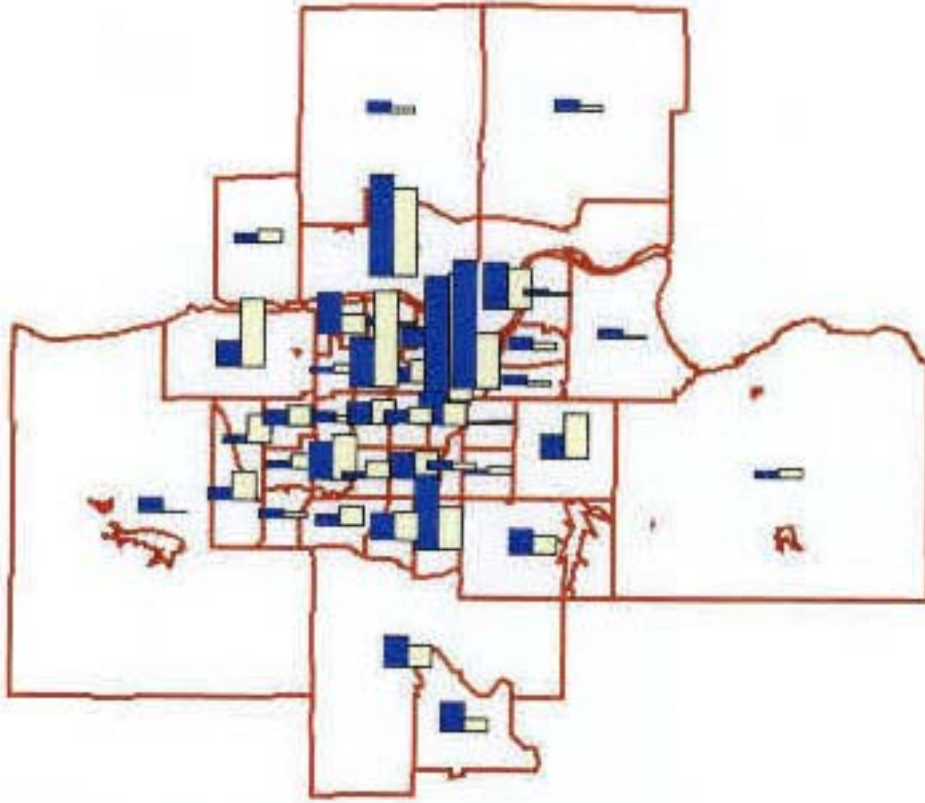
Projected Variable	R <sup>2</sup> Value for Projected Horizon Year	
	1980	1990
Population	0.44	0.23
Dwelling Units (DUs)	0.53	0.23
Average Family Income	0.59	0.49
Retail Employment	-	0.67
Non Retail Employment	-	0.93

Table 4.1 shows that with the exception of 1990 employment data, the projected socioeconomic input variables were far from reality. Non retail employment was very well projected with the retail employment projected fairly accurately relative to the other three variables (the census' employment data for 1980 could not be obtained for this study). One would expect that the longer the projection period the more likely the projection values will differ from the actual ones. The table clearly shows that 1990 (20-year) estimates were poorer than 1980 (10-year) estimates. Retail employment was not as accurate as the non-retail employment. However, since the retail employment is a small component of the total employment, the total employment also has a high accuracy.



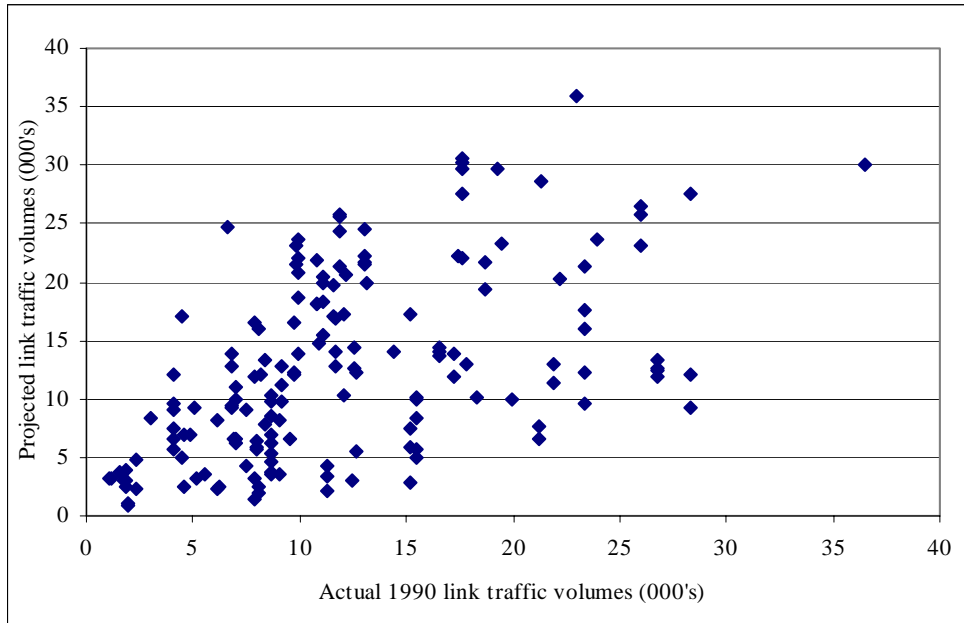
**FIGURE 4.1: Comparison of Projected Versus Actual Population for 1980**

Figure 4.1 shows the comparison of projected versus actual population of the Topeka Urban Area, by census tracts, for the horizon year 1980. The projections underestimated population growth in the west and east sections of the metropolitan area by more than 50%. Sections close to the central business area (CBD), were generally overestimated. The northern and southern sections of the urban area were also generally underestimated.



**FIGURE 4.2: Comparison of Projected Versus Actual Total Employment for 1990**

Figure 4.2 shows the comparison of projected versus actual total employment for the Topeka Metropolitan Area. Like other previously discussed data, the total employment was underestimated in the western part of the metropolitan area where the West Ridge mall shopping center and other businesses were not anticipated at the time the projections were made. Almost all census tracts in the western part of the metropolitan area had their total employment underestimated between 30 and 70%. Although the northern areas were generally overestimated in terms of expected employment, however, their employment level is still very low to have much impact. For areas close to the CBD, most parts were overestimated while others were underestimated. In general terms, total employment was accurately projected (approximately  $R^2 = 0.92$ ).



**FIGURE 4.3: Projected Horizon Year Traffic Volumes Versus Actual Traffic Count Volumes**

The 1990 forecasted link by link traffic volumes from Report 74 were compared with actual ground traffic counts for the same horizon year. Figure 4.3 shows a scatter plot of predicted versus ground count traffic volumes. In general, the original study model did not produce a good prediction of the horizon year traffic volume, producing an  $R^2$  value of 0.28. However, this comparison may be misleading because the network used to forecast traffic for 1990 (“NET 74R”) is substantially different from the 1990 actual existing (“NET 90”) network as some of the important highway links proposed in 1974 were not constructed by 1990. Looking at a link by link prediction accuracy, there are differences ranging between -74% and 459%. Sixty six percent of the road links were either overestimated or underestimated by more than 20%, while 34% have estimation error (projected versus actual count) within 20%, i.e., either underestimation or overestimation. Given the nature of traffic volume fluctuations and their

prediction difficulties, an error between 0 and 20% can be acceptable in practice, that is, the actual daily traffic counts on any given road link in a network can vary by that amount.

More importantly, the end product of all these projections in the travel demand analysis is directed towards estimating the number of lanes required to accommodate the projected traffic volume (refer to Figure 2.1). The Highway Capacity Manual (TRB, 1994) planning procedure was used to assess the number of lanes needed for a specified level of service (LOS) for projected horizon year. The results showed that 65% of the road links could be operating at the same LOS for both actual and projected traffic volumes and 35% operated at different LOS. However, the difference between projected and actual traffic volumes would have warranted a different number of lanes for only 1.2% of the road links.

Since the LOS criteria encompasses a range of traffic volumes for a particular level of service (i.e., A, B, C, D, or E), and is not a point value estimate, a variability of 20% in traffic volume may still be within the range of the same level of service. Thus, the high variability noted in terms of projected traffic versus actual traffic volume did not adversely affect the number of lanes designed and constructed to accommodate the traffic volume.

### **4.3 Summary of Traffic Assignment Results**

The effectiveness of the various network alternatives can be measured by the number of vehicle miles of travel (VMT) and vehicle hours of travel (VHT) on each network system. The fewer the vehicle miles of travel per day for the whole network, relative to other alternatives, the more efficient the roadway network. In other words, the higher the VMT, the higher the cost to the road users. Likewise, the fewer the total VHT per day the more efficient the network is relative to alternative highway networks. Table 4.2 summarizes the measures of effectiveness (MOEs) for the ten scenarios (plan alternatives) as described in Chapter 3. A further discussion of the

results of Table 4.2 is outlined in Section 4.3.1. The values recorded are the average daily VMT and VHT.

**TABLE 4.2: Results of the Measures of Effectiveness for the Scenarios Considered**

Network Alternative	Input Alternative	VMT	VHT
NET 74 E+C	Report 74	3,763,940	114,413
	Census data	4,016,623	125,858
NET 74 L	Report 74	3,880,796	111,194
	Census data	4,180,758	134,535
NET 74 R	Report 74	3,881,024	110,418
	Census data	4,114,960	130,076
NET 90	Report 74	3,755,591	113,482
	Census data	3,952,927	122,656
NET 00	Report 74	3,839,937	110,220
	Census data	4,039,581	121,052

In Table 4.2 the abbreviations are as defined in Section 3.3.1, that is, “NET 74R-74” means Report 74 network with US-75 bypass connected at Burlingame area loaded with Report 74 data, “NET 74R-Census” means Report 74 network with US-75 bypass connected at Burlingame area loaded with 1990 census data. “NET 74L-74” means Report 74 network with a US-75 bypass connected at Gage area loaded with Report 74 data, “NET 74L-Census” means Report 74 network with a US-75 bypass connected at Gage area loaded with 1990 census data. “NET 74EC-74” means Report 74 (existing + committed) network loaded with Report 74 data,



“NET 74EC-Census” means Report 74 (existing + committed) network loaded with 1990 census data. “NET 90-74” means actual 1990 existing network loaded with Report 74 data, “NET 90-Census” means actual 1990 existing network loaded with 1990 census data, “NET 00-74” means actual 2000 existing network loaded with Report 74 data, and “NET 00-Census” means actual 2000 existing network loaded with 1990 census data.

The above results prompt further analysis by evaluating how various socioeconomic assumptions and network alternatives formulated affect the travel and road users as follows:

- Analysis One. Various socioeconomic inputs were applied to each network alternative to study the effect of different assumptions on land use, and socioeconomic and demographic data on the resulting traffic assignment and the overall regional travel.
- Analysis Two. The same socioeconomic input data was applied to different road network alternatives to study the effect of the decision made of implementing the existing network alternative as compared to the original proposed network alternative from Report 74.

The comparisons of the two “analyses” described above are best illustrated by Table 4.3 (analysis one) and Table 4.4 (analysis two).

**TABLE 4.3: Comparisons Done for Analysis One**

Network Alternative	Socioeconomic Data		
	Report 74	Census Data	
NET 74EC	↑	↑	COMPARE
NET 74L	↑	↑	COMPARE
NET 74R	↑	↑	COMPARE
NET 90	↑	↑	COMPARE
NET 00	↑	↑	COMPARE

**TABLE 4.4: Comparisons Done for Analysis Two**

Network Alternative	Socioeconomic Data		
	Report 74	Census Data	
NET 74EC	←	←	COMPARE
NET 74L	←	←	COMPARE
NET 74R	←	←	COMPARE
NET 90	←	←	COMPARE
NET 00	←	←	COMPARE

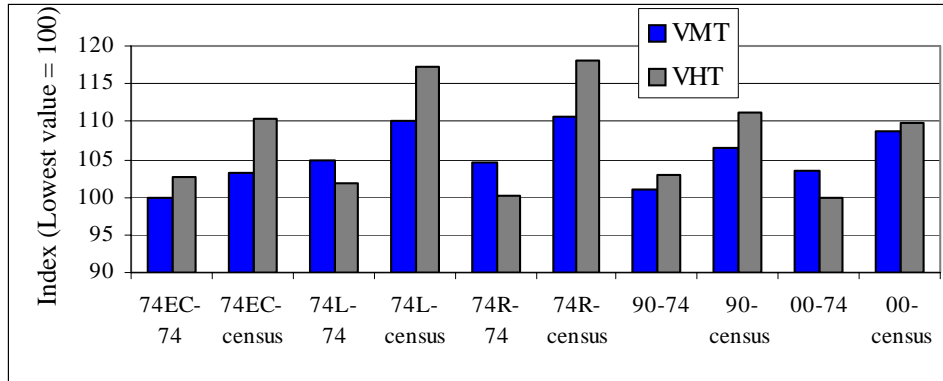
#### **4.3.1 Effect of Socioeconomic, Demographic and Land Use Input Data**

With census data loaded onto the Report 74 recommended network (“NET 74R”, from Table 4.2), it is observed that this results into 233,936 VMT per day higher than predicted by Report 74 data, which is equivalent to 85.4 million VMT per year. Also, the census data predicts 19,658 VHT per day or 7.2 million VHT per year higher than that predicted using Report 74 data.

When the same census data was loaded onto the 1990 existing network, “NET 90”, the result is the prediction of 197,336 VMT per day higher than was predicted by Report 74 data, which is equivalent to 72 million VMT per year. The daily VHT predicted by loading the census data onto “NET 90” are higher than was predicted by Report 74 data by 9,174 VHT which is equivalent to 3.3 million VHT per year.

When the same census data was loaded onto the 2000 existing network, “NET 00”, the result is the prediction of 197,644 VMT per day higher than predicted by Report 74 data, which is equivalent to 72.9 million VMT per year. The daily VHT predicted by loading the census data are higher than that of Report 74 by 10,832 VHT, which is equivalent to 3.95 million VHT per year.

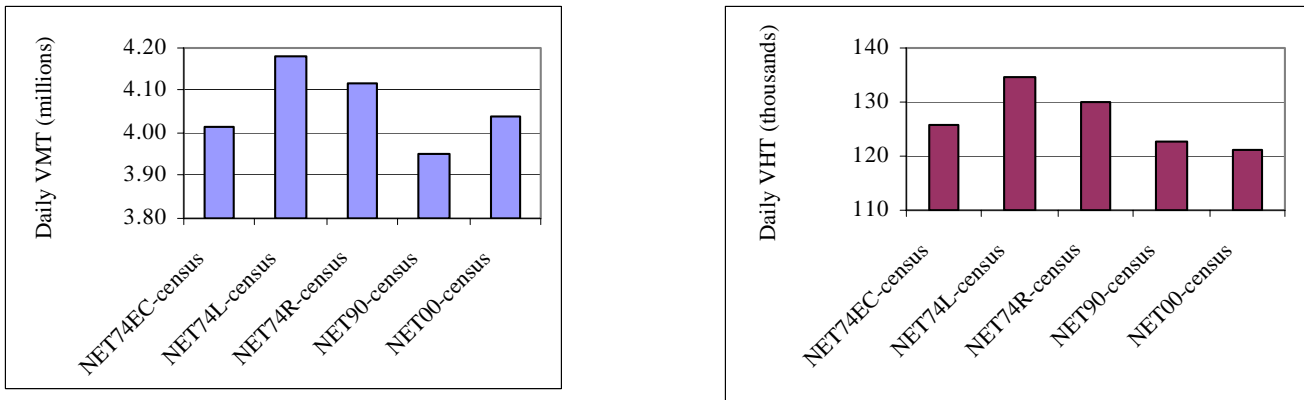
From the above values, it is clear that the different assumed land uses, demographic and socioeconomic growth scenarios have different effects on the resulting VMT and VHT measures of effectiveness of the highway network on which this data is loaded. The difference in the resulting measures of effectiveness will depend how the growth assumptions differ among the alternatives formulated. Figure 4.4 shows this effect.



**FIGURE 4.4: Comparison of Socioeconomic Assumptions to the Network’s MOE Values**

**4.3.2 Effect of Implementing Different Highway Network Plans**

It is obvious that the choice of which highway network to implement, effects the road users in terms of the distances they have to travel and the time they have to spend on their trips. When the same assumptions of socioeconomic, demographic and land use patterns were loaded onto the five highway network alternatives, the results showed varying VMT and VHT values. These results are shown in Figure 4.5 where the network alternatives are loaded with census data. In terms of VMT, “NET 90” seems to be the most efficient network alternative as it minimizes the VMT, but in terms of VHT, it is “NET 00” which is the most efficient, as road users have to spend the least time driving on the network’s roadways. This raises the question of which MOE should be used to determine the most efficient network between “NET 90” and “Net 00”.



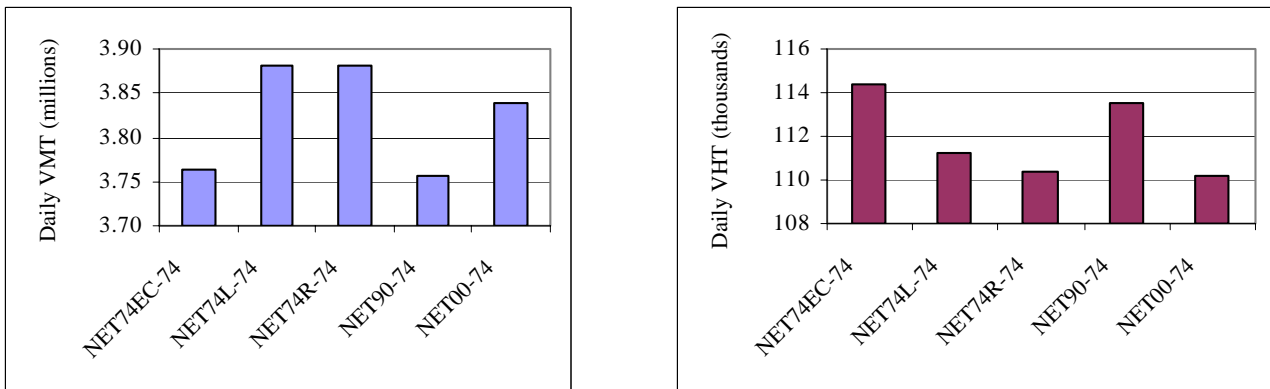
**FIGURE 4.5: VMT and VHT Results When Network Alternatives - Loaded with Census Data**

By looking closely at the two highway networks, one will find that “NET 00”, the Topeka highway system existing in 2000, is similar to “NET 90”, which is the highway system that existed in 1990, albeit with some additional, very important roadway segments which were added in the period between 1990 and 2000. The most important ones are the US-75 bypass, K-4 including a bridge crossing Kansas River north of US-24, and two ramps added to connect I-70 and I-470 highways. These additions provided more travel path options, and probably increased distances traveled but provided easy accesses to the interstates, which likely increased vehicle speeds and decreased travel time. Also, the US-75 bypass relieved congestion on Topeka Boulevard that may be likely contributed to the reduced daily VHT in “NET 00” alternative.

The results obtained from the travel demand model are supported by noting that the additional road sections in the 2000 existing network increased the overall VMT by the addition of more mileage on the network while higher speeds and easy access to freeways reduced the overall VHT on the network. Therefore, as a result, road users spend more time on fewer congested roadways in the 1990 existing network (hence fewer VMT in “NET 90”), while

spending less time on “NET 00”. This argument is supported by traffic assignment results summarized in Table A-1 in Appendix A. Table A-1 shows that “NET 00” assigns about 10% more vehicles to freeways than does “NET 90” due to better access to the freeway links. From the foregoing discussion, “NET 00” is more efficient than “NET 90”.

Figure 4.6 shows the VMT and VHT results when the same highway network alternatives as previously described are loaded with the Report 74 assumptions of demographics, land use and socioeconomic data. An important point to note is that “NET 74L” and “NET 74R” have the highest VMT with all scenarios because they have the highest mileage of the five networks because some of the road segments, according to Report 74, were proposed to be constructed by 1990 were never constructed. However, some of the intersections and roadways were improved, which was not anticipated during the study leading to Report 74. Again, “NET 90” is more efficient in terms of VMT and “NET 00” is more efficient in terms of VHT.



**FIGURE 4.6: VMT and VHT Results When Network Alternatives – Loaded with Report 74 Data**

### **4.3.3 Concluding Remarks on Comparing Alternatives with Traditional TDM Tools**

In traditional transportation demand modeling (TDM), it is usual to develop one set of socioeconomic, demographic and land use assumptions and load them onto various highway network alternatives in order to select the one that seems to be the “optimum” or the “best” alternative. Under this condition, comparison and evaluation of network alternatives using VMT as the MOE as was done in Report 74 (Johnson et al., 1974), does not appear to be a reliable and accurate procedure. The author believes that VHT is better for evaluating network alternatives because even the travel skims in traffic assignment procedures are mostly built on travel time on the shortest paths. This can identify the more congested network alternative(s). Therefore, both VHT and VMT should be used to assess the network alternatives with the VHT being given more weight in the decision process. The desired alternative should be the one that minimizes both values. However, it may not be possible to have both values minimized in a single network alternative, as is the case in this study.

The next section presents a proposed new technique that should result in more sound decisions among alternatives such as those discussed above.

## **4.4 Robustness Analysis Results**

### **4.4.1 Overview**

The disadvantages of traditional planning methodologies for optimizing networks are described in the literature (Rosenhead, 1980a; O’Sullivan et al., 1979; Caplin and Kornbluth, 1975) and illustrated with the examples presented above in previous sections. The major problem with these traditional procedures is that the projected or anticipated growth may not happen. The foregoing discussion in this report presents a good example. Planners who prepared Report 74 expected that the socioeconomic-demographic and land use projections they made would

materialize in the horizon year (twenty years later) and that the traffic volumes they projected were going to be realized. In this study it has been observed that the network proposed in Report 74 was not developed by 1990 as expected, and the 1990 census data showed that most of the projected socioeconomic-demographic-land use data were poorly projected and the traffic volumes from 1990 ground counts on major road links were generally poorly correlated with the ones projected in Report 74 mainly due to networks not being exactly equal. In other words, the projected future for 1990 in Report 74 did not happen. There is no evidence indicating that there was any review before or after the projected horizon year came and passed to check the validity of the original assumptions and expectations.

To put the above discussion in the context of this study, after one highway network alternative was selected, other “candidate” alternatives were discarded all together and there was no procedure for going back to try to figure out if there was any validity or realism among the other alternatives that were not selected. In order to make the methodology more flexible and responsive to future changes, the authors believe that robustness methodology has great utility and allows keeping all alternatives “open”. All alternatives developed with traditional planning methodologies are thought to be formulated based on realistic assumptions, however, no one knows for sure which alternatives will represent the real future or be closest to real future conditions.

#### **4.4.2 Robustness Scores for Individual Road Link Segments**

The methodology used to come up with an individual link’s robustness score was explained in detail in Section 3.5. The way this methodology was used is explained in detail below using an example and reference to Table A-2 in Appendix A. A road link was considered to be included in the analysis, i.e., it needs future attention if the projected volume is at least 0.95



of the link capacity ( $V/C \geq 0.95$ ). Therefore, if  $V/C \geq 0.95$ , the link gets a score of “1”, and if  $V/C < 0.95$ , the link gets a score of “0”. The steps used in the calculation are illustrated by using a Topeka Boulevard road link between 45<sup>th</sup> Street and 44<sup>th</sup> Street as follows:

1. For the “NET 74E+C-74” alternative, the link’s  $V/C \geq 0.95$ , its score is “1”.
2. For the “NET 74E+C-Census” alternative, the link’s  $V/C < 0.95$ , its score is “0”.
3. For the “NET 74L-74” alternative, the link’s  $V/C \geq 0.95$ , its score is “1”.
4. For the “NET 74L-Census” alternative, the link’s  $V/C < 0.95$ , its score is “0”.
5. For the “NET 74R-74” alternative, the link’s  $V/C \geq 0.95$ , its score is “1”.
6. For the “NET 74R-Census” alternative, the link’s  $V/C < 0.95$ , its score is “0”.
7. For the “NET 90-74” alternative, the link’s  $V/C \geq 0.95$ , its score is “1”.
8. For the “NET 90-Census” alternative, the link’s  $V/C \geq 0.95$ , its score is “1”.
9. For the “NET 00-74” alternative, the link’s  $V/C \geq 0.95$ , its score is “1”.
10. For the “NET 00-Census” alternative, the link’s  $V/C < 0.95$ , its score is “0”.

Therefore, the ultimate or final robustness score for the Topeka Boulevard link between 45<sup>th</sup> Street and 44<sup>th</sup> Street was obtained by adding together the above individual scores and divided the total to the number of alternatives considered (in this case = 10):  $1 + 0 + 1 + 0 + 1 + 0 + 1 + 1 + 1 + 0 = 6$ . Thus, the robustness score =  $6/10$ . The final scores for all the road links considered were obtained by the same procedure used in the example above.

The results of the final robustness scores for individual road link segments are shown in Table 4.5. Again, the robustness score of a link is the sum of individual “1” and “0” obtained from each alternative, depending whether its  $V/C$ -ratio is greater or lower than the cut-off point defined, divided by the number of all plan scenarios formulated in Chapter Three. More detailed information of the robustness scores of individual links is presented in Table A-2 of Appendix A.

**TABLE 4.5: Robustness Scores for Individual Road Links**

SN	Link	From	To	Robustness score
1	US-75	Gage	37th	2/10
2	Kansas	37th	Topeka	4/10
3	8th St	Topeka	Harrison	10/10
4	8th St	Harrison	Jackson	9/10
5	8th St	Jackson	Kansas	9/10
6	Topeka	49th	45th	4/10
7	Topeka	45th	44th	6/10
8	Topeka	44th	43rd	6/10
9	Topeka	43rd	41st	6/10
10	Topeka	41st	40th	9/10
11	Topeka	40th	38th	4/10
12	Topeka	38th	37th	4/10
13	Topeka	37th	36th	2/10
14	Topeka	36th	34th	1/10
15	Topeka	34th	33rd	2/10
16	Topeka	32nd	29th	4/10
17	Topeka	21st	20th	1/10
18	Topeka	17th	14th	1/10
19	Topeka	Huntoon	12th	3/10
20	Topeka	12th	11th	10/10
21	Topeka	11th	10th	10/10
22	Topeka	10th	9th	9/10
23	Topeka	9th	8th	8/10
24	Topeka	8th	7th	10/10
25	Topeka	7th	6th	10/10
26	Topeka	6th	5th	10/10
27	Topeka	5th	4th	10/10
28	Topeka	4th	3rd	10/10
29	Topeka	3rd	Laurant	10/10
30	Topeka	Laurant	Gordon	10/10
31	Gage	I-470 SB	I-470 NB	1/10
32	21st St	Gage	Arnold	1/10
33	21st St	Oakley	Randolph	1/10
34	21st St	Randolph	High Ave	3/10
35	21st St	High Ave	Mac Vicar	8/10
36	21st St	Mac Vicar	Jewell	8/10
37	21st St	Western	Tyler	10/10
38	21st St	Tyler	Topeka	10/10
39	21st St	Topeka	Van Buren	10/10
40	21st St	Van Buren	Kansas	10/10
41	21st St	Madison	Adams	10/10
42	21st St	Virginia	Indiana	10/10
43	21st St	Iowa	California	3/10

### **4.4.3 Discussion of the Robustness Analysis Results**

Several important road segments/corridors that were widened or improved during the period between 1974 and 1990 have received relatively high robustness scores meaning that they were robust projects and their choice for improvement can be justified. All the important major roadways serving high traffic volumes are the ones that have the highest robustness scores. For example, Topeka Boulevard, a major north-south arterial passing through the CBD, link segments in the vicinity of the CBD and those which connect the northern part of the urban area with the CBD, all have high scores relative to other road links. Also, the proposed widening of 21<sup>st</sup> Street in Report 74, a west-east major arterial, is equally justified by the robustness scores obtained for most of its link segments. Robustness analysis could be an important first step in the planning decision sequence whereby important links that should be given immediate or first priorities are identified, for possible further action. Other considerations, like financial and budgetary constraints can then be checked to determine which links among those highly prioritized by the robustness analysis scores, fit within existing constraints or are critical to current traffic flows and may require immediate attention. Details of robustness analysis are presented in the following sections.

## **4.5 Framework – Robustness Analysis in Transportation Planning Decisions**

### **4.5.1 Introduction**

The success of the procedure being developed here, as in all travel demand modeling, depends highly on the accuracy of input data based on realistic development and growth assumptions to be tested which should encompass all possible growth scenarios. In other words, the travel demand process will continue to depend on the accuracy of projected land use, anticipated zoning structures and expected future demographic parameters.

It is strongly recommended that substantial effort should be made by both transportation planning and urban planning personnel to agree on all possible future growth scenarios. Ideally, decisions should not be politically motivated to impress the policymakers who want to see high future growth figures being presented.

#### **4.5.2 Methodology**

The framework for applying the robustness analysis procedure being proposed here involves six simple steps which are also represented in the form of a flowchart in Figure 4.8 at the end of this section.

1. The planning team agrees on a manageable number of future land use, demographic and socioeconomic scenarios depending on their understanding of the local area and the availability of sufficient past and present data. Brain storming sessions may be helpful at this stage and consensus among team members should be reached and agreed upon.
2. Feasible, alternative highway networks are proposed, testing different improvements such as widening of different road link segments and construction of new road segments. These should be developed in the context of trying to improve the projected travel of the horizon year being modeled. The goal is to reduce congestion on specific highways, and in general, improve the efficiency of travel movements on the whole network. This stage, too, requires detailed discussion involving knowledgeable personnel on the team.
3. Any travel demand modeling software can be used and traffic assignment simulation is performed as usual for all feasible scenario combinations formulated in steps 1 and 2 above. It is best to concentrate on a few realistic, possible scenarios than to have an endless list of combinations that are very highly correlated to each other.
4. Calculate the V/C-ratio by projected traffic volume divided by capacity for each link in each scenario. Define the cut-off for V/C-ratio value for

determining which road links need to be included for robustness analysis. This value should be taken as the one that indicates that the road link may experience congestion at the projected horizon year and thus requires some improvements to handle the future traffic volume efficiently.

5. For each scenario where the link's  $V/C \geq cut\ off\ value$ , give it a value "1" (one) and to the scenario where its  $V/C < cut\ off\ value$ , give it a value of "0" (zero). For each particular link, add together all its resulting "one" and "zero" to get its total score. These "score" calculations can be presented mathematically as follows:

$$\left. \begin{aligned} score &= 1, \text{ iff } \frac{v}{c} \geq x \\ score &= 0, \text{ iff } \frac{v}{c} < x \end{aligned} \right\} \dots\dots\dots(\text{Equation 4.2})$$

Where:

$V/C$  = volume to capacity ratio

$x$  = cut-off value of  $V/C$  ratio

6. Finally, the final robustness score of the link is determined by dividing the total number of scores obtained in step five above to the total number of scenarios. Note that the total number of scores cannot be higher than the number of scenarios. This relationship can also be presented mathematically as shown in equation 4.3 as follows:

$$R = \frac{\sum_{i=1}^N scores}{N} \dots\dots\dots(\text{Equation 4.3})$$

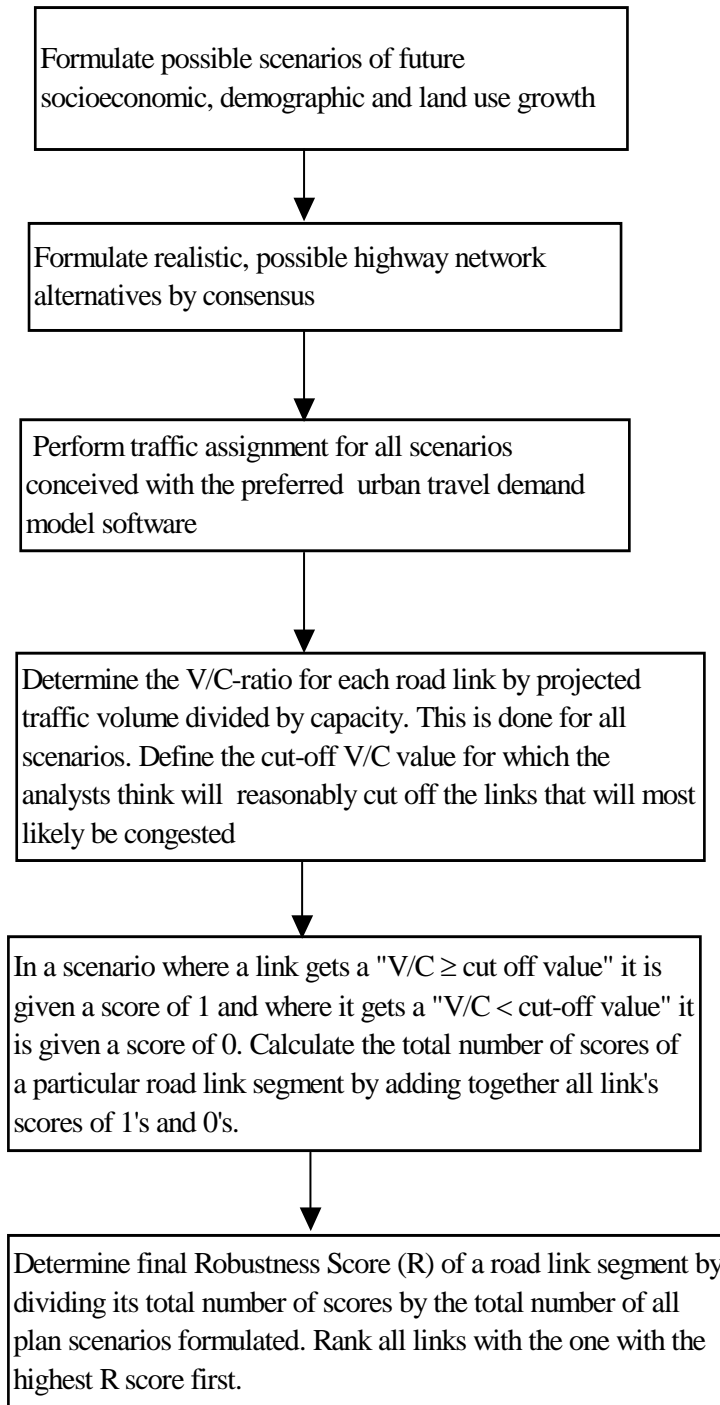
Where:

$R$  = final robustness score for a particular link,

$\Gamma$  scores = sum of all scores for a particular link obtained by adding  
all 1's and 0's obtained over all scenarios, and

$N$  = the number of all plan scenarios.

Then rank all the link robustness scores in order, starting with the highest robustness score. The higher the robustness score value, the more robust the road link is whatever future possible decision path maybe. This makes sense because the choice is made of initial investment decisions that are good investments in a variety of different possible future scenarios representing a feasible planning of transportation infrastructures.



**FIGURE 4.7: A Flowchart of the Robustness Analysis Procedure in Transportation Planning Decision Making**

## Chapter 5

### Conclusions and Recommendations

#### 5.1 Conclusions

From the analysis of the projected data versus actual data collected after the future horizon year has come and gone, the following conclusions can be made:

- Within the limited context of the original long range study done for the Topeka Metropolitan Area, it can be concluded that poor traffic volume forecasts mainly originate from poor projections of urban activities such as socioeconomic, land use and demographic data, which are the basis of traffic projections. In order to achieve better traffic forecasting, reliable and realistic socioeconomic, land use and demographic variables for a future horizon year should be projected first.
- It is good practice to rely first on short term projections and use the results (after the short term horizon has arrived) to review the intermediate and long term projections and test whether the original expectations are still achievable.
- Although overall projected traffic volumes versus actual ground counts had a poor correlation, the individual link-by-link performance was not as bad. About 34% of the links in this study have a traffic prediction error within 20% which means that most of them had correctly predicted the right number of lanes needed. More than 98% of the road network links had their number of lanes correctly estimated from the projected 20-year traffic volumes.
- It is well known that it is not easy to produce perfect projections for long future periods, however if the projections of traffic are made carefully and end up differing from actual traffic volume by not more than 20 to 30%, they may still be good enough for estimating the correct number of lanes.



From the travel demand analysis and formulation of a procedure to aid in transportation planning decisions, the following conclusions can be made:

- Selecting an alternative by optimization procedures which pick only the alternative that is thought to be the best in terms of the measures of effectiveness chosen, has many shortfalls, most notably, lack of flexibility due to performing as if the procedure is deterministic.
- Robustness analysis is more efficient in performing transportation planning decisions because it acknowledges the uncertainties associated with the whole planning procedure and thus leaves all options open for future adjustment in case the need arises.
- Robustness analysis can be used to rank the links properly by giving higher robustness scores to all road link segments that are known to be important and which handle higher daily traffic volumes.
- The vehicle miles of travel criterion (VMT) as a measure of effectiveness for comparing the efficiency of highway network alternatives was found to be a weak procedure as it may lead to selecting the less efficient scenarios. It does not properly identify highway networks which are congested due to few route choices available to road users. The vehicle hour of travel (VHT), in this case, has been identified as a better MOE in such evaluations as it can easily determine the network that will be more congested. However, it is recommended that the network that minimizes both, is more preferred although sometimes one can be confronted with conflicting results between these two MOEs.
- The traditional method of optimization, whereby one highway alternative is selected based on the outcome of the measures of effectiveness needs to be improved. The new paradigm being advocated here is the application of robustness analysis, without optimization of any kind. This approach makes the decision process flexible by letting all assumed scenarios contribute into the decision to be made.

- The application of robustness analysis to past Topeka growth strategies has demonstrated that the process is a viable approach with great potential.

## **5.2 Recommendations**

- It is recommended that more studies of this kind be performed for different areas whereby original study documents are available and the projected horizon year has come and gone. The major assumptions and the performance of the models used in such studies have to be reviewed to determine how much they affect the final projected traffic volumes.
- It is recommended that the use of robustness analysis for making urban transportation planning decision be tested further as it has great potential. The whole process is normally surrounded with uncertainties for which the robustness methodology tends to minimize by reducing the possibility of getting surprised by unexpected results.

## **5.3 Contribution of the Research Effort**

This research has demonstrated, after the fact, that robustness analysis could have been used as a tool to make better planning decisions in Topeka. There should be no reason it would not be widely applicable to other cities. It is anticipated that the results of this research effort will pave the way and stimulate further research in this area, e.g., how robustness analysis can be more widely demonstrated with other cities and be further developed to improve urban transportation planning decision-making.

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## **APPENDIX A**





**FIGURE A-1: Traffic Assignment Results on "NET 74R" Loaded with Census Data as Input**



**FIGURE A-2: Traffic Assignment Results on “NET 90” Loaded with Census Data as Input**



**FIGURE A-3: Traffic Assignment Results on “NET 00” Loaded with Census Data as Input**

**Table A-1: Measures of Effectiveness (MOEs)**

Table A-1. Measures of Effectiveness (MOEs)									
	NET 90-74			NET 00-74			NET74EC-Census		
Class	VDT	VHT	Speed	VDT	VHT	Speed	VDT	VHT	Speed
Freeway	1190724.7	18533.1	64.25	1309105.8	21149.3	61.9	1224913	19880.6	61.61
Expressway	0	0	0	0	0	0	0	0	0
Major	1493893.8	54735.5	27.29	1490992.1	50910.8	29.29	1635364	62800.9	26.04
Minor	433456.6	16977.4	25.53	417011.3	15956.9	26.13	607811.7	23361.6	26.02
Collector	453476.7	16591.2	27.33	441830.6	15804.3	27.96	349484.2	12831.9	27.24
Local	176901.2	6320.8	27.99	174106.9	6100.8	28.54	192223.3	6672.5	28.81
Other	7137.7	324.1	22.02	6889.8	298.2	23.1	6828.2	310.7	21.98
<b>TOTAL</b>	<b>3,755,591</b>	<b>113,482</b>		<b>3,839,937</b>	<b>110,220</b>		<b>4016625</b>	<b>125858</b>	
	NET 90-Census			NET 74R-74			NET74EC-74		
Class	VDT	VHT	Speed	VDT	VHT	Speed	VDT	VHT	Speed
Freeway	1226812.6	19746.5	62.13	1351324.6	21466	62.95	1192727	18705.5	63.76
Expressway	0	0	0	0	0	0	0	0	0
Major	1691393.3	65141.6	25.96	1519652.4	51375.1	29.58	1501565	54289.5	27.66
Minor	435888.1	16578.3	26.29	512530.9	19036.8	26.92	556304.9	21522.5	25.85
Collector	427200.7	14804.1	28.86	311946.6	12076.5	25.83	322316.6	13012.8	24.77
Local	164469.6	6060.1	27.14	178652.3	6165.2	28.98	183759.9	6550.5	28.05
Other	7163	325.5	22.01	6917.4	298	23.22	7266.1	332	21.89
<b>TOTAL</b>	<b>3,952,927</b>	<b>122,656</b>		<b>3,881,024</b>	<b>110,418</b>		<b>3763940</b>	<b>114413</b>	
	NET 00-Census			NET 74R-Census			NET 74L-Census		
Class	VDT	VHT	Speed	VDT	VHT	Speed	VDT	VHT	Speed
Freeway	1363301.1	25207.8	54.08	1448022.2	25538.9	56.7	1430602	25131.1	56.93
Expressway	0	0	0	0	0	0	0	0	0
Major	1668509.4	59562.5	28.01	1624198.7	66286.2	24.5	1655693	69814.7	23.72
Minor	419484.9	15575.5	26.93	545385.9	20198.6	27	572864.3	21015.4	27.26
Collector	417039.5	14432.9	28.9	307437.7	11221.9	27.4	326628.9	11773.7	27.74
Local	164067.6	5931.9	27.66	182604.6	6490.6	28.13	186177.9	6416	29.02
Other	7178.2	341.8	21	7311	339.5	21.53	8791.6	384.5	22.86
<b>TOTAL</b>	<b>4,039,581</b>	<b>121,052</b>		<b>4,114,960</b>	<b>130,076</b>		<b>4180758</b>	<b>134535</b>	
	NET 74L-74								
Class	VDT	VHT	Speed						
Freeway	1329022.2	21065.7	63.09						
Expressway	0	0	0						
Major	1535561	52243.3	29.39						
Minor	519029.7	19350	26.82						
Collector	309467.1	11963.1	25.87						
Local	179781.5	6242.3	28.8						
Other	7934.1	329.9	24.05						
<b>TOTAL</b>	<b>3880795.6</b>	<b>111194.3</b>							

**Table A-2: Detailed Information on Robustness Scores (R) for Individual Link Segments**

Table A-2. Detailed information on robustness scores (R) for individual link segments

Link	From	To	74NetE+C	74CensE+C	74Net-L	74Cens-L	74Net-R	74Cens-R	Net-90	Cens-90	Net-00	Cens-00	Count	R
US-75	Gage	37th	0	0	1	1	0	0	0	0	0	0	2	2/10
Kansas	37th	Topeka	1	1	0	1	0	1	0	0	0	0	4	4/10
8th St	Topeka	Harrison	1	1	1	1	1	1	1	1	1	1	10	10/10
	Harrison	Jackson	1	1	1	0	1	1	1	1	1	1	9	9/10
	Jackson	Kansas	1	1	1	0	1	1	1	1	1	1	9	9/10
Topeka	49th	45th	0	0	0	0	1	0	1	1	1	0	4	4/10
	45th	44th	1	0	1	0	1	0	1	1	1	0	6	6/10
	44th	43rd	1	0	1	0	1	0	1	1	1	0	6	6/10
	43rd	41st	1	0	1	0	1	0	1	1	1	0	6	6/10
	41st	40th	1	1	1	1	1	0	1	1	1	1	9	9/10
	40th	38th	0	0	0	0	0	0	1	1	1	1	4	4/10
	38th	37th	0	0	0	0	0	0	1	1	1	1	4	4/10
	37th	36th	0	0	0	0	0	0	1	0	1	0	2	2/10
	36th	34th	0	0	0	0	0	0	1	0	0	0	1	1/10
	34th	33rd	0	0	0	0	0	0	1	0	1	0	2	2/10
	32nd	29th	0	0	1	0	1	0	1	0	1	0	4	4/10
	21st	20th	1	0	0	0	0	0	0	0	0	0	1	1/10
	17th	14th	1	0	0	0	0	0	0	0	0	0	1	1/10
Huntoon	12th		1	1	0	0	0	0	1	0	0	0	3	3/10
	12th	11th	1	1	1	1	1	1	1	1	1	1	10	10/10
	11th	10th	1	1	1	1	1	1	1	1	1	1	10	10/10
	10th	9th	1	1	1	0	1	1	1	1	1	1	9	9/10
	9th	8th	1	1	1	0	1	0	1	1	1	1	8	8/10
	8th	7th	1	1	1	1	1	1	1	1	1	1	10	10/10
	7th	6th	1	1	1	1	1	1	1	1	1	1	10	10/10
	6th	5th	1	1	1	1	1	1	1	1	1	1	10	10/10
	5th	4th	1	1	1	1	1	1	1	1	1	1	10	10/10
	4th	3rd	1	1	1	1	1	1	1	1	1	1	10	10/10
	3rd	Laurant	1	1	1	1	1	1	1	1	1	1	10	10/10
	Laurant	Gordon	1	1	1	1	1	1	1	1	1	1	10	10/10
Gage	I-470 SB	I-470 N	0	1	0	0	0	0	0	0	0	0	1	1/10
21st St	Gage	Arnold	0	0	0	0	0	0	0	1	0	0	1	1/10
	Oakley	Randolp	0	0	0	0	0	0	0	1	0	0	1	1/10
	Randolp	High Av	0	0	0	0	0	1	0	1	0	1	3	3/10
	High Av	Mac Vic	1	1	0	0	1	1	1	1	1	1	8	8/10
	Mac Vic	Jewell	1	1	0	0	1	1	1	1	1	1	8	8/10
	Western	Tyler	1	1	1	1	1	1	1	1	1	1	10	10/10
	Tyler	Topeka	1	1	1	1	1	1	1	1	1	1	10	10/10
	Topeka	Van Bur	1	1	1	1	1	1	1	1	1	1	10	10/10
	Van Bur	Kansas	1	1	1	1	1	1	1	1	1	1	10	10/10
	Madison	Adams	1	1	1	1	1	1	1	1	1	1	10	10/10
	Virginia	Indiana	1	1	1	1	1	1	1	1	1	1	10	10/10
	Iowa	Californi	1	1	0	0	0	0	0	0	1	0	3	3/10

**ADDENDUM to: KSU-01-3**

**Socioeconomic Data Development using QRSII's  
Activity Allocation Model**

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# **SOCIOECONOMIC DATA DEVELOPMENT USING QRS II'S ACTIVITY ALLOCATION MODEL**

## **Introduction**

By the time this research project started, the available QRS II version 5 could not forecast the spatial distributions of population and employment in the urban area. However, during the course of the execution of the project, version 6 of QRS II was released with a new feature that incorporated the activity allocation model. Towards the end of this study, an attempt was made to use QRS II to estimate the activity allocation for Topeka using the 1970 data to calibrate the model and use it to forecast for 1990 provided that the model gives promising results with the 1970 data. This Appendix C documents what was done in this regard.

## **Data Requirements**

QRS II requires data for districts. Districts are collections of one or more zones. Required data for districts consist of:

- an identifying name for the district
- ratio of population to employment
- amount of land that can be used for residential development
- amount of land that can be used for service development
- basic employment, and
- the average amount of time it takes to travel within the district

As a rule of thumb, QRS II manual suggests that for initial network development, the number of districts have to be about one-eighth of the square root of the population. For Topeka urban area with a population of about 165,400, the number of districts required is about 51. Since data could

only be obtained in the form of census tracts, then it was decided that census tracts form the district boundaries. Therefore, 44 census tracts formed 44 districts. There was no reasonable way data could be divided to obtain 51 districts.

Each district requires six sets of data: Intradistrict time; Population to employment ratio; Basic employment; Net developable area; Service developable area; and Persons per dwelling unit. These data were estimated from Report 74 and 1970 census data. The results of the activity allocation model are presented in the following section.

### **Activity Allocation Results from QRS II**

Table C.1 compares the activity allocation estimate for total employment and population in each district versus the actual 1970 census data for the same districts. Figure C.1 shows the traffic assignment results developed by using QRS II activity allocation estimates. Figure C.2 shows the width plot of activity allocation by districts as estimated by QRS II model.

### **Discussion of Results**

The results being presented here were obtained by one run of the activity allocation model without performing any kind of calibration. Due to limited time and resources, no further calibration was attempted. However, it can be more interesting if this kind of work can be extended further.



Table C.1. Activity allocation estimates from QRS II compared with the actual 1970 data

Zone	Land Use Estimate		Land Use Actual		Error in Percentages	
	Employment	Population	Employment	Population	Employment	Population
1	11114	311	19805	2271	-43.9	-86.3
2	4910	469	6732	1105	-27.1	-57.6
3	551	377	1585	3011	-65.3	-87.5
4	401	438	790	5066	-49.2	-91.4
5	196	188	771	3995	-74.6	-95.3
6	390	312	1029	3464	-62.1	-91.0
7	4716	3451	5207	3996	-9.4	-13.6
8	1493	2418	2217	4759	-32.7	-49.2
9	335	498	328	3338	2.1	-85.1
10	473	508	643	4761	-26.5	-89.3
11	181	600	475	4616	-61.9	-87.0
12	186	620	140	3305	32.5	-81.3
13	180	508	300	5372	-40.1	-90.5
14	365	269	463	763	-21.1	-64.8
15	898	523	1304	2247	-31.1	-76.7
16.01	112	363	249	2646	-55.2	-86.3
16.02	210	647	553	6175	-62.0	-89.5
17	1844	7248	1756	1223	5.0	492.6
18	113	395	891	4666	-87.3	-91.5
19	165	415	502	3956	-67.1	-89.5
20	104	350	285	4328	-63.4	-91.9
21	343	374	2753	5328	-87.6	-93.0
22	257	551	378	3696	-32.1	-85.1
23	1180	4883	1864	991	-36.7	392.7
24	995	2573	1175	2703	-15.3	-4.8
25	199	389	729	3150	-72.7	-87.7
26.01	211	525	404	2401	-47.7	-78.1
26.02	331	775	475	2818	-30.3	-72.5
27.01	182	395	406	4207	-55.2	-90.6
27.02	198	406	406	4042	-51.1	-89.9
28	278	517	1426	4983	-80.5	-89.6
29	567	710	3737	4679	-84.8	-84.8
30	1535	2094	1199	5006	28.0	-58.2
31	845	2584	950	5841	-11.0	-55.8
32	360	2067	200	1343	80.2	53.9
33	1702	11031	331	3249	414.3	239.5
34	2587	11041	179	3711	1345.1	197.5
35	19209	69860	221	62	8591.6	112577.7
36.01	4652	25561	61	455	7525.9	5517.8
36.02	2514	11006	194	1439	1195.8	664.8
37	1762	6392	729	2185	141.7	192.5
38	1860	11057	1682	6533	10.6	69.3
39.01	1668	9304	757	1947	120.4	377.9
39.02	4837	26301	373	959	1196.7	2642.5
Total	77206.2	221302.2	66654	146791		
Average	16%	51%				



Figure C.1. Traffic assignment results due to activity allocation estimated by QRS II model

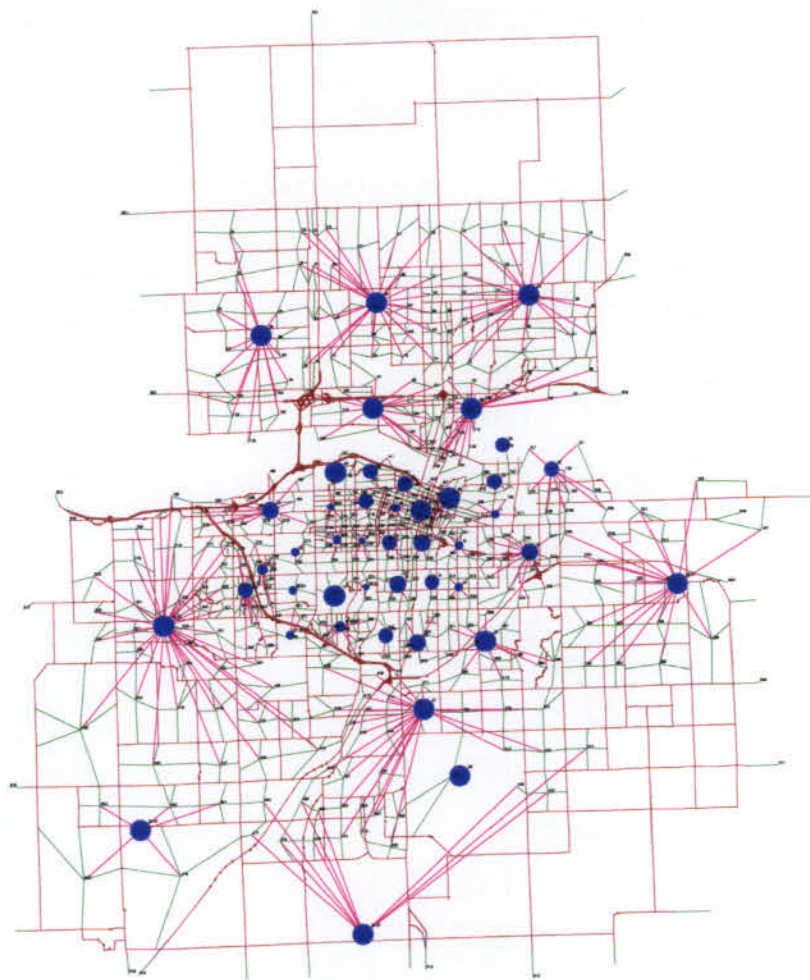


Figure C.2. Width plot of activity allocations in the districts

Table C.1 shows that the activity allocations in smaller inner census tracts were highly underestimated while the outlying larger ones were highly overestimated. Even Figure C.2 shows a similar trend. Thus, the results from the first attempt of activity allocation shows that areas with large developable areas, especially all outlying census tracts were assigned more activities as compared to inner census tracts close to the CBD area. Therefore, further calibrations are needed to

enable the model to depict the actual situation. However, even that initial attempt sheds some light that QRS II's activity allocation model can do a good job if good working data is available and proper calibration is performed.