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Urban Transportation Planning Decision Making: A Robustness Analysis Approach

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Chapter Three
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 the factors, may be reliability of software in providing reliable outputs, level of sophistication of the software and its user-friendliness, cost of software acquisition, input data demand and availability, etc.

For GIS software, several commercial ones which have been used widely include ArcInfo and ArcView developed by Environmental Systems Research Institute (ESRI, 2000), Maptitude and TransCAD developed by Caliper Corporation (Caliper, 2001), MapInfo developed by MapInfo Corporation (MapInfo, 2001) and MGE developed by Intergraph (Intergraph, 2001), etc.

For UTP software, several commercial ones which have been widely in use include QRS II developed by AJH and Associates (Horowitz, 2000), EMME/2 developed by INRO Consultants (INRO, 1998), TRANPLAN by Urban Analysis Group (Tranplan, 2001), and TMODEL 2 by TMODEL Corporation (TMODEL, 2001).

In this study, Maptitude was chosen as a GIS platform. The main reason was that it is the software available and used by Kansas Department of Transportation (KDOT). 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".

aptitude 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.

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The main reason for choosing QRS II is similar to that of choosing Maptitude, i.e., it is the software mainly used by KDOT and recommended by them for this project. Since QRS II was mainly developed as a "quick response", low cost and easy-to-use software, mainly for small and medium cities, it is highly suitable to most Kansas cities.

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 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 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 book, all "past future" projections made in previous studies were supposed to be compared with what actually took place. For example, projected population 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 of

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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, 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 with 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
The first task was to create a geographic file of TAZs similar to those of Report 74. 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. Traffic analysis zone boundaries were delineated and redefined to resemble those used in Report 74 by using the GIS's spatial analysis and manipulation capabilities and were easy to interactively delineate. The "Tools-Map Edit" command in Maptitude was used to redefine areas and modify the TAZs.

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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 a zone is split 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 attribute data is combined. Whenever one performs overlays or uses geographic editing, Maptitude uses this aggregation method

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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.

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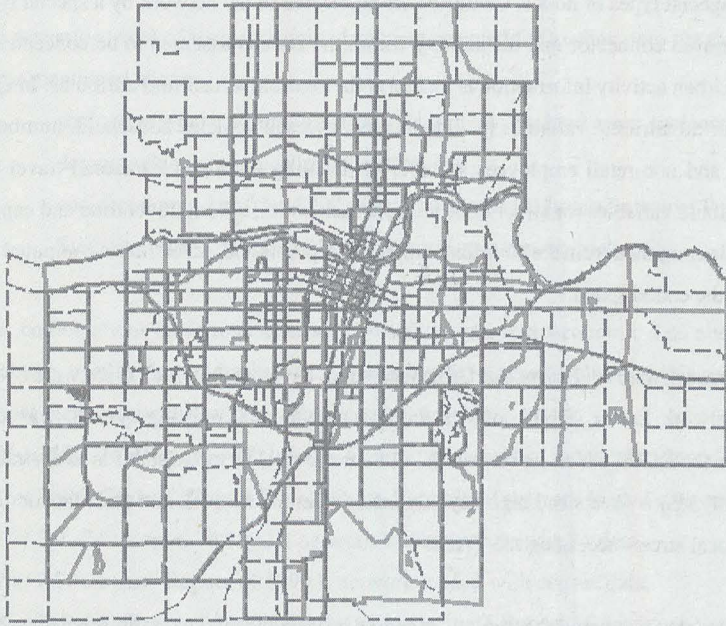
Key:

———————— Report 74 TAZs boundaries

– – – – 2000 TAZs boundaries

Figure 3.1. Topeka urban area map showing Report 74 TAZs superimposed on 2000 TAZs.

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:

- the existing 1974 network alternative with minimum development (in Report 74 was termed as Existing + Committed),

- 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),

- 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),

- the actual 2000 existing network as supplied by KDOT, and

- the actual network as it existed in 1990.

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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 in 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. Some of the major road links that differentiate the networks can be easily seen.
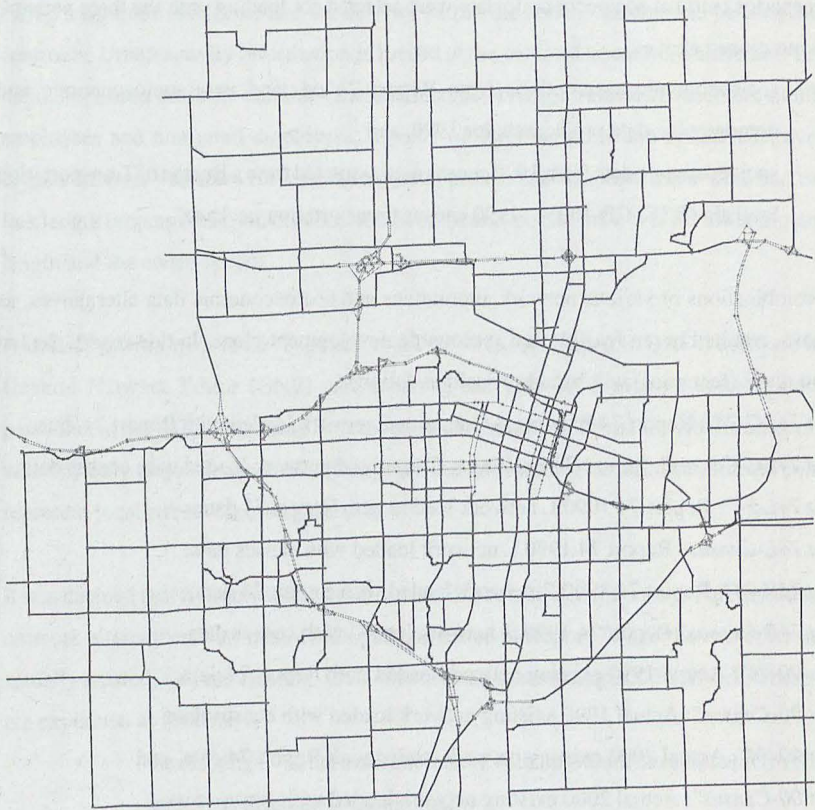
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Figure 3.2 Base highway network recommended in Report 74

The 2000 Topeka traffic network that was supplied by KDOT was modified so as to obtain the other four 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.
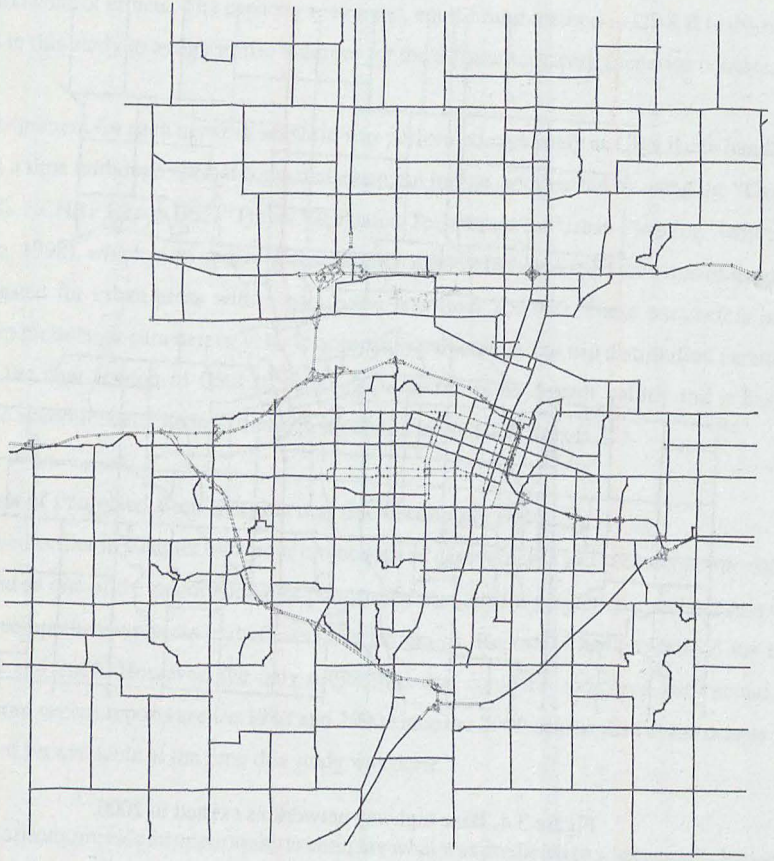
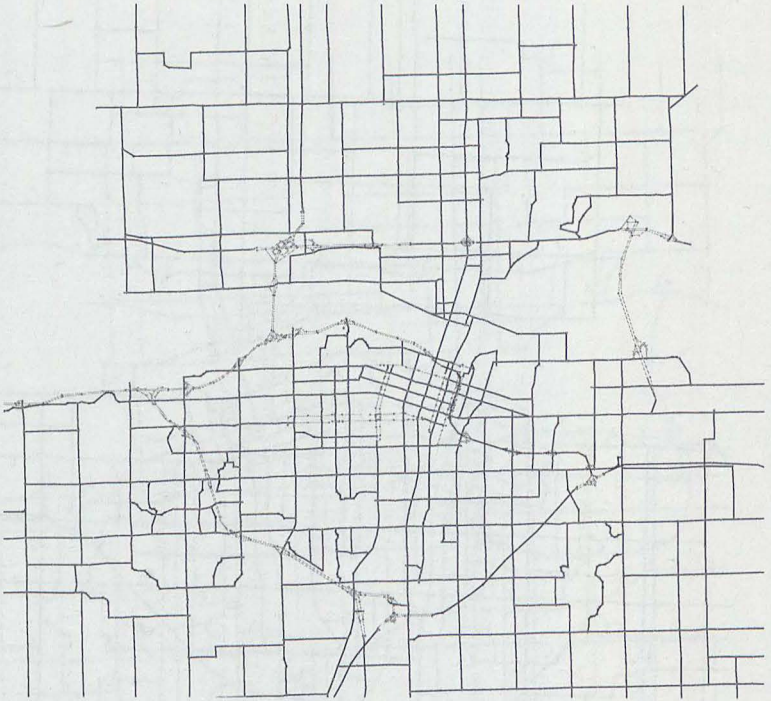Figure 3.3. Base highway network as existed in 1990

Figure 3.4. Base highway network as existed in 2000

3.3.2 Development of Alternate Traffic Assignments in QRS 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, poorly 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 come and passed. 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) include:

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- population,
- number of dwelling units (DUs),
- retail employment,
- non-retail employment, and
- average household income.

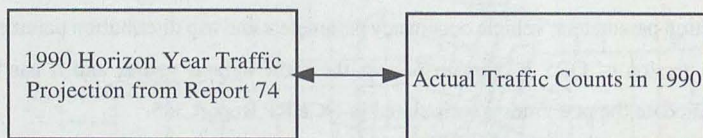The comparisons mentioned above are illustrated in Figure 3.6.

| 1990 Horizon Year Traffic Projection from Report 74 | ⟷ | Actual Traffic Counts in 1990 |

Figure 3.5. Symbolic comparison of projected traffic volumes vs. actual ground traffic counts

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.
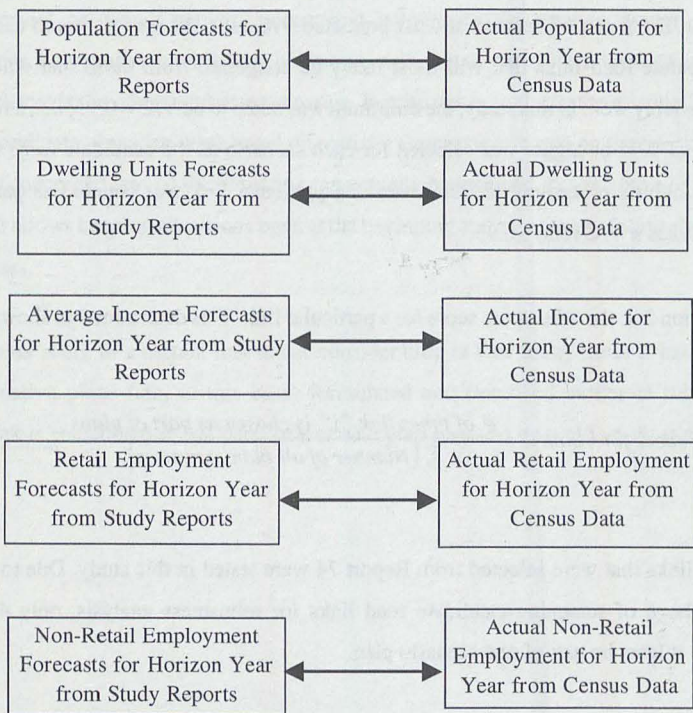
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Population Forecasts for Horizon Year from Study Reports	⟷	Actual Population for Horizon Year from Census Data
Dwelling Units Forecasts for Horizon Year from Study Reports	⟷	Actual Dwelling Units for Horizon Year from Census Data
Average Income Forecasts for Horizon Year from Study Reports	⟷	Actual Income for Horizon Year from Census Data
Retail Employment Forecasts for Horizon Year from Study Reports	⟷	Actual Retail Employment for Horizon Year from Census Data
Non-Retail Employment Forecasts for Horizon Year from Study Reports	⟷	Actual Non-Retail Employment for Horizon Year from Census Data

Figure 3.6. Symbolic comparison of projected socioeconomic data vs. actual data

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) predicted the possibility of being congested at the horizon year. So, it can be debated at what predicted V/C-ratio the analyst has to use as a cut-off point to separate road links that will most likely be congested from those that will most likely perform relatively well. In this study, the minimum was taken to be V/C = 0.95, i.e., a road link with a V/C-ratio of 0.95 or higher was selected for each scenario as the candidate to be tested by the robustness analysis procedure. In other words, a particular link was counted as part of a given scenario if it has a V/C ratio ≥0.95.

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

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

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 confident one is that an improvement is in order under any circumstances.

The robustness procedure does not choose a scenario that seems to be optimum, but simply keeps open all scenarios that seem to have possibilities. 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 viable alternative plans (ten, in this case) 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.