Winter 2003

Application of Robustness Analysis for Developing a Procedure for Better Urban Transportation Planning Decisions

Deogratias Eustace
University of Dayton, deustace1@udayton.edu

Eugene R. Russell
Kansas State University

E. Dean Landman
Kansas State University

eCommons Citation

Eustace, Deogratias; Russell, Eugene R.; and Landman, E. Dean, "Application of Robustness Analysis for Developing a Procedure for Better Urban Transportation Planning Decisions" (2003). *Civil and Environmental Engineering and Engineering Mechanics Faculty Publications*. 6.
https://ecommons.udayton.edu/cee_fac_pub/6

Application of Robustness Analysis for Developing a Procedure for Better Urban Transportation Planning Decisions

---

This paper shows that robustness analysis is a technique with a potential for aiding decision makers in choosing transportation investment projects. In this paper, it has been demonstrated that it 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 future options that currently seem attractive. The results of the robustness analysis from the case study used in this paper 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 is needed to be taken under conditions of uncertainty. A general framework to be used in such cases is proposed.

by Deogratias Eustace, Eugene R. Russell, Sr., and E. Dean Landman

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 good results. According to Marshment (2001), the most notable setback is a lack of coordination between land use and transportation planning agencies. Most of the time, land use plans are not coordinated with transportation plans.

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 uncertainty conditions, to make early decisions in a time-phased sequence that preserves more future options.

Since transportation forecasting is full of uncertainties, the robustness technique emphasizes the need to leave all alternatives considered viable to be open, minimizes the possibility of surprises, and allows early decisions in a time-phased sequence that still keep those viable alternatives as options. Robustness analysis, unlike the traditional optimization techniques currently in use in long range transportation planning decisions, can increase the flexibility and minimize the uncertainties of the planning

Journal of the Transportation Research Forum. Published in *Transportation Quarterly*,
Vol. 57, No. 1, Winter 2003 (107–121). © 2003 Eno Transportation Foundation, Inc., Washington, DC.

process, which can lead to better and more reliable decision making.

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 road projects in west Topeka, Kansas, before the West Ridge Shopping Center was conceived, were grossly understated. This development, which was not originally anticipated, greatly changed the land use and travel patterns of the area. Even though the best information available at the time was used in making the forecast, the result could be either a costly over or under design. The professional transportation community has been quite concerned about the quality of traffic forecasting data that is used as a basis for multi-million dollar investment decisions.

This paper attempts to formulate a procedure that increases the flexibility and minimizes the uncertainties of the transportation planning process and thus reduces the risk level. The Topeka Kansas Metropolitan Area was selected as the study area. Current information shows that the city has a population of 123,993 and the Metropolitan Statistical Area (MSA) has a population of 165,400 (Topeka Chamber of Commerce 2001). Topeka is the capital of the state of Kansas. Two major interstates, I-70, a west-east highway, and I-335, merge at Topeka, and with I-470 form a ring around the city.

LITERATURE REVIEW

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, note 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.

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

Rosenhead (1980a) points out that the most influential and common methodology of planning is rational comprehensive planning. In this approach a decision maker establishes an agreed 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 values.

Therefore, rational comprehensive planning does not handle 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 designated as "optimal."

Future Predictions (Forecasting) and Decision Making

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. The poor predictability of the future and of the impact of alternatives is very general and common.

Van Zuylen et al. (1999) report 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 filled in, which result 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. This approach is useful if there is a fair amount of certainty that the different scenarios that are used cover the entire range of possible futures. A similar approach is to look for a strategy that reduces the maximum risk for all scenarios; the robustness of a decision can be tested with the help of scenarios. 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-Loustainau and Sussman 1999).

Decision Making for Flexible Future Forecasting. Van Zuylen et al. (1999) mention five specific methods of decision making that they believe provide a specific way to deal with 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
- developing and using better forecasting models

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 to solving transportation investment problems.

Rosenhead (1980b) argues that a planning process should be nonoptimizing, and be based on establishing a set of feasible solutions. He continues to add that planning should accept the uncertainty of future states, attempt to keep options open, and aim at a loose fit on the planned activities. Robustness analysis is a technique that seems to have potential in aiding decision makers in choosing investment projects and is discussed in detail in the following section.

Robustness Analysis

"Robustness", and analysis based on it, embodies a particular perspective on flexibility (Khisty and Sriraj 1999; O'Sullivan et al. 1979; Rosenhead 1980b; 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 that could be made, and they will be compared in terms of the possible future commitments with which they appear to be compatible (Rosenhead 1989a).

Gupta and Rosenhead (1968) and Rosenhead et al. (1972) first applied the idea of robustness as a decision criterion to industrial plant location. 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 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 envisaged 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."

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 an 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 nonoptimizing, and be based on establishing a set of feasible solutions. It should accept the uncertainty of future states, keep options open, and aim at a loose fit for the planned activities. Rosenhead (1980b) notes further that there is no single, unique methodology for flexible planning, or even for robust planning.

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 the decision 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 (1) (Khisty and Sriraj 1999; Rosenhead 1989a; Rosenhead et al. 1972):

$$(1) \quad r(d_i) = \frac{n(S_i)}{n(S)}$$

Where:

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

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

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

Equation (1) defines the robustness of an initial planning decision. However, in transportation planning the analyst normally sets several planning horizons such as opening horizon (opening year), short-term horizon (normally five years), mid-term horizon (usually 10 years), and long-term horizon (20-30 years). Robustness tests can be applied for different planning horizons to identify which road links in the network are likely to become congested first. Therefore, the analyst can address the anticipated network problems at different planning horizons depending upon the robustness outcomes.

Robustness analysis provides an approach to the structuring of transportation problems where uncertainty is high and where sequential time-phased, decision making is necessary. Robustness analysis is a technique, which emphasizes the need—under conditions of uncertainty—to make early decisions in a sequence to preserve many future options that currently seem attractive (Khisty and Sriraj 1999; Rosenhead 1989a).

Traditional Procedure Used in Urban Transportation Planning

In traditional transportation demand modeling (TDM), it is usual to develop one or more sets of future socioeconomic, demographic, and land use assumptions and combine them with various highway network alternatives in order to select the one that seems to be the "optimum" or the "best" scenario. Under this approach, comparison and evaluation of network alternatives is normally done by use of vehicle miles of travel (VMT) as the measure of effectiveness (MOE), (Johnson et al. 1974). The scenario whose network alternative minimizes the study area VMT (an optimization technique) is normally selected over other scenarios. The long-range urban transportation planning for the projected future (20 to 30 years) will normally be planned based on the selected scenario, and the other scenarios are then discarded.

STUDY METHODOLOGY

Traffic Networks Development in QRS II Software

A street network of the Topeka Urban Area, developed in QRS II software by use of the General Network Editor (GNE), and depicting the current network situation, was created by personnel in the KDOT Bureau of Transportation Planning. As usual for most urban transportation planning (UTP) models, this is an abstract network whereby only major streets and highways are included in the network and local streets are replaced by centroid connectors that represent local streets accessing the traffic analysis zones (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 the earlier planning study (Johnson et al. 1974), which will hereby be referred to as "Report 74") that makes projections for 1990, and the two other networks that actually existed, i.e., the existing 1990 network and the existing 2000 network. The five alternatives are explained as follows:

1. The existing 1974 network alternative with minimum development assumed (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 (referred to as 1990.L in Report 74)
3. The network alternative that was recommended and selected in Report 74 that made projections for 1990 (in this case, Highway US-75 bypass was connected to I-470 in the vicinity of Burlingame Road and was referred to as 1990.R)
4. The actual 2000 existing network as supplied by KDOT

5. The actual network as it existed in 1990

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

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

Therefore, combinations of various network alternatives and socioeconomic data alternatives, as outlined above, resulted in 10 feasible and reasonable development plans. In this report, the 10 development plans (scenarios) will be abbreviated as follows:

1. *Net 74EC-74*—Report 74 Existing + Committed network loaded with Report 74 socioeconomic data
2. *Net 74EC-Census*—Report 74 Existing + Committed network loaded with 1990 census data
3. *Net 74L-74*—Report 74 1990.L network loaded with Report 74 socioeconomic data
4. *Net 74L-Census*—Report 74 1990.L network loaded with 1990 census data
5. *Net 74R-74*—Report 74 1990.R network loaded with Report 74 socioeconomic data
6. *Net 74R-Census*—Report 74 1990.R network loaded with 1990 census data
7. *Net 90-74*—Actual 1990 existing network loaded with Report 74 socioeconomic data
8. *Net 90-Census*—Actual 1990 existing network loaded with 1990 census data
9. *Net 00-74*—Actual 2000 existing network loaded with Report 74 socioeconomic data
10. *Net 00-Census*—Actual 2000 existing network loaded with 1990 census data

The 2000 Topeka traffic network that was supplied by KDOT was modified 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.

The Use of Robustness Analysis to Develop a Decision Criterion

In this study, robustness analysis was 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 (1) was modified to suit 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.

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 considered in the original study (Report 74) that were the result of a one-year analysis done by the Topeka Area Planning Study (TAPS) Committee (Johnson et al. 1974).

QRS II software was used to perform the four-step process of the travel demand modeling. The traditional four-step sequential process of the travel demand model includes: (1) Trip generation—predicts the number of person trip ends that are generated by and attracted to each defined traffic analysis zone (TAZ) 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 (modal split)—determines the modes that will be used to travel on each zonal interchange; and (4) Trip (traffic) assignment—assigns trips to specific highway or transit routes. Travel demand software, like QRS II, performs the four steps automatically and computes the final traffic volumes assigned to particular routes.

For this research study, traffic volumes projected for each scenario were generated as the outputs of the trip assignment model. From trip assignment results, links that had high volume-capacity ratios (V/C ratios) predicted the possibility of being congested at the horizon year (the future year that the projections are made for—1990 in this case). It can be debated at what predicted V/C-ratio the analyst should use as a cut-off point to separate road links that will most likely be congested from those that will probably perform relatively well. In this study, the minimum was taken as 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.

About 115 links that were selected from Report 74 were tested in this study. Using the criterion described above for screening candidate road links for robustness analysis, 43 road links were included in at least one scenario plan.

Using the general robustness analysis formula, Equation (1), the robustness score for a particular link "i" is determined as shown in Equation 2.

$$(2)\quad \textit{Robustness score for (Link i)} = \frac{\textit{\# of times link "i" is chosen as part of plans}}{\Sigma\ (\textit{Number of all plan scenarios})}$$

Usage of Robustness Scores. After the travel demand modeling outcomes are obtained, robustness analysis can be applied. The robustness scores were used to assess the road links needed to be given priority for construction, expansion, or to be upgraded to higher standards. Therefore, the higher the robustness score for a particular link in the network the more important the link is, thus its priority should be higher.

The robustness procedure does not choose a scenario that seems to be optimum, but simply keeps all scenarios, which seem to be possible candidates "open." All links that were proposed in Report 74 to be constructed or improved or widened were included as viable options for all network scenarios considered.

In this case, the viability of a link to be given a priority in terms of improvement does not depend on which network scenario includes it. 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, depending on the best knowledge of the planners concerned, any of the scenarios can actually happen, and none have to be discarded. It allows keeping all options open at the beginning and keeping the "doors open" for any changes when the need arises in the future.

The robustness score of a certain link under consideration is how many times it has been part of the 10 viable alternative plans formulated. A particular link is considered to be "part" of a certain plan scenario if its V/C-ratio is at least 0.95.

ANALYSIS AND DISCUSSION OF RESULTS

Robustness Analysis Results

Planners who prepared Report 74 expected that the socioeconomic-demographic and land use projections they made would materialize in the horizon year, 20 years later. In fact, the projected future for 1990 in Report 74 did not materialize. Of the 115 road links proposed in Report 74 for future development, only 43 received at least a minimum robustness score.

As in the traditional optimization procedure, after one highway network alternative was selected, other "candidate" alternatives were discarded and there was no procedure for going back to determine if there was any validity or realism among the other alternatives which were not selected. In order to make the methodology more flexible and responsive to future changes, the authors believe that the robustness methodology has great utility, by 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 future or will be closest to actual future conditions.

Robustness Scores for Individual Road Link Segments. The special methodology used to estimate an individual link's robustness score has been explained earlier. The way this methodology was used is explained in detail below using an example. A road link was considered to be included in the analysis, i.e., it needs future attention if the projected volume is at least 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 45th Street and 44th Street as follows:

1. For the NET 74EC-74 alternative, the link's $V/C \geq 0.95$, its score is 1
2. For the NET 74EC-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

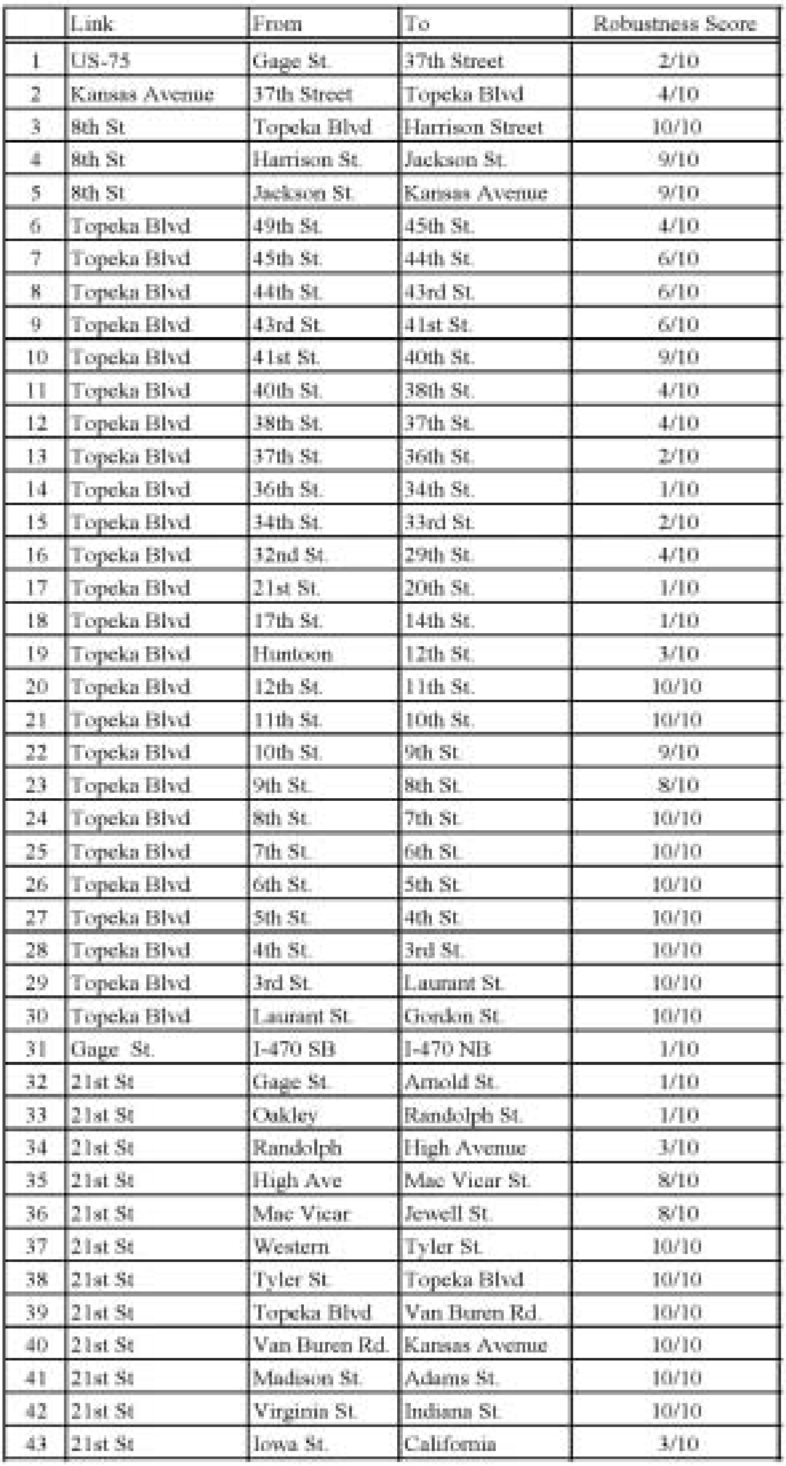
Therefore, the ultimate or final robustness score for the Topeka Boulevard link between 45th Street and 44th Street was obtained by adding together the above individual scores ($1 + 0 + 1 + 0 + 1 + 0 + 1 + 1 + 1 + 0 = 6$) and dividing the total by the number of alternatives considered (in this case, 10). 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 1. Again, the robustness score of a link is the sum of individual "1" and "0" scores obtained from each alternative, depending on whether its V/C-ratio is greater or lower than the cut-off point (0.95), divided by the number of all plan scenarios formulated in this paper.

Discussion of the Robustness Analysis Results

Several important road segments/corridors that were widened or improved during the

Table 1: Robustness Scores for Individual Road Links



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

period between 1974 and 1990 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 central business district (CBD), link segments in the vicinity of the CBD, and links that connect the northern part of the urban area with the CBD, all have high scores relative to other road links. Also, the robustness scores obtained for most of its link segments equally justify the proposed widening of 21st Street in Report 74, a west-east major arterial. Robustness analysis could be an important first step in the planning decision sequence whereby important links that should be given immediate attention or a high priority are identified, for possible further action. Other considerations, like financial and budgetary constraints can then be checked to determine which links among those given are high priorities by the robustness analysis scores, fit within existing financial constraints or are critical to current traffic flows and may require immediate attention.

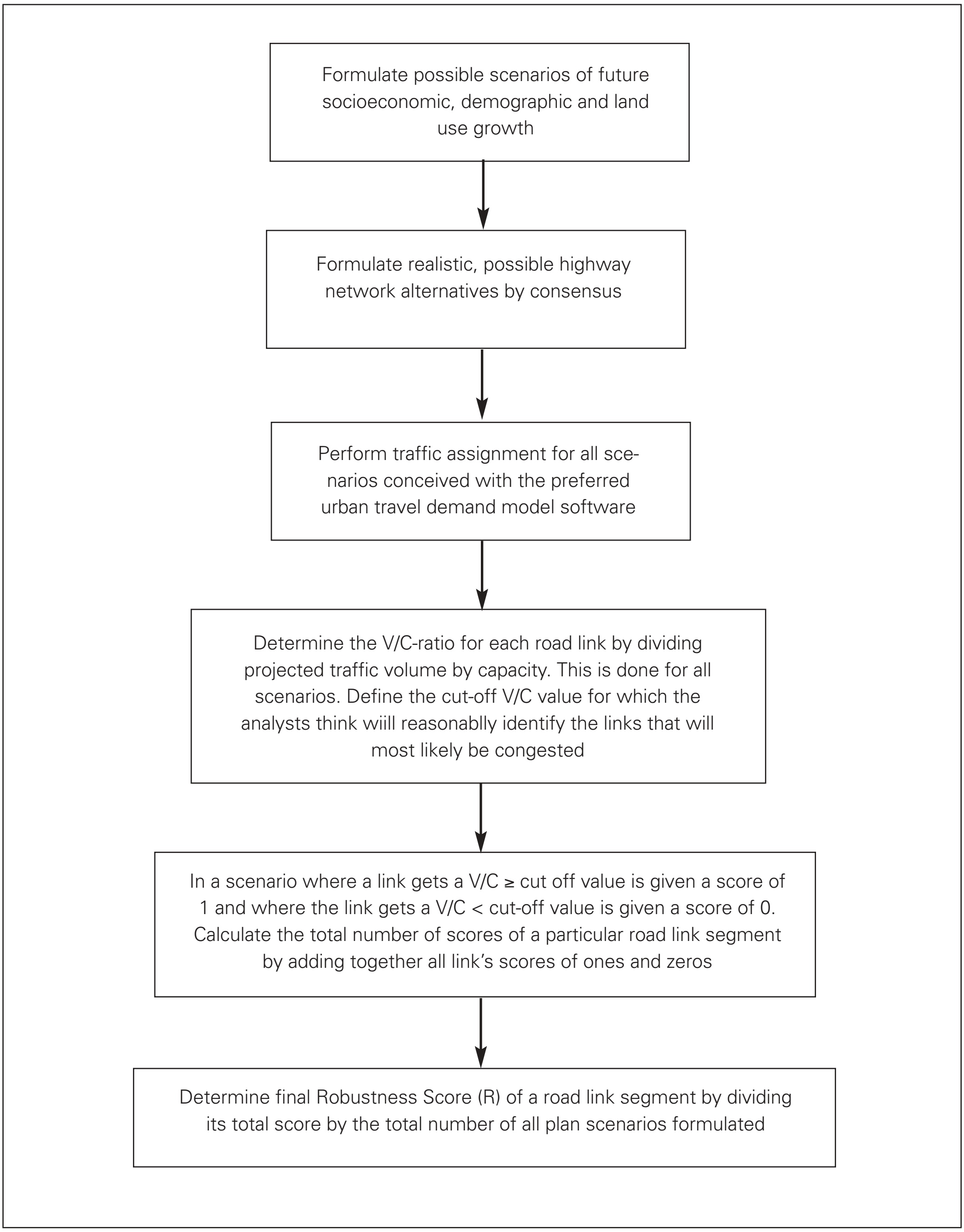
Proposed Framework for Robustness Analysis in Transportation Planning Decisions

The success of the procedure being developed here, as in all cases of travel demand modeling, depends highly on the accuracy of input data, realistic development and growth assumptions, and scenarios to be tested. It is strongly recommended that substantial time should be taken by both transportation planning and urban planning personnel to agree on a significant number of possible future growth scenarios.

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 1.

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. Brainstorming 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 the scenario combinations formulated in steps 1 and 2 above. It is best to concentrate on a list of a manageable number of 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 dividing traffic volume 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 the road link may experience congestion at the projected horizon year and thus requires some improve-

Figure 1: Proposed Flowchart of the Robustness Analysis Procedure in Transportation Planning Decision Making



ments 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, sum the ones and zeros to get its total score. These score calculations can be presented mathematically in Equation (3) as follows:

$$\left.\begin{array}{l} score = 1, \text{if } \frac{V}{C} \geq x \\ \\ \text{score} = 0, \text{if } \frac{V}{C} < x \end{array}\right\} \quad (3)$$

Where:
V/C = volume to capacity ratio
x = cut-off value of V/C ratio

6. Finally, the robustness score of the link is determined by dividing the total score obtained in step five above by the total number of scenarios. Note that the total score cannot be higher than the number of scenarios. This relationship can also be presented mathematically as shown in Equation (4) below.

$$R = \frac{\sum_{i=1}^{N} \text{scores}}{N} \quad (4)$$

Where:
R = robustness score for a particular link,
Σscores = sum of all scores for a particular link obtained by adding all ones and zeroes obtained over all scenarios, and
N = the number of planning scenarios.

The denominator (N) of Equation (4) is necessary since the number of planning scenarios may differ for various analysts. The last step is to 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, regardless of the future possible decision path. Figure 1 shows the proposed framework flowchart.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

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

- It has been observed that selecting an alternative by optimization procedures, which pick only the alternative thought to be best in terms of the measures of effectiveness chosen has many shortcomings, the most notable one is lack of flexibility by assuming the selection is deterministic by nature.
- Robustness analysis has been shown to be an efficient method 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.
- The robustness analysis can 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 traditional method of optimization, whereby one highway alternative is selected based on the outcome of the measures of effectiveness should be discouraged. The new paradigm being advocated here is the application of robustness analysis, without optimization. This makes the decision process flexible by letting all assumed scenarios contribute to the final decision.

Recommendations

- It is recommended that the robustness analysis be tested further in this area of urban transportation planning decision making as it seems to have great potential.

The whole planning process contains uncertainties which the robustness methodology can minimize by reducing the possibility of poor decisions based on a single scenario that does not materialize.

References

Best, G., G. Parston, and J. Rosenhead. "Robustness in Practice: The Regional Planning of Health Services." *Journal of the Operational Research Society* 37(5) (1986): 463-78.

Caplin, D. A. and J. S. H. Kornbluth. "Multiple Investment Planning Under Uncertainty." *Omega 3* (1975): 423-41.

Friend, J. K. and W. N. Jessop. "Local Government and Strategic Planning." Tavistock Publications, London, 1969.

Goetz, A. R. and J. S. Szyliowicz. "Revisiting Transportation Planning and Decision Making Theory: The Case of Denver International Airport." *Transportation Research*. Part A 31(4) (1997): 263-280.

Gupta, S. K. and J. Rosenhead. "Robustness in Sequential Investment Decisions." *Management Science* 15(2) (1968): B18-B29.

Johnson, Brickell and Mulcahy. *Consulting Engineers. 1990 Transportation Plan: Topeka Area Planning Study.* Topeka-Shawnee County Metropolitan Planning Commission (1974).

Khisty, C. J. and P. S. Sriraj. "Transportation Project Selection Through Robustness Analysis for Developing Countries." *Transportation Research Record* 1695, TRB, National Research Council, Washington, DC (1999): 24-48.

Marshment, R. *Transportation Planning Challenges and Opportunities*. http://www.nationalacademies.org/trb/publications/millenium/00129.pdf. Accessed on March 28, 2001.

McDowell, J. J. "Traffic Forecasting Models for Transportation Plans: How Successful Have They Been?" *Institute of Traffic Engineers Proceedings,* Imprint: New York, NY (1972): 3-7.

Mierzejewski, E. A. "Recognizing Uncertainty in the Transportation Planning Process." *65th ITE Annual Meeting Compendium of Technical Papers* (1995): 343-356.

Munoz-Loustainau, A. and J. M. Sussman. "Scenarios and Regional Strategic Transportation Planning." *Transportation Research Record* 1685, TRB, Washington, DC (1999): 91-98.

O'Sullivan, P., G. D. Holtzclaw, and G. Barber. *Transportation Network Planning*. Croom Helm, London, 1979.

Rosenhead, J., M. Elton, and S. K. Gupta. "Robustness and Optimality as Criteria for Strategic Decisions." *Operational Research Quarterly* 23(4) (1972): 413-431.

Rosenhead, J. "An Education in Robustness." *Journal of the Operational Research Society* 29, (1978): 105-111.

Rosenhead, J. "Planning Under Uncertainty: I. The Inflexibility of Methodologies." *Journal of the Operational Research Society* 31(4) (1980a): 209-216.

Rosenhead, J. "Planning Under Uncertainty: II, A Methodology for Robustness Analysis." *Journal of the Operational Research Society* 31(4) (1980b): 331-341.

Rosenhead, J. "Robustness Analysis: Keeping Your Options Open." J. Rosenhead Ed. *Rational Analysis of Problematic World: Problem Structuring Methods for Complexity, Uncertainty and Conflict.* John Wiley & Sons, Chichester, UK (1989a): 193-218.

Rosenhead, J. "Robustness to the First Degree." J. Rosenhead Ed. *Rational Analysis of Problematic World: Problem Structuring Methods for Complexity, Uncertainty and Conflict.* John Wiley & Sons, Chichester, UK (1989b): 219-238.

Skamris, M. K. and B. Flyvbjerg. "Accuracy of Traffic Forecasts and Cost Estimates on Large Transportation Project." *Transportation Research Record* 1518, TRB, National Research Council, Washington, DC (1996): 65-69.

Souleyrette, R. R., Z. N. Hans, W. L. Garrison, and L. Wazny. "Analysis of Trends Underlying Urban/Regional Impacts of Traffic Growth." *Journal of Urban Planning and Development,* ASCE (1995): 158-171.

Topeka Chamber of Commerce. Topeka Metropolitan Area Facts. http://www.topekachamber.org/quality/demographics.shtml. Accessed on April 27, 2001.

Van Zuylen, H. J, M. S. van Geenhuizen, and P. Nijkmap. "Unpredictability in Traffic and Transport Decision Making." *Transportation Research Record* 1685, TRB, National Research Council, Washington, DC (1999): 21-28.

***Deogratias Eustace** is a transportation engineer with the URS Corporation, Tallahassee, FL office. He holds a Ph.D. in Transportation Engineering from Kansas State University, a BSc (Eng.) honors degree, and a MSc (Eng.) degree from the University of Dar-Es-Salaam, Tanzania. His professional interests are urban transportation planning, travel demand modeling, transportation safety, and sustainable transportation.*

***Eugene (Gene) R. Russell** is a professor of Civil Engineering at Kansas State University(KSU). He holds the Mark and Margaret Hulings Chair in Engineering. He is director of the Center for Transportation Research and Training (CTRT) and also Directs the Traffic Assistance Services for the Kansas (TASK) project that develops short courses, handbooks, and manuals for local (county, small city, town) persons involved in low-volume road safety, such as the popular* Handbook of Traffic Control Practices for Low-Volume Rural Roads, *which is now being updated to a third edition, and* Guidelines for the Use of Guardrail on Low-Volume Roads. *At KSU he has been director or co-director of more than 70 highway research projects and has authored or coauthored more than 100 papers and technical reports. Prior to joining KSU, Russell was a research associate for Purdue's Highway Extension and Research Project for Indiana Counties (HERPIC). He has a Ph.D. from Purdue in Urban Planning, an M.S. from Iowa State University in Soils Engineering, and a C.E. degree from the University of Missouri-Rolla. Early in his 43-year career in Highway Engineering, he worked for state highway departments in Illinois, California, and Iowa.*

***E. Dean Landman** is an adjunct professor in Civil Engineering at Kansas State University. He retired from the Kansas Department of Transportation with 34 years of service in the Division of Planning and Development. He headed the urban planning unit, supervising the development of long range transportation plans for the metropolitan areas of Kansas. He then headed the planning function for all modes when the agency became a department of transportation. After that he was mainly involved in statewide policy planning until he retired. Landman has both his bachelor's and master's degrees in Civil Engineering from Kansas State University. He has authored or co-authored a number of articles relating to urban planning.*