2006-36

Final Report

Beyond Business as Usual: Ensuring the Network We Want Is the Network We Get

Research

Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
MN/RC-2006-36		
4. Title and Subtitle		5. Report Date
Beyond Business as Usual: Ensuring the Network We Want is the Network We Get		September 2006
		6.
7. Author(s)		8. Performing Organization Report No.
David Levinson, Norah Montes de Oca, Feng Xie		
9. Performing Organization Name and Address		10. Project/Task/Work Unit No.
Department of Civil Engineering University of Minnesota 500 Pillsbury Dr S.E., Room 122 Minneapolis, MN 55455		11. Contract (C) or Grant (G) No. (c) 81655 (wo) 141
12. Sponsoring Organization Name and Address		13. Type of Report and Period Covered
Minnesota Department of Transportation Office of Research Services 395 John Ireland Boulevard Mail Stop 330 St. Paul, Minnesota 55155		Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes		
http://www.lrrb.org/PDF/200636.pdf		

16. Abstract (Limit: 200 words)

This research, extending the Mn/DOT-funded project *If They Come, Will You Build It*, assesses the implications of existing trends on future network construction. It compares forecast networks (using models estimated on historical decisions developed with previous research) under alternative budget scenarios (trend, above trend, below trend), with networks constructed according to alternative sets of decision rules developed with Mn/DOT and Metropolitan Council staff. The comparison evaluates alternative futures using a set of performance measures to determine whether the network we would get in the absence of a change in policies (allowing historical policies to go forward) outperforms or underperforms the networks developed by applying suggested decision rules. This evaluation methodology enables new decision rules for network construction (building new links or widening existing links) to be tested. The research suggests a path beyond "business as usual".

This research incorporates results from the different scenarios tested. It presents the processes, approaches and development to encode historical decision rules. After analyzing flowcharts developed from the interviews of staff at different levels of government, if-then rules are generated for each jurisdiction. This research then describes the details and processes necessary to run the network forecasting models with various decision rules. Results for different scenarios are presented including adding additional constraints for the transportation network expansion and calibration process details. A comparison and analysis between scenarios is made in order to provide a final conclusion on what scenario will produce the greatest benefit for the Twin Cities Metropolitan Area Transportation Network.

17. Document Analysis/Descriptors		18.Availability Statement	
transportation planning, travel demand modeling,	forecasting, network growth	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	206	

Beyond Business as Usual:
Ensuring the Network We Want Is the Network We Get

Final Report

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September 2006

Published by:
Minnesota Department of Transportation
Research Services Section
395 John Ireland Boulevard, MS 330
St. Paul, Minnesota 55155-1899

Acknowledgements

The project that supported this research was funded by MnDOT, and was the collaborative work of several individuals in addition to the authors. The crash rate model was developed with Kit Lim, and is described in Appendix 3. Shanjiang Zhu also aided with the programming and running of the models.

Special mention goes to all Mn/DOT managers, directors, engineers, county engineers and staff from all jurisdictions as well as Metropolitan Council Coordinators that make this research possible through interviews, opinions and suggestions. Mark Filipi at the Metropolitan Council was instrumental for his willingness to provide fundamental data for this research. A recognition to all county budgeting and accounting departments, John Williams from the Minnesota House of Representatives Research Department, as well as John Jernberg from the Office of the State Auditor for providing important data for this research. Also a recognition to the Technical Advisory Panel: Rabinder Bains, Paul Czech, Edward Idzorek, Clark Moe, Brian Gage, Lezlie Vermillion, Lynn Moratzka, Gene Franchett and Todd Graham for their valuable suggestions and comments.

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Executive Summary

This research, extending the Mn/DOT-funded project *If They Come, Will You Build It*, assesses the implications of existing trends on future network construction. It compares forecast networks (using models estimated on historical decisions developed with previous research) under alternative budget scenarios (trend, above trend, below trend), with networks constructed according to alternative sets of decision rules developed with Mn/DOT and Metropolitan Council staff. The comparison evaluates alternative futures using a set of performance measures to determine whether the network we would get in the absence of a change in policies (allowing historical policies to go forward) outperforms or underperforms the networks developed by applying suggested decision rules. This evaluation methodology enables new decision rules for network construction (building new links or widening existing links) to be tested. The research suggests a path beyond "business as usual".

This research presents the processes, approaches and development of encoding historical decision rules. After analyzing flowcharts developed from the interviews of staff at different levels of government, if-then rules are generated for each jurisdiction. It then describes the details and processes necessary to run the network forecasting models with various decision rules. Results for different scenarios are presented, including adding additional constraints for the transportation network expansion and calibration process details.

A graphical comparison and descriptive analysis between scenarios is made in order to conclude which scenario will produce the greatest benefit for the Twin Cities Metropolitan Area Transportation Network.

The following scenarios are tested:

1) Baseline: Stated Decision Process to all counties for existing links.

2) Most structured decision rules (Hennepin County rules) in all counties

3) Least structured decision rules (Scott County rules) in all counties

4) Budget changes (a) +100%, (b) +200% and (c) +400% (d) -10% and (e) -25%.

5) Change split between budget expansion and new construction to 75-25.

6) Revealed Decision Process: Levinson-Karamalaputi (LK) model for expansion and new construction (with only legacy links available for new construction).

7) Revealed Decision Process: Levinson-Karamalaputi (LK) model for expansion and new construction (with full set of potential new links available for new construction).

Table: Differences Between Scenarios

Scenario	Expansion Decision Rules	New Construction Decision Rules	Total Budget	Expansion Construction Budget Split	New Link Choice Set
1	Stated	Revealed	Standard	50/50	Legacy
2	Most structured	Revealed	Standard	50/50	Legacy
3	Least structured	Revealed	Standard	50/50	Legacy
4	Stated	Revealed	Reduced, Expanded	50/50	Legacy
5	Stated	Revealed	Standard	25/75	Legacy
6	Revealed	Revealed	Standard	50/50	Legacy
7	Revealed	Revealed	Standard	50/50	All potential

This research finds that as the budget rises, the Vehicle Kilometers of Travel (VKT) rises. In the scenarios where the budget is expanded, the network expands, accessibility (the ability to reach destinations) increases, and consequently users will spend less time on the road (and system wide Vehicle Hours of Travel (VHT) declines).

One measure of effectiveness is the average travel time per trip. For 2030, Scenario 4c (with a 400% budget increase) provides the lowest trip time between all scenarios. It is around 8 minutes less per trips than Scenario 1 (base). Scenario 2 (with the most structured rules) provides 6 minutes less as well. Scenario 3 (with the least structured rules) and Scenario 5 (favoring new investment early on) have 5 minutes less than the base scenario. Similarly, by 2030 all scenarios provide less vehicle hour travel than the base scenario.

Scenario 4c (which increases the budget by 400%) provides the highest accessibility of all scenarios every period of time. Scenario 6 (Revealed decision rules) provides the least accessibility. The other scenarios were very similar to Scenario 1 (the base).

In the modeling process, we assumed that “legacy links”, (described in more detailed in Appendix B), those links that are on state plans but un-built would be built under almost every scenario (Scenario 7 excepted). Thus Highways 610 and 212 will be constructed in either 2005 (i.e., 2005-2009) or 2010 (i.e., 2010-2014).

Only one scenario provided freedom to construct new links that had not been pre-designated on plans (Scenario 7). It would be valuable to examine the kinds of changes to the network that might occur if more new construction could take place, and it were less confined to existing plans. The legacy links will soon be completed; it is unclear whether this means there will be no additional new links on the state network.

Additional research needs to take place to determine how budgets are allocated between expansions of existing links versus construction of new links.

Overall, one of the benefits of a modeling exercise such as conducted in this research is not simply the predictions, it is that the process, which requires coding decisions into a computer program in a logical way forces the specifications of all of the assumptions that are often expressed vaguely in typical spoken and written human communication. There are many parts of the decision-making process that are underspecified in written documents, leaving ambiguity and opportunities for special-case politics rather than systematic consideration and evaluation of decisions according to agreed upon principles.

This research finds that in order to provide a significantly better transportation network given the system's mature stage, there is a need for investment. A greater investment resulted in lower travel times and, as a result, higher accessibility. Specific decision rules applied to the network, given a fixed budget, only make marginal changes in network performance compared with changes in total investment.

1. Introduction

A core problem of transportation planning is to identify infrastructure projects in which to invest scarce resources to maximize the public good. Some agencies proactively develop comprehensive transportation plans to guide these decisions and to provide certainty for other agents in the urban system, others make decisions by reacting to evolving market conditions and travel demands. Whether or not there is a comprehensive plan describing the "final" state of the network, the timing of future investment decisions is rarely specified beyond the current (typically six-year) Capital Investment Program. Moreover, a plan does not often tell us more than where the center-lines of roads or other facilities might go, and perhaps the functional classification of those roads, generally it avoids details about the capacity and other operational characteristics of those roads.

The interaction of transportation and land use has been described as a positive feedback system. Transportation investments induce demand, including travelers making trips they previously avoided, making longer trips, switching modes, and rescheduling, but these investments have also been associated with encouraging development in corridors, and helping organize development over space. A population that demands transportation services occupies newly developed land, leading to further investments. As a result of these positive feedback processes, the sequence of investments matters greatly. An early investment in facilities in one corridor will encourage growth in that corridor, driving additional demand, to the detriment of investments in other corridors.

From the late 1950s through the 1980s, the Minnesota Department of Transportation (Mn/DOT) and other state transportation agencies focused primarily on the construction of the US Interstate Highway System. Mn/DOT relied on the nationally developed Interstate Plan and the locally developed Backbone System Plan to guide this effort (Transportation System Plan, 2001). After completion of the Interstate, focus shifted within transportation agencies throughout the country from large-scale capital-intensive investments to the improved management of a mature infrastructure and an increased concern for the environment.

Policy plans in the 1970s and 1980s aimed to complete the metropolitan Interstate Highway System. Because the system was smaller and still new, the focus on management and preservation in those plans was not nearly as great as today. By the mid-1990s, the excess roadway capacity built in previous decades was largely utilized, and problems with levels of congestion started to rise in the metropolitan area (Minnesota Department of Transportation, 2001) (Figure 2). According to Mn/DOT staff, over the last 10 years congestion has been the driving force for projects around the metro area. Non-recurring congestion has increased as well, and it was found that 13% of traffic crashes were secondary crashes from incident-related congestion (Minnesota Department of Transportation, Office of Traffic, Security and Operations, 2005). Without excess roadway capacity, safety issues rising in prominence, and some new budget constraints, the need for different planning strategies arose. Operations and management took pre-eminence over construction of new facilities.

One of the purposes of this work is to explore the different decisions made to select expansion, reconstruction and new construction projects.

Decisions for investing in infrastructure are complex and political as well as technical. These rules have changed over time, and like the networks they are supposed to shape, have matured. This research investigates the timing and location of transportation investments in the seven county Minneapolis-Saint Paul Metropolitan Area in Minnesota, and how those investments affect welfare.

Over time there has been no single criteria for selecting expansion and new construction projects. Safety issues, road conditions, and capacity are factors that were involved in the selection process. That process was at best informal. A County Engineer stated that in the past, "The way that pavement and preservation projects were selected depended on what road the county engineer drove and decided needed to be fixed. The department director would drive different roads and would say what to change. Decisions were not so difficult because the decision-making process was based more on how the system was perceived and there was little oversight of the process but trust in the engineers." Today, the Minnesota Department of Transportation (Mn/DOT)'s number one policy is to preserve the transportation system.

This research assesses the implications of existing and proposed network construction decision rules by comparing the networks across a set of performance measures (including, but not limited, to cost, accessibility, mobility, equity and reliability). It answers:

1. Will "business as usual" network construction decision rules produce desirable networks?

2. Will new decision rules produce improved networks?

3. How can the logic of network expansion and self-fulfilling prophecies be harnessed to produce networks consistent with planning vision?

This research incorporates models developed previously by the University of Minnesota research team. Working with Mn/DOT, Metropolitan Council staff and representatives of local government agencies, it develops ways of assessing the network (performance measures), derive existing decision rules, and develop proposed investment decision rules to grow the network in alternative (and hopefully desirable) ways. As part of this research, a simplified travel demand model is constructed, which provides a research platform on which alternative scenarios may be tested.

To illustrate the concept of a "decision rule", the SONG 1.0 model (Yerra and Levinson 2005) assumes that capacity will increase (decrease) by the ratio of link revenue (proportional to traffic) and link cost (proportional to link type and existing capacity). So if revenue exceeds costs, (say revenue = 1.1* cost) the link is expanded (say by 10%); if revenue is less than cost, the link shrinks. This simple rule, applied with some constraints, has been applied both to hypothetical grid networks and to the Twin Cities planning network, and produces an outcome that paints realistic patterns of historic network change (Zhang and Levinson 2003). Other historical decision rules have been developed as part of the Mn/DOT-funded project "If They Come, Will You Build It".

Those decision rules are positive in that they explain what has taken place. Planners would like a normative answer, what should be done? Simplistically, a normative decision rule might be to compute the benefit/cost ratio for every link, and expand links with the highest ratio. That is very complicated to do for large numbers of links (and for each link requires some assumption about every other link), so other simpler rules might be used. Expand links in fast growing areas. Expand links that are inexpensive to expand. However, various rules may be in conflict, some type of scoring system would need to be developed. The links with the highest scores, subject to a budget constraint, would be expanded or newly constructed.

Both sets of rules (positive and normative) can be coded into a network growth model,. Alternative resulting networks, using different normative decision rules can be compared with anticipated networks resulting from stated decision rules (developed from interviews with staff who “stated” what the process was).

Historical decision rules, that best reproduced observed results, such as estimated from a statistical model, can also be tested. The outcomes are compared against specific performance measures developed with Mn/DOT. These measures include cost, accessibility, mobility, equity, and reliability as well as other important indicators of the network's outcome.

This research extends an earlier project funded by the Minnesota Department of Transportation (Mn/DOT). In particular this research makes predictions about the construction of future projects, while the previous research examined historical data. That project, “If They Come, Will You Build It” (Levinson, Karamalaputi and Chen 2003) developed empirical models of existing link expansion and new link construction and examined the growth of a highway network based on the present and historical conditions of the network, traffic demand, demographic characteristics, project costs and budget. The effects of expanding a link on its upstream and downstream neighbors, as well as on parallel links, were also considered. The data span two decades (1980-2000) and consist of physical attributes of the network, their construction and expansion history and traffic levels on each of the links. An algorithm was developed to designate adjacent and parallel links in a large network. A non-linear cost model for new construction and highway expansion was developed for the Twin Cities Metropolitan Area. Results of a logit (and a mixed logit) model to predict whether a link would be expanded show that high capacity links are less likely to be expanded and a higher budget results in more links being expanded. Traffic drives expansion, however the rate of network expansion, has decreased over time. While there are differences by type of road, they are small, indicating that the model is reliable for general use. The new link construction (or link formation) problem predicts (using logit and mixed logit models) new highway construction based on the present conditions of the network, traffic demand, project costs and budget constraints. Results show that new links providing higher potential access are more likely to be constructed. As with link expansion, a higher budget results in more links being constructed, supporting the underlying economic theory. That historical model is tested along with newly developed decision rules to compare the performance of networks under those alternative assumptions.

Chapter 2 outlines the model, SONG 2.0, that is developed to simulate past and future network growth at the metropolitan level.

Chapter 3 defines the performance measures used as evaluation criteria for alternatives networks.

Chapter 4 presents the investment model component of SONG 2.0, including the budget model, budget allocation rules, cost model, and investment decision rules. The existing investment decision rules were developed as part of interviews with Mn/DOT, Metropolitan Council, and local government staff. Alternative decision rules are the product of discussion with Mn/DOT staff.

Chapter 5 shows the results of the analysis, both graphically as a map of where investments are predicted under a particular set of scenarios, as well as numerical summaries of performance.

Chapter 6 concludes and provides guidance for future investment procedures.

Several appendices are provided that give detail beyond what is presented in the main text. These are provided for completeness, and would be of interest to the technically inclined reader. In particular, Appendix 1 describes the travel demand component of SONG 2.0, a simplified version of a traditional four-step planning model, with an implementation of Stochastic User Equilibrium traffic assignment. This model is generally consistent with that used on previous research projects (e.g. the Mn/DOT funded project *Building Our Way Out of Congestion? Highway Capacity for the Twin Cities* by Davis and Sanderson 2003). Appendix 3 describes the crash rate model employed in this research.

2. Overview of System of Network Growth: SONG 2.

The framework for the System of Network Growth (SONG 2.0) model is shown in

Figure , which represents graphically the structure of the program**.** SONG is written in the Java programming language. It was developed collectively by the research team (David Levinson, Feng Xie, and Norah Montes de Oca), and is described here for completeness.

As with any transportation planning model, SONG 2.0 begins with initial network conditions, input land use and demographics, and model parameters. What distinguishes SONG from typical planning models is that the network structure in subsequent years is endogenous to the model. The travel demand model, detailed in Appendix 2, includes trip generation, trip distribution, and route assignment. The results of the travel demand model produce a flow pattern and measures of effectiveness.

These results are inputs to the investment process, which requires budget estimates (in part determined by vehicle distance traveled, as revenue depends on the gas tax), and the cost of potential links. The investment model ranks potential improvements (separately for the state and each county). The highest ranked projects are funded until the separate budgets are exhausted. Once there is no budget available, there is a leftover deficit for the next time period.

The projects will change the network topology, hierarchy, and capacity, which are updated endogenously. A new link information file is created for the next period of time and it is stored as a text file. This text file will be used as input for the following time period and so on. Updated land use for the next time period is introduced, and the time period is incremented. Once all the time periods are processed, and the model has completed the final time period, the program ends.

The Traffic Analysis Zone information is updated each time period. The information (i.e. population, retail employment, non retail employment and households per zone) obtained from the Metropolitan Council was in ten year-time periods. In order to update zones from 2000 to 2030, interpolation of demographics between these years was necessary.

For counties like Ramsey, Scott and Washington the ranking points between projects is similar due to the simplicity of the deduced decision making process. A link information file is created for the next period of time and it is stored as a text file. This text file is then used as base for the following time period and so on. Once all the time periods are processed, the program ends.

The main data structure of the program has different matrices. The "Link information" matrix has 21 attributes. This matrix includes link id, nodes a and b, link type, link length, free flow speed, number of lanes, capacity, volume, county to which the link belongs, the minimum distance to downtown Minneapolis or St. Paul, links that are within 5 miles of any Central Business District (CBD), Average Daily Traffic (ADT), crash counts and three constraints.

The "Demographic information by TAZ" matrix has nine attributes: Transportation Analysis Zone (TAZ) id, households, population, residential density, cars, distance to the nearest downtown, county to which the TAZ belongs, retail employment and non-retail employment.

The "Jurisdiction information" matrix has attributes that identify every link with its own jurisdiction: State, Anoka, Carver, Dakota, Hennepin, Ramsey, Scott and Washington, it also contains number of households, total vehicle miles traveled, total budget, maintenance budget and construction budget.

A "crash data" matrix is also developed, which tracks crashes by node and link.

The program begins with the Metropolitan Council's planning model 1990 network geometry and attributes; link capacities are exogenous between 1990 and 2005. The link capacities are not increased endogenously until after year 2005.

The investment model is iterated at five-year increments. The main advantage for doing so is the reduced computation and thus shorter running time compared to smaller periods of time (e.g., one-year).

The first step in the process is to update the Traffic Analysis Zone (TAZ) information, which was obtained from the Metropolitan Council.

Trip generation is run. The model estimates free flow travel times on paths, this means that there is no traffic on the network before the first iteration. The trip distribution is initially determined using free-flow times. That demand is assigned with the traffic assignment model. This produces a very congested situation. The new output congested times are then used to re-estimate demand. The travel demand model is re-iterated until an equilibrium between demand and link travel times is reached. This resulting equilibrium flow pattern (the flow produces travel time on the links that generates the same flow) is used as the input for the first period of the model.

The model is then run for 1990. Trip generation, trip distribution and trip assignment are executed recursively to obtain equilibrium. Using congested initial conditions allows the model to converge (find equilibrium) more quickly, thereby reducing run-time, and the results are the congested flow pattern in equilibrium.

Scenarios are numbered by the first year in each five-year period (thus 2005 represents the period from 2005-2009, 2010 represents the period from 2010-2014, and so on).

3. Performance Measures

The design and performance of transportation systems provide opportunities for mobility, and it influences patterns of growth and the level of economic activities through the accessibility it provides to land. (Meyer and Miller 1984) Performance measures describe the present state of the system and its complexity. They indicate how well a system is doing. They monitor the accuracy of previous projections and help to steer future decisions. They inform a community what areas need attention. If agencies can come up with the right performance measures they may increase their productivity.

Performance measures can be used to assess the effectiveness of the system. And although efficiency can mean different things to different users, it also means specific things to analysts requiring different measures. There is a need for information that makes sense so it can be turned into knowledge, and with that knowledge be able to obtain some effective results. To develop effective performance measures we can ask what outcome the system needs to produce.

According to Dahlgren (1998) "Performance measures should inform decisions. They should:

- reveal problems, which can be thought of as opportunities for improvement,
- facilitate judging and choosing among strategies to utilize these opportunities,
- measure the actual performance of the chosen strategy.
-

Thus they inform decisions regarding the overall level of resources to devote to transportation, where to allocate these resources, and how best to use resources."

Some performance measures are better than others, but there are three main criteria suggested (Caltrans 1998) for selecting measures of effectiveness:

- it aids in identifying opportunities to increase the system wide net benefits through public investment in improvements or changes in management,
- it minimizes the cost to achieve necessary measurement accuracy, and
- it produces the right incentives.

Every society wishes for a good transportation system that provides mobility, accessibility, and all the other necessary characteristics to have a good quality of life. But at the same time society wishes that the damage (from pollution emissions, noise or toxic spills to endangering some local animal species) to the environment would be at a minimum. Some performance measures track the impact that transportation has towards the environment in terms of resources saved (e.g., fuel conserved or pollution avoided).

Other performance measures are practical if data are available, for example: passenger or freight roadway condition, capacity, passenger or freight modal choices, freight specifics (business access to freight services-percent of manufacturing industries within 30 miles of interstate or four lane highways, quality and quantity of freight services (percent of goods moved), roadway (percent of truck VMT or tonnage affected by weight restrictions on bridges, bridges weight limits, and so on.

Most cities have intersection Level of Service (LOS) as one of their performance measures, which ranges from A (less than 10 seconds of delay) to F (more than 80 seconds of delay) for intersections. Street segments may be tracked with volume/capacity ratio, where 0.80 or lower represents free flow conditions, while 1.2 represents very congested conditions.

But some performance measures are more about perception than numbers. Motorists want to feel comfort when traveling and one of the factors that they care the most is their travel time. People start thinking about the transportation system when safety is involved, for example, when there are automobile accidents. Part of society may associate crashes with poor night visibility or poor markings, depending on their own perception of the system.

Minnesota

Mn/DOT evaluates the performance of the trunk highway system on a system-wide basis. Some of the measures that the department identifies do not directly indicate system performance but help it recognize where improvements can be made to the system to improve the system overall. These performance measures are based upon strategic issues raised by current policy.

Mn/DOT establishes its strategic transportation issues in its Transportation System Plan. It considers mobility, access management, safety, infrastructure conditions, modal travel, and inter-modal travel as important ways to track the transportation system. These measures accommodate more than one mode of travel or address more than one system objective.

According to the interviews of officials at different government jurisdictions, the principal performance measure categories that are taken into consideration in the transportation investment decisions are safety/crash reduction, congestion/capacity/ADT, cost effectiveness, air/environmental quality, pavement/maintenance, community involvement, and access management.

While it is not realistic to measure every aspect of the transportation system, it is necessary to select a range of indicators that represent and reflect the quality of service and how attractive it will be to drivers. Ideally it would be beneficial to provide a single aggregate indicator to compare with measures of other modes. Performance measures for which data are available include mobility (congestion), accessibility, equity, consumers' surplus, reliability, and safety. These performance measures help quantify quality of life. They are discussed in turn. All measures of effectiveness in this research are calculated for five year-period intervals.

Mobility

Mobility is defined as the ease of moving on the transportation network. Measures of mobility describe the ease with which elements of the transportation system, or the transportation system as a whole can be used. One of the challenges for transportation planners these days has become to be able to provide better levels of mobility on highways and transit facilities,

For the purposes of this project, which is studying the growth of and investment in highway networks, mobility measures are congestion related measures like LOS, volume to capacity ratio, trip time, and average speed. The most straightforward way to measure mobility is using link and origin-destination travel times.

$$VHT = \sum_i vht_i$$

$$vht_i = f_i \cdot T_i$$

Where:

VHT total vehicle hours traveled on system

vht_i vehicle hours traveled on link *i* ;

f flow on link (veh/h);

T Link travel time (h).

The principal way that government agencies deal with mobility is through strategies to minimize the length of congested highways. However measures of congestion are inherently arbitrary. Another candidate measure for mobility would be total distance traveled, which is computed as:

$$VKT = \sum_i vkt_i$$

$$vkt_i = f_i \cdot L_i$$

Where:

VKT total vehicle kilometers traveled on system

vkt_i vehicle kilometer traveled on link i ;

L Link length (km).

Accessibility

Accessibility can be defined as the measure of the ease with which number of destinations, pieces of land and their associated activities can be reached. When there is development, accessibility increases. When the network gets faster accessibility increases. Accessibility is a measure that relates how well the transportation system connects activities taking places at locations.

$$A = \sum_i A_i R_i$$

$$A_i = \sum Q_j f(T_{ij})$$

Where:

A system accessibility

A_i accessibility of zone i;

Q_j destinations at zone j;

R_i origins at zone i

T_{ij} travel time between i and j.

Equity

Equity can be defined as the state, quality, or ideal of being just, impartial, and fair. Outcome or result equity is measured by benefits per group, considering the distribution of the outcome across individuals and groups. Process equity ensures all groups are represented in the decision-making process. A concern is that sometimes there is a trade-off between efficiency and equity. In some jurisdictions this performance measure plays an important role due to community pressure covered on fairness concepts. One way to understand how to measure equity is with the Lorenz Curve and Gini Coefficient shown in .

The Lorenz curve is a graph that shows, for the bottom x% of households, the percentage y% of the total income, which they have. The percentage of households is plotted on the x-axis, the percentage of income on the y-axis. For transportation analyses, income can be replaced with delay.

A perfectly equal distribution in a society would be one in which every person has the same delay. In this case, the bottom N% of society would always have N% of the delay. A perfectly unequal distribution, by contrast, would be one in which one person has all the delay and everyone else has none. In that case, the curve would be at $y = 0$ for all $x < 100$, and $y = 100$ when $x = 100$. We call this curve the line of perfect inequality. The Lorenz curve is used to calculate the Gini coefficient, which is the area between the line of perfect equality and the Lorenz curve, as a percentage of the area between the line of perfect equality and the line of perfect inequality ().

Reliability

Reliability is the quality or state of being dependable, trustworthy. Mn/DOT defines reliability as " the percent of travel on a corridor that takes no longer than the expected travel time plus a certain acceptable additional time" (Metro Division Transportation System Plan 2001).

When it comes to this performance measure almost in general, travelers would agree that this is a very important one. It encourages addressing problems associated with delays. When people know how long they will be stuck in traffic every day, they can plan ahead for that specific amount of time. But if that delay changes day to day, it disrupts schedules. Reliability can be measured with data by variability of travel time. It is computed as the inter-day travel time deviation of all trips with the same OD that start at the same time interval across different days (Bates *et al.* 1987).

$$V_t = std(T_{t,1}, T_{t,2}, \ldots T_{t,n})$$

Where:

V_t Inter-day travel time variation of trips starting at time interval t;

std(.) std(.) The standard deviation of (.);

$T_{t,n}$ Travel time of trips starting at time interval t in day n.

The difficulty with using reliability measures in analyses such as used in this project is that traditional transportation planning models do not account for day-to-day variability in travel times, they are instead deterministic. A stochastic transportation forecasting methodology is required in order to assess reliability. This may include the use of random crash events, which are a major source of delay. This kind of analysis is not used in practice, but has been tested in research projects. Thus, reliability performance measure cannot be calculated due to the fact that the model used on this project does not have day-to-day changes.

Benefit-Cost Ratio

One way to measure cost-effectiveness is through the benefit/cost (*B/C*) ratio. There are different kinds of costs that play an important role in the transportation network system. Some of them have to do with pollution, accidents, fatalities, lost time, congestion, property damage accidents per vehicle distance traveled, lost times (number of hours lost in delay) and so on.

The benefits can be measured with consumers' surplus, but the cost that is easier to capture since it is much more local. Cost depends on the physical condition of the transportation infrastructure and equipment. Cost to maintain roadways like service life, percent of lane-miles by pavement condition, tons of asphalt placed by maintenance crews, hours out of service, maintenance hours, current average maintenance costs.

Mn/DOT places a high priority on strategies that have a high benefit-to-cost ratio. It looks for maintaining a balance between the total costs of planned corridor investments and the financial resources available. The users cost involves multiplying the travel time, distance and crashes by the appropriate dollar value.

$$B/C = \Delta CS / E$$

Where:

ΔCS Change in consumers' surplus

E Amount of money needed for capital and maintenance cost

Although a Benefit-Cost Ratio has been described as one of possible performance measures, because of the dynamic nature of the model, there is no perfectly fair way to compare values with some fixed or empirical values. This performance measure can only be calculated to compare benefits between the different alternatives.

Safety

Safety is one of the most important issues looked at when deciding what projects to build in any transportation network. In economic theory, the benefit of a safety project is represented by the number of lives saved multiplied by the value of life, and injuries avoided multiplied by a value of injuries, plus property damage reduced multiplied by some estimate of property damage. Although it is relatively hard to set a value for a life, it may be computed by examining how individuals reveal their preferences for known risks.

One of the main benefits that result from improvement projects are the expected reduction in the likelihood of crashes. We hypothesize a model of the following form:

$$C_e = f\,(L, S, I, F, V, \ldots)$$

Where:

C_e Expected crashes;

L Link length (km);

S Speed (km/h);

I Recent investment (age since last investment);

F Functional classification (road type)

V Volume (i.e. Average Daily Traffic).

Appendix 3 presents a statistically estimated model using crash data, which was ultimately not used in the model.

4. Investment Models

The Investment Models included Budget, Costs and Constraints, and Decision Rules. These may vary by unit or level of government, and are discussed below.

Budget Models

In order to predict how much construction will occur in a given year, there is a need to know the available transportation budget. Transportation budgets need to be separated into operations, maintenance, and construction budgets. Maintenance is defined as preservation outlays like pavement reconstruction, it does not include snow removal for example, which would be operations. Based on current spending patterns, this research assumes 21% of the total budget is spent in expansion and 79% is spent in operations and maintenance. Sensitivity analyses will test the effects of varying these shares.

The construction budget further allocates funds between capacity expansion of existing facilities (which generally aim to relieve existing congestion problems) and the amount spent on new facilities (which open up new areas to development).

In the transportation planning network, links that belong to the state (including Interstates, US Highways, and state highways) are ranked by state rules and are constrained by state budgets. Links that are under the county jurisdiction are ranked by the respective county level decision rules. These links include County State Aid Highways (CSAH) and county roads. Other links that are not owned by these jurisdictions (such as park roads or roads owned by cities or townships) are not modeled in this investment model, and are assumed static. For this reason there is a need to estimate two different budget models: State Budget Model and County Budget Model in order to allocate the right amount of money to a specific link.

Once all links have been scored under each jurisdiction's rules, links are sorted and the budget is spent on the ones that have higher priority. A general assumption is that counties will spend all their budgets in that time period. If budgets are short on building one last project, counties will borrow from the next time period (decreasing available revenue in that subsequent period).

In order to predict the budget more accurately, the VKT numbers are adjusted because there is some discrepancy between published VKT and real counts. Published VKT data is obtained through public agencies based on measured and estimated traffic counts. Further, the planning network used in this research does not include every link belonging to a particular jurisdiction, it means that VKT produced by this model may be underestimated

The process for investing in the Transportation Planning network is explained graphically in Figure .

State Budget Model

The State budget model is estimated by regressing expenditures on Interstate, U.S., and State Highways made by the Minnesota Department of Transportation (Mn/DOT). There is no distinction between the sources of funding for the data; it could come from the State budget or from federal funding. The regression model takes into consideration data available for the years 2000 to 2004. The budget models presented in this research are the ones that gave the best fit and had the highest statistical significance for explanatory variables. A variety of regression models were tested, they included variables like population, annual growth, residential density, network size, number of crashes, pavement conditions, households, income per household, car ownership, year, households per population. However, the simplest model proved to have greatest explanatory power.

State budget = *f (total VKT)*

Where the VKT represents total vehicle km traveled for only the Interstates, US highways, and Minnesota state highways. The results are shown in . This model produced an r-squared of 0.82. Each vehicle mile (km) traveled adds approximately 1 cent (1.6 cents) to the state road budget. There were a total of 35 observations (7 counties by 5 years each). shows the correlation between variables. Factors other than vehicle travel are used in determining revenue in practice, however, they are also highly correlated with vehicle travel.

County Budget Models

The county budget models are estimated by regressing the expenditures made by the counties on County State Aid Highways and county roads.

A number of variables were tested, including population, annual growth, residential density, network size, number of crashes, pavement conditions, households, income per household, car ownership, year, households per population, and shortest distance from the zone's centroid to either downtown Minneapolis or St. Paul. presents the model that provided the highest r-squared (0.92) with significant variables. The final model was based on 28 observations for the years 1990, 1995, 2000 and 2003 (four years by seven counties). shows the correlation between variables.

Population, autos and employment data was obtained from the Twin Cities Metropolitan Council staff. Some data was obtained through its website and it is in tracts and block groups format, so additional work was done in Arc/Info to aggregate that data to the county level. Other data was obtained from the respective counties. Because of the lack of format consistency from the information gathered through the counties, this research used data provided by the Office of the State Auditor as the dependent variable.

County budget = *f (total VKT, households, year)*

The model results can be compared with what is reported by the counties to the Office of State Auditor and the apportionments established by Minnesota Legislature to the counties. Data was obtained from the House Fiscal Analysis Department about State Expenditures showing all operating funds for the year 2000, shown in .

According to the Minnesota House of Representatives, the HUTDF is divided according to the Minnesota Constitution, 95% of the fund is allocated by constitutional formula: 62% for Trunk Highways, 29% for County State Aid Highway Fund, 9% for Municipal State Aid Street Fund); while 5% may be set aside and apportioned by law.

shows the allocation of other dollar amounts of money into each different road type per county. This data is for every road in the state. When these results were applied to the seven metropolitan area counties: Anoka, Carver, Dakota, Hennepin, Ramsey, Scott and Washington, we obtain the results in .

Excluding Carver County, these dollar amounts have only a 15.5% average difference between what the Legislature establishes each road type would receive and what each county reported as spent for that specific year. For this reason there is some confidence that the model that will result from the regression analysis will provide a reasonable estimate. These numbers may differ for various reasons, for example money not spent from previous years may be spent in the current year, and bonds allow greater spending in the current year than the allocation.

Allocation Between Expansion and New Construction

A major modeling issue is allocation of the 21% of the budget devoted to network expansion between expanding existing links and building new links. The number of existing links is known, as are their attributes (congestion level, crash rate, etc.). Possible future links (new construction) on the other hand pose a much more challenging problem.

Only a few links, dubbed "legacy links" in this analysis have already been clearly laid out. These legacy links have appeared on state maps and plans since at least the 1960s, and have been political promises to the affected areas that a new road would come to that area. In the Twin Cities, state level legacy links include the extensions of Highway 610 and Highway 212. A map () shows all of the links that were proposed in [Metropolitan Transportation Study, 1960] that were (A) Proposed and built, (B) Proposed and non-built (marked in red), and (C) Not proposed at the time, but built. (Links that were not proposed and not built cannot be easily mapped). shows the original map from the 1960s Metropolitan Transportation Study.

For lower levels of government, such long-term plans are uncommon in the Twin Cities, yet from time to time, new links are constructed. A model to develop a set of possible new links was estimated by Levinson and Karamalaputi (2003). A series of rules were used to identify potential links (depending on the traffic at the nodes (which were assumed to already exist), length (not too short, not too long), and local characteristics (not crossing more important links). That set of rules produced some 20,000 possible new links, of which a few dozen were built in the past 20 years.

Since the rules for prioritizing expansions of existing links and construction of new links are different, it is very difficult to compare them on a standard metric. One can compare two expansion projects or two construction projects, but there is no easy translation between them. Thus it is easier to establish separate budgets for link expansion (which largely serves existing needs) and new link construction (which opens up new areas to development), rather than making them compete directly for resources. From 1978 to 2004, in the Twin Cities Metropolitan Area, there were 945 lane km (587 lane miles) added to the transportation system. From those, 821 lane km (511 lane miles) were new construction and 122 lane km (76 lane miles) were expansions of existing facilities. A fixed percentage 85% of the dollar amount spent during those 26 years went to new link construction while 15% was allocated to link expansion and reconstruction. The cost per lane mile for new construction was $2,406,580 ($1,494,952 per lane km) while for expansion it was $1,206,840 ($751,802 per lane km), which represents a 50% difference. Additional research should try to better understand the tradeoff in recent years.

Costs and Constraints

This research uses a model of facility construction cost estimated by Levinson and Karamalaputi (2003a). This model, given in , takes into consideration facility size, new construction (vs. expansion), road type, as well as the distance from the nearest downtown.

This model was estimated on facilities that actually were built. It is important to mention that the cost model will underestimate costs because of roads that were not built, for which high cost may have been a discouraging factor. One way to account for this is to better consider constraints on investment as additional costs. Alternatively, constraints can reduce the points allocated to potential projects. Two major constraints are available right-of-way and environmental factors.

Interstates, highways, county roads and streets often require taking real property for right-of-way (ROW). This aspect needs to be addressed when analyzing results of the expansion/new construction of the possible transportation network additions. While in some areas there is a possibility of obtaining land on the side of existing roads to expand them if needed at a reasonable price, in many urban areas this is infeasible because of existing structures. The available right of way in the heart of urban communities is a constraint.

This research tried to consider the right-of-way (ROW) available on both sides of the roads that are prospects for expansion using GIS. But there was no data available for this specific type of analysis. A GIS land use file including a category named "right of way" was available, but for this analysis more specific data was required. (i.e. spatial location of each building within the parcel data, as well as specific location of highways within the ROW, lane width, sidewalk width, and so on).

There are significant terrestrial and wetland ecological areas in the seven county metropolitan area to take into consideration for the predicted expansion of the transportation network. The areas are classified by the Department of Natural Resources as Outstanding, High, Moderate and Non-classified based on the importance of ecological attributes like size, shape, cover type diversity and adjacent land use (). These areas include individual forests, grasslands and wetlands. Potential links that traverse these ecologically sensitive areas, as well as bodies of water like rivers and/or lakes and over parks as well, are marked as constrained. (and).

The observed investment models (discussed below) rank links by benefits, not costs. Costs are used to allocate available funds. When a link predicted for expansion and/construction is constrained by any of these areas, instead of allocating points, points will be taken away. Based on a scale 0 to 100, constraints will cause 90 points to be de-allocated from that link, which in an era of constrained budgets, should ensure it does not get funded.

Decision Rules

Two classes of decision rules are used in the analysis: stated rules, garnered from interviews and revealed rules, determined by statistical analysis.

For the stated rules, in order to uncover formal and informal procedures, performance measures and decision rules that have been actually used, interviews were undertaken with Minnesota Department of Transportation (Mn/DOT), the Metropolitan Council, County, and City of Minneapolis planners, engineers and staff involved in the decision-making process on future network growth. These interviews were conducted in groups as well as individually.

The method consisted of recorded face-to-face interviews using open-ended questions, which can be an effective means of generating a variety of responses. These responses represent differing perspectives to a standard list of questions. Also face-to-face interviews, while often time consuming and laborious, have the highest response rates. (Neuman, 2000)

The following free-form questions were asked in each interview.

- What is the procedure for a project to be approved for construction?
- What are the most important policies to look at when making decisions about a project for the network growth?
- What are the main criteria to choose between different projects?
- What performance measures are considered important when selecting a project?
- Is there a ranking system that the projects go through to be selected?
- Have there been changes in the criteria used today as the one that was used 20 years ago about network development?
- Are there any informal procedures for the decision-making process?
- How important of a role do politics play on the decision-making process?

Interviews were conducted with staff at the state DOT, the Metropolitan Council, six of the seven counties in the metro area, and the city of Minneapolis.

The revealed decision rules apply the statistical models estimated in Levinson and Karamalaputi (2003a,b). Both models were estimated on two decades of data from the Twin Cities. The expansion of facilities on the existing network by one or two lanes is a estimated using a discrete choice model with independent variables describing conditions of the network, traffic demand, other demographic characteristics, estimated project costs, and a budget constraint. The likelihood of expansion of a link depends also on its upstream and downstream neighbors, as well as on the state of parallel links. The model suggests that high capacity links are more likely to be expanded.

New highway construction was estimated in a discrete choice model to be based on the status of the network, project costs, the conditions on upstream and downstream and parallel links, and budget constraints. Algorithms were developed to generate a large choice set of potential new links, to which the discrete choice model was applied. New links providing greater potential access are more likely to be constructed.

City of Minneapolis

In the City of Minneapolis, located within Hennepin County, the community, the Park Board, the Library Board, Department of Public Works, the Capital Long-Range Improvement Committee (CLIC), the Mayor and City council are all involved in the project selection process.

The Capital Long-Range Improvement Committee (CLIC) uses the goals, expectations and policies of the City of Minneapolis Comprehensive Plan in the evaluation of capital requests. The committee is authorized to have 33 appointed members, composed of two members per Council Ward and seven at-large members for the Mayor, members include lawyers, neighborhood activists, state consultants, senior planners with over 20 years of experience, and homemakers. Members of this committee are knowledgeable of the issues facing the city, where most of the members have lived in for over 25 years. The CLIC committee reviews some projects that have been previously approved by the City Council as well as new projects for the fifth year of the five year plan.

The process starts with a group meeting to explain to each scorer how the process works. At this meeting the group is split into two task forces, 1) Transportation (officially titled "Transportation and Property Services"), and 2) Human Development (officially titled "Government Management, Health and Safety and Human Development").

Each scorer receives a book containing all the proposals, which are submitted by various City departments, independent boards and commissions. (i.e. Library and Park Boards, Public Works Department, Traffic Control Department).

All scorers are encouraged to read project descriptions and prepare questions before the next meeting. Projects are presented by the different city departments named above. It is emphasized that there is a need to try to make long-term investments on the right infrastructure that the city needs. The committee meets weekly for a couple of months, reviewing more than a hundred projects every year.

The evaluation system has four sections, 1) Project Priority, 2) Contribution to City Goals, 3) Operating Cost Considerations, and 4) Qualitative criteria. All these sections have point allocations that sum to a maximum of 300 points. shows an example of all the categories that the projects are scored based on.

Flowchart 1 describes the concepts on which the ratings are going to be based in an illustrative way. Each task force ranks projects in its field as a group. The task forces define the ranges that must be used for approximately two-thirds of the points for each project as a group and the remaining one-third is scored individually. The categories ranked by each task force as a group are 1) Level of Need, 2) In adopted Five Year Plan, and 3) Contributions to City Goals/Objectives.

When a project focuses on transportation, the assigned task force reviews it. Each project is assigned a level of need by the presenters, which the task force may change. Very few projects qualify for the “critical” evaluation. If a motion is carried to change the level of need from “critical” to “significant” by the task force, both task forces will score that part of the project between the range of 41-50 (instead of the initial 51-60 points proposed by the presenter) depending on how strongly each member feels about this project.

Each scorer ranks only one-third of the project individually, this is the qualitative criteria. The individual scoring depends basically on how each scorer perceives the project, keeping in mind the basic city goals. In order to help the scorers for this part of the point allocation process, the City of Minneapolis asks the Department of Public Works to present its position on each project, so the scorers would have a more realistic idea of how the project is viewed by staff.

The Operating Costs category is placed in the CLIC Rating Form with the Contributions to City Goals/Objectives sub-total. This category ranges from –25 to 25 points. The -25 points are given if exceptionally large amounts of new operating funds are needed. The main question to be answered by each project presenter is if this project would result in an estimated annual operating cost increase or decrease. The city aims to be very careful to fund only projects that it would be able to afford later.

The committee tries to follow presenters’ recommendations on the project priority, but if a member does not agree with that recommendation, amendments are taken to change it as well as the significance level. Presenters explain how the project would benefit the city and what would happen in some cases if the project does not get funded.

Members of the committee make suggestions of possible alternatives to presenters about projects that did not get high scoring. Comments are given as feedback to presenters for next year’ selection process in case they want to submit the same project again.

After the point allocation process takes place, the CLIC tries to fund the projects with the highest scores. Project selection is based on points as well as the funding category available.

When a project is presented and does not have any other way of funding, CLIC is reluctant to allocate points to that project.

When it comes to funding city level projects, there are different sources: Federal Aid Fund, Municipal State Aid (MSA) for population over 5,000, Net Debt Bond Revenue (property taxes), Permanent Improvement Tax Revenue, Property Assessment Revenue (tax increase), gas taxes, and bonds. Federally funded projects at any level require a local match provided by the sponsoring agency. These can come from state trunk highway fund, regional bond funds, city or county funds or from Department of Natural Resources (DNR). Cities and counties can request federal funding for their trunk highway system projects that are needed in their geographic area.

After the committee is done ranking the projects, a spreadsheet is assembled which has the top third of all projects. On this spreadsheet projects are divided by: Municipal Building Commission, Library Board, Park Board, Public Works Department Facility Improvements, Street Paving, Sidewalk Program, Heritage Park Infrastructure, Bridges, Traffic Control & Street lighting, Bike trails and Miscellaneous projects. In this case, the presenters are requesting funding from Net Debt Fund, not Capital Funding. There are cases when projects with a low score get funded because they have a high amount of Municipal State Aid (MSA) funding, which the city chooses to take advantage of.

There could be some other projects that ranked high but do not have any other way of funding and or have negative comments, which the committee is reluctant to support and are unlikely to get funded. There are even cases where presenters ask to moved up a project with a memo. But it is the committee decision to consider it.

Counties

At the county level funding sources vary depending if the project is to be a County State Aid Highway (CSAH) or a County Road (CR). The CSAHs (classified as “minor arterials” or “collectors”) are eligible for state aid under the Minnesota Highway User Tax Distribution Fund (HUTDF), State Bond Funds, Federal Aid, and County Property Taxes. The remaining roads under the county’s jurisdiction (CR) get their funding almost entirely from county property taxes. The county can still compete for federal and state bridge bond funding. Counties receive 29% of HUTDF, cities and townships through Municipal State Aid programs receive 9%, while the state allocates the remaining 62% to state trunk highways.

In the Twin Cities Metropolitan Area there are seven counties: Anoka, Carver, Dakota, Hennepin, Ramsey, Scott and Washington Counties. Anoka, Scott, Dakota and Washington Counties do not have a point ranking system for their project selection process, although they do have priorities that influence the selection process. Ramsey and Hennepin Counties, have a point ranking systems described in detail below.

Ramsey County

Ramsey County’s Public Works Technical Advisory Committee (TAC) ranks projects. The TAC is comprised of city engineers and administrators representing cities of small, medium and large population within the county. The TAC and the County’s Public Works Department use a list of rating factors to determine a rating/prioritizing score for projects.

According to Flowchart 2, the current rating factors of Ramsey County’s Transportation Improvement Program has a point ranking system through percentages, which only adds up to 90% as the official document states and it goes as follow:

1) Structural deficiencies (10 percent). Structural deficiencies in the physical condition of the road adjusted to consider the average daily traffic per lane.
2) Need for Maintenance (10 percent). A project for which drainage issues have been identified adjacent to the roadway will receive 50% of this score. The remaining 50% of this score relates to other factors such as maintenance problems not considered in the pavement management score. The scoring may be based on both measurable factors and professional judgment.
3) AADT (10 percent). The total number of vehicles that travel daily on average on a road.
4) Geometrics/Safety (20 percent). The level of service and the number and nature of accidents may be considered in this factor.
5) Cities' position (30 percent). A City in a letter or resolution expresses the need for a project. It is suggested that a City prioritize the projects requested. Projects prioritized will be scored based on the priority given to each one.
6) Access Management (10 percent). Project located in a City with an adopted access management policy. City agrees to work with the county to combine or eliminate access points as part of the project in an effort to reduce vehicular crash rates, reduce congestion, and improve pedestrian safety.

The county is looking at changing the percentage numbers, lowering the percentage given to the city's position, including a storm-water management plan and a design-capacity category. The design-capacity category refers to the extent to which a roadway is currently functioning under or over its design capacity. For a two-lane existing roadway with AADT between 0 and 8,000, the roadway is under capacity; more than 8,000 is over capacity. For three-lane existing roadway with AADT between 0 and 15,000, the roadway is under capacity; more than 15,000 is over capacity. Four-lane roadways are assumed to have adequate design capacity. Four-lane roads would receive points for intersection deficiencies under the geometrics category.

According to the Ramsey County Public Works Director the political involvement in this process is almost removed. Politicians are informed exactly how the process works and what is the actual criteria for selecting projects through the written formal plan.

Hennepin County

Hennepin County has the most complete ranking system and formal process, which are shown in Flowchart 3. It has four main criteria that are used to score projects. This criterion is composed of three technical factors (road capacity, pavement conditions, and crash rates), and a municipal support factor (approval). Table 10 shows more details on these factors. According to the Transportation CIP Project Scoring it is possible to determine which projects have the greatest technical need, and for which funding may be the most appropriate, presuming that sufficient municipal support exists or could be generated. A total score for all four factors is listed and is followed by a number indicating the rank for each factor in particular.

It is recognized that there are other factors that may influence the selection, as coordination with other projects, type and availability of funding, geopolitical distribution of projects, and high crash rates.

Minnesota Department of Transportation – Metro District

The Metropolitan Council and Metro District staff agreed that at the state level, Mn/DOT is driven by its strategic plan, when making investment decisions it looks at 3 priorities: preserve, manage, and expand (Metro Division Transportation System Plan 2001). The first formal policy plan that articulated the preserve-management-expand criteria was written in the mid-1990s. (Metropolitan Council Manager of Transportation Systems Planning)

When it comes to large capacity expansion projects, especially new links, Mn/DOT first examines the previous plans before it considers performance criteria, so the outcome today aims to retain commitments, thus implementing maps drawn decades ago. Flowchart 4 shows another rule that assumes if Mn/DOT has reconstructed or added capacity to a roadway section in the last 10 years or is in its current STIP, that roadway is not going to be touched within the next 30 years. This does not mean that it won't get any attention if maintenance is required.

The Department identifies the needs, based on performance measures and targets, for a twenty to twenty-five year horizon with both a financially constrained (extrapolating the current budget) and unconstrained plan (Metro Division Unmet Needs Report-draft, 1998). The majority of the needs in that analysis are mobility related. Mn/DOT uses speed targets to evaluate different system level investments. For freeways the target is 45 mph (72 km/h), for arterials it is 40 mph (64 km/h).

According to the Metropolitan Council Manager of Transportation System Planning while there are expansion possibilities in the suburbs, in the heart of the city where there is the core of the traffic problems, there are really very limited expansion opportunities. Targets are established by the system plans to ensure that preservation needs and safety needs are fully met, and remaining funds are then used for mobility.

By setting aside some funds, Mn/DOT attempts to ensure that projects related to satisfying safety needs get funded. Safety projects have a better chance to get funded if they are on the 200 high crash locations list, which traffic safety experts within the agency update every three years. Safety issues often lead to expansion rather than to management investments.

State planners invest to serve multiple aims. To make a specific investment that is only a safety fix is extremely difficult when other projects also address preservation and mobility. It is virtually impossible to not address multiple objectives on roads in the metro area, when a road is rebuilt to modern standards, not only will it (hopefully) be safer, it will have new pavement (satisfying preservation) and perhaps additional capacity with higher speeds (satisfying mobility needs). Thus capacity-expansion projects on roads that have recently been resurfaced or rebuilt are less likely to be selected than capacity-expansion projects on roads that also need reconstruction.

System plans have set aside specific percentages of dollars available every time; according to staff, these percentages are 50 to 60 percent for preservation, about 20 to 25 percent for management and 30 to 15 percent for expansion.

Mn/DOT does not produce a rank list that says a specific project will be built before any other project; the reason for this is primarily that it can't be guaranteed that a project is going to complete engineering and pass environmental reviews in a specific time or order. Detailed engineering before funding is now unlikely, as it is believed that without available funds for construction, money should not be spent on design. Once a project is selected, it still must be designed before construction can start, adding delays, though the move towards design-build may speed this process.

Although lists are produced identifying un-met needs, they do not currently prioritize projects based on performance criteria.

When Mn/DOT goes from the planning stage of projects towards much more specific construction phases it encounters issues that may delay those projects, including local community approval, environmental impact, right of way purchase, and inflation.

When Mn/DOT gets to the project selection stage, it takes into consideration how long the list of needs is for each category and whether or not certain projects are eligible.
The State Transportation Improvement Program Highway Investment Plan categories are:

1) Preservation: bridge repairs, road repairs, resurfacing, and reconditioning.

2) System Management: Cooperative agreements: Right of Way (ROW); Supplements/Overruns; Enhancement Activities; Landscaping-Rest Area-Wetland Mitigation; Planning; Safety, Traffic and Capacity; Safety, Hazard Elimination; Safety, Rail/Highway; and Traffic Management.

3) Replacement: Bridge Replacement, and Reconstruction.

4) Expansion: Interregional Corridors (IRC), and other Major Construction.

Many projects get moved from one category to another depending on needs level of a particular area. Today at the state level there is no explicit prioritizing between safety and mobility.

Legislature and state government sometimes establish principles that override performance criteria. These principles include ensuring geographic balance, minimizing encroachment on valued open space, as well as threats to the environment. There are other principles that are established as: obliteration of scenic views or even changes to familiar traffic patterns, "sensitive" lands, triggering environmental laws designed to protect wetlands, wildlife habitats, and historic sites and other valued features. These considerations can prevent the highest rated transportation projects from proceeding first. The stream of funding influences the projects that get selected.

Table 11 describes the sources of transportation funds that come to the region and the processes followed for project selection and the agency responsible for the selection process.

In general, federal aid funds may pay for almost anything that is eligible under the state trunk highway or state aid programs. At the state level, the funding sources available are the Trunk Highway Funds, Bonds, and general bonds designated by the legislature. These last ones are the Federal Highway User Trust Fund and the Minnesota Highway Trust Fund. The State Trunk Highway Fund receives 62% of State highway user funds that can be used for principal arterial projects.

Flowchart 4 represents the project selection process what was found through the interviews. But according to the 1997 Transportation System Plan, for improvement and expansion projects, there is a ranking point system (shown in Flowchart 4-1), which we adopt. Although Mn/DOT staff made no reference to it, and on questioning implied it was deprecated, it provides the only basis we have to quantify Mn/DOT project rankings.

Cooperative Agreements

For local projects, State Aid Cooperative Agreements may be used, which is managed by the Mn/DOT State Aid Office. There is no point system, it is a free form process where agencies submit applications (sometimes just 2 pages long), which are reviewed by the Mn/DOT functional groups (i.e. Bridge, Maintenance, GIS, Hydraulics, Construction, Soils/Materials, Transportation Planning or Preliminary Design, Right of Way, Surveys, Site development, Design Standards, Traffic). A panel of 5 or 6 city-county engineers that do not have any projects that specific year are brought together and rate the projects. The projects are separated by categories: preservation, management, improvement and expansion, which are in Mn/DOT's priority order. However not all preservation projects get selected before management projects. Within each category this panel ranks projects. There is less time involved in this process compared with the Metropolitan Council selection process and it works well according to the North Metro Area Manager. The application is not as time consuming as the one the Transportation Advisory Board (TAB) has.

At the area level if the minor arterial streets are owned by the state instead of the county, the funding sources are through Federal Aid. There are three significant federal aid programs by which projects can be funded: Transportation Enhancement Program (TE), Congestion Mitigation & Air Quality Improvement Program (CMAQ) and Federal Funds Surface Transportation Program (STP).

Transportation Advisory Board and Metropolitan Council

In the Twin Cities region the Transportation Advisory Board (TAB), which includes local officials, and the Metropolitan Council, which does not, act as the Metropolitan Planning Organization and thereby allocate federal funds. The TAB, created by the state legislature in 1974, consists of 34 members, 10 municipal elected officials, 7 county commissioners, 4 representatives of state and regional agencies (Minnesota Department of Transportation, Minnesota Pollution Control Agency, Metropolitan Airports Commission, and the Metropolitan Council), 8 citizen representatives, 4 transportation mode representatives, and 1 chair. The TAB is responsible for soliciting and evaluating applications for federal transportation funding, and for conducting public hearings.

The TAB puts together a group of scorers who rate projects. This group of scorers is the Technical Advisory Committee (TAC), which is formed by state, regional, county, city and township representatives. Most of the volunteer scorers have many years of experience in transportation as planners, engineers or as specialists in safety, air quality, and so on. The TAC's Funding & Programming Committee (F&PC) ranks all categories of projects except Hazard Elimination/Safety and Railroad Surface and Signals.

The projects that are looking for federal funding go through the Metropolitan Council selection process and criteria. The Metropolitan Council through the TAB has a point ranking system to select projects. Each project is assigned a numerical ranking in different categories, for a maximum of 1,200 points for the Surface Transportation Program. Each scorer reviews the responses to one criteria, not the entire project. This point system does not allow a valid comparison across categories in terms of deciding what project is better.

The project scorers evaluate the responses in questioning if the project provides the benefit described in the application and how well the responses for a particular question compare to each other within the project category. The project that provides the most benefit in each category will get 100% of the points available, the rest are rated based on how they compare to the best project in that category.

For example, the project that provides the greatest air quality benefit will get 100 percent of the points available. The rest are prorated based on how they compare to the best project. If project A provides the most carbon monoxide reduction at 400 kg/day and project B provides the next best benefit with 300 kg/day. Project A gets 100 percent of the points for air quality and Project B gets 75 percent of the benefit that Project A provides. If Project C reduced carbon monoxide by 280 kg/day, it would receive 70 percent of the total points, and so on.

In general, projects need to meet the qualifying criteria: federal eligibility requirements, regional rules (consistency with 2030 Regional Development and Transportation Policy Plan, be adopted on the TAB roadway functional classification system, maximum and minimum federal funds).

The new bonus demonstration has the objective of making coordinated and comprehensive transportation investments to encourage, shape and facilitate plans for existing and future mixed use development and redevelopment of a concentrated area. It is a one page application requirement and a presentation of Transportation Investment Planned Economic Development District (TIPEDD) concept before a scoring committee.

shows the point range variation for the Surface Transportation (STP). This point range depends on the funding category. There is also a Congestion Mitigation Air Quality Improvement (CMAQ) and a Transportation Enhancement (TEP) Programs. An STP project may function as a reliever, expander, connector, augmenter, or non-freeway principal arterial. Under CMAQ a project may function as Transit expansion or Demand/System Management (). For TEP a project can be functioning as Scenic and Environmental, Bicycle and Pedestrian, or Historical and Archaeological Groups ().

For the 2005 Regional Solicitation there have been some changes on point allocation values and there is an additional new bonus point demonstration. As for the qualifying criteria, some of the changes for 2005 are: advanced construction payback is not eligible, projects already in the TIP are considered to be fully funded and not eligible unless specifically stated otherwise in the TIP, only one STP roadway or CMAQ transit expansion project can be selected per corridor, the concept of "maturity of a project" has changed, and the list of pollutants in the air quality criteria has been expanded.

Flowcharts 5, 5-1, 5-2 and 5-3 show the selection process in a graphically manner.

Informal Processes

It is important to mention that the process for decision making was deduced for levels of government that do not have a formal one, based on the information obtained through the interviews and public documents. This research tries to represent the process as much as possible assigning percentages based on the general questions asked to each person interviewed.

Anoka County

Anoka County's priorities are safety, pavement quality and preservation. The county believes that it is less costly to invest in rehabilitation projects than waiting until total reconstruction is needed. The proposed road improvements must have a benefit/cost ratio greater than 1 in order for a project to move forward and there must be a corridor and environmental study.

According to Anoka County Highway Department Multimodal Transportation Manager there will be no new roads built in the county for the next couple of years, only a few capacity additions on existing facilities.

The county has an overlay program analysis, which considers road segments that have specific Annual Average Daily Traffic (AADT) and Pavement Quality Index (PQI). The projects with higher values are the county's top priority. These analyses are done every two years and there are 8 safety projects each year. Sometimes it takes about 7 to 10 years to get all the proper documents ready depending on how big the project is.

Flowchart 6 shows this process graphically.

Scott County

In Scott County, the priorities are safety and roadway capacity (i.e. level of congestion). One of the county's guidelines is to keep Annual Average Daily Traffic (AADT) less than 15,000 on 3-lane roadways. The county has noticed that when AADT values rise to between 12,000 and 15,000, crash rates increase. The input from the townships and cities within the county also plays an important role in the decision-making process. The county averages 6 expansion projects every 8 years.

Flowchart 7 shows this process graphically.

Dakota County

Dakota County's informal process starts by using the prior years County Board adopted CIP (2005-2009). For example, projects not completed in 2005 will be "pushed back" to 2006.

The Dakota County's Transportation Plan for 2025 identifies four principles that apply to all aspects of the transportation system: transportation planning; safety and standards; social, economic & environmental impacts; and public & agency involvement. Its top priorities are safety, environmental impact, and roadway capacity.

With a collision rate per county highways of approximately 2.2 crashes per million vehicle miles traveled (1.4/mvkt) for the three-year period from 2000 through 2002, the county considers an intersection can operate safely with up to 75,000 vehicles per day.

When there are two projects and the county only has money for one of them, projects are analyzed to determine which one would best implement policy, strategy, investment level, and/or address an emerging need. The project development time would also be looked at. The project that would benefit the system the most would be programmed first and the other project would be programmed within the CIP but for a future year. Some projects requested are not included due to funding constraints.

Flowchart 8 shows this process graphically.

Washington County

Washington County's top priorities are safety, the capacity of the roadway, and pavement conditions. While it does not have a point system for road expansion, it does have a traffic signal ranking system (TSRS) and a pavement preservation ranking process. The TSRS program budgets for one traffic signal installation per year based on available funding. Today, the county is trying to formalize the process. The county selects one traffic signal project a year based on TSRS ranking. Pavement preservation projects get selected through the ranking based on the Pavement Condition Index (PCI). The implementation depends also on matching funds from local jurisdictions. In the past projects were subjectively selected based on what roads the county engineers drove and believed needed to be fixed. Flowchart 9 shows this process graphically.

There is a second flowchart proposed by this jurisdiction that includes an additional element to consider in the selection process, political issues (Flowchart 10).

Analysis and Evaluation

Based on the findings of this research, every level of government has different priorities. But not each level of government has a point allocation system. In order to complete this project there was a need to allocate points informally to those jurisdictions that do not have a formal scoring system. This point allocation was based on each jurisdiction's priorities.

According to , the main criteria used by most of the jurisdictions is pavement conditions /maintenance, followed by capacity utilization measures like Average Daily Traffic (ADT) and finally safety. Flowcharts were sent to each jurisdiction for final review and endorsement (the status of whether the flowchart was endorsed is shown in the table).

Explicit use of benefit/cost ratios was not a common criterion, in all of the interviews only three jurisdictions mentioned them: Anoka and Washington Counties and Mn/DOT. Clearly the factors comprising benefits and costs are important in many of the other decision processes, but it tends not to be laid out as clearly. This may be because the jurisdictions believe there are non-monetizable factors. This is particularly true with safety; engineers and planners were reluctant to state the explicit trade-off between spending on safety projects vs. spending on capacity projects. There must be a trade-off, we do not spend all of our resources on safety projects, but it is not something to be admitted. The city of Minneapolis and the Metropolitan Council are the jurisdictions that expressed concerns for air/environmental quality as a factor for their decision-making process. Hennepin and Ramsey Counties have allowed community involvement be an important part of their process. At the State level the biggest concerns to take care of, evolve around what every day user notices: congestion and a comfortable ride (pavement conditions).

If-Then Rules

The decision flow-charts can be operationalized as If-Then rules. The If-Then rules implement a point allocation that covers the decision rules that are considered by each government jurisdiction in a numerical ranking format.

These points are assigned based on the characteristics of the roadways located in each county. Every county has its own decision rules. Counties that did not provide decision rules were assigned decision rules of a similar adjoining county. For decision rules that are based on perception, there was no logical or numerical way to allocate points, therefore these type of decision rules were not taken into consideration for any of the calculations (e.g. public support for a specific project).

The four main rules that were common between flowcharts were Safety, Pavement Conditions, Level of Service, Capacity. Pavement quality is not used because of data format unavailability (the existing dataset cannot be easily incorporated in GIS format and is incomplete). Appendix 4 shows the points associated with each flowchart variable.

If-Then rules need to be continuous in order to ensure that each project obtains a unique score from a jurisdiction. The approach taken by the researchers was through multiplying the base ranking points by the ratio of the characteristics of a specific rule.

Candidates are ranked for 5 year-periods of time, and then there is an estimate of the number of lanes that need to be added in order to satisfy the demand and the traffic conditions.

There are some difficulties with some of the If-Then rules. Due to Scott County's If-Then Rules simplicity, no expansion is considered. This means that there is no investment in any period of time. Some assumptions were needed to be taken into consideration: because of the absence of two counties' If-Then Rules, other neighbor counties rules were "borrowed" to be applied to those two counties missing their own rules.

Example:

```
//ORIGINAL RULE:if(AADT>30000)juris_score[1][i]+=50;

//if(AADT >20000)juris_score[1][i]+=38;

//else if (AADT >10000)juris_score[1][i]+=25;

if(adt>30000)juris_score[1][i]+=Math.min(50,38+(50-38)*(AADT-
30000)/(100000-30000));

else if(adt>20000)juris_score[1][i]+=25+(38-25)*(AADT-20000)/(30000-20000);

else if (adt>10000)juris_score[1][i]+=0+(25-0)*(AADT -10000)/(20000-10000);
```

5. Scenarios and Results

This chapter describes the scenarios and presents model results.

Scenario Definitions

In order to see different results on the Twin Cities transportation network, it is necessary to test different scenarios. Some of the scenarios proposed can be implemented easily due to the fact that jurisdictions are using them already. Others are subject to budget availability.

The following scenarios are tested:

1) Baseline: Stated Decision Process to all counties for existing links.

2) Most structured decision rules (Hennepin County rules) in all counties.

3) Least structured decision rules (Scott County rules) in all counties .

4) Budget changes (a) +100%, (b) +200% and (c) +400% (d) -10% and (e) -25%.

5) Change split between budget expansion and new construction to 25-75.

6) Revealed Decision Process: Levinson-Karamalaputi (LK) model for expansion and new construction (with only legacy links available for new construction).

7) Revealed Decision Process: Levinson-Karamalaputi (LK) model for expansion and new construction (with full set of potential new links available for new construction).

Table: Differences Between Scenarios

Scenario	Expansion Decision Rules	New Construction Decision Rules	Total Budget	Expansion Construction Budget Split	New Link Choice Set
1	Stated	Revealed	Standard	50/50	Legacy
2	Most structured	Revealed	Standard	50/50	Legacy
3	Least structured	Revealed	Standard	50/50	Legacy

4	Stated	Revealed	Reduced, Expanded	50/50	Legacy
5	Stated	Revealed	Standard	25/75	Legacy
6	Revealed	Revealed	Standard	50/50	Legacy
7	Revealed	Revealed	Standard	50/50	All potential

In brief, the stated decision rules are those developed from interviews described in previous chapters. Revealed decision rules were developed from statistical estimation of actual investment decisions as part of the Mn/DOT funded project If They Come Will You Build It, (Levinson and Karamalaputi 2003a, b). In Scenario 2, the most structured decision rules (those from Hennepin County) are applied for link expansion to every county, while in Scenario 3, the least structured decision rules (those of Scott County) are applied for expansion. For new construction, the revealed decision rules are used to prioritize links in all cases.

The budget assumptions are based on the baseline budget model estimated earlier, except in Scenario 4, where the budget alternatives are tested. The budget is split evenly between expansion of existing links and new construction, except in Scenario 5, where three-fourths of all dollars are allocated to new construction. When opportunities for new links are exhausted (all of the legacy links have been built), that budget is reallocated to link expansion.

For all scenarios, once a link has been expanded, it is no longer taken into consideration for expansion. For new construction, state roads are assumed to be two lanes in each direction, whereas county roads are only one lane in each direction. Newly constructed roads are eligible for expansion if necessary in the future. Because the legacy links may encounter constraints (i.e. parks, bodies of water, existing structures, etc.), it is assumed that these legacy links will go around those constraints.

All of the scenarios take existing links as a baseline and consider them for expansion. The scenarios differ in what links to consider for new construction. Scenarios 1-6 all use only legacy links as links that are eligible for new construction. Scenario 7 adds to that and develops a set of additional potential links that have not been pre-specified on maps. Because of the relative scarcity of legacy links that are available for investment, in Scenario 7 a large set of links for new construction are generated using Levinson and Kalamaputi's (2003 b) model.

In Scenario 7 a choice set for potential new construction begins by identifying all existing node pairs that meet a specific set of criteria. The type of potential link is identified based on the highest level link coming into each of the nodes. If a node is attached to a freeway link, a potential new link will be part of the freeway link level. The potential links are constrained: new streets cannot cross existing higher level roads – highways or freeways, but freeways and highways can cross streets. Every combination of two existing nodes is considered and the possibility of establishing a link between them is evaluated. The candidate link should be longer than 200 meters and shorter than 3200 meters in the Twin Cities area. A total of 14,826 potential links are identified in the

Twin Cities Metropolitan Area, though only a few of them are constructed each year according to the traffic condition and budget constraints.

Potential links that would cross parks, water areas and other ecological areas are excluded from the set (and will not be constructed in the model). However, legacy links with such constraints are constructed with a penalty in length since the link has to detour in order to get built. This penalty length was assumed to be 1.4 times the airline length, which is the straight-line distance from an origin to a destination without following existing road horizontal alignment. This is like giving the new link a 90-degree angle detour and consequently makes it more expensive to construct. It is assumed that all expansion and construction decisions for links are symmetric, which is typical in the Twin Cities Metropolitan Area. This means that in case of expansion and new construction an equal number of lanes will be added in both the ij and ji directions. However for one-way streets, only one-way expansion is considered, which allows asymmetric developments. Only legacy links that encounter constraints are allowed to be constructed.

While the expansion rules were more or less clearly identified as part of the interviews to established stated decision rules, in all scenarios the rules for new construction follow the revealed decision rules identified by Levinson and Karamalaputi (2003b). This requires several steps. We first identify supply and demand links for each possibility. Supply links feed the origin node of the possible link. Demand links are disperse traffic from the destination node of the same link. The second step is to find parallel existing links of each possible link.

There are four main parameters to identify the actual links that are parallel to the possible one.

1) Parallel degree
2) Perpendicular distance. The closer two links are the most likely they are parallel.
3) Distance between origin and destination of two links.
4) Length ratio. If links are similar in length ratio they are most likely to be parallel to each other. In this parameter if links are similar the idea is that one of the possible links could replace an existing one.

An empirical study decided weights of each parameter. All parallel indicators weights are added and then ranked between them to choose the most parallel existing link for each possible link.

Once all demand links, supply links and parallel links are defined, the cost for each potential link is calculated. All links are ranked incorporating the demand flow and supply flow, the flow to capacity ratio of parallel link, and cost for new construction. The distance to the nearest downtown, and population of the surrounding minor civil division are also relevant variables. The closer a potential link is to downtown the most likely that link will not be built due to extremely higher construction cost (i.e. ROW). A logit model is used to determine the probability of building a new link and then these links are ranked by the stated rules.

In Scenarios 6 and 7, revealed decision rules are used for expansion of existing links in addition to new construction. The revealed expansion model predicts how transportation agencies expand their network by considering the traffic flow, flow on adjacent and parallel links, cost, geometric location and constraints such as parks, and water areas. All existing links are candidates for expansion.

The likelihood for link expansion is estimated as a function of measurable properties such as flow to capacity ratio of parallel links, increase of VKT, distance to nearest downtown, flow on adjacent links, population increase on the nearest Minor Civil Division. These properties have a positive contribution on expansion likelihood, while capacity, length, flow to capacity ratio, cost and capacity difference compared to adjacent links reduce this likelihood. Both models were estimated by investigating expansion and new construction locations in the Twin Cities area since 1978. Most of the described variables are statistically significant and the model can well describe reality. More details can be found in Levinson and Karamalaputi (2003a).

It is assumed that all expansion and construction decisions for links are symmetric, which is typical in the Twin Cities Metropolitan Area. This means that in case of expansion and new construction an equal number of lanes will be added in both the *ij* and *ji* directions. However for one-way streets, only one-way expansion is considered, which allows asymmetric developments.

Based on the dataset structure, corresponding links are identified in the opposite direction by looking for the most parallel link in the opposite direction within 30 meters. If we fail to identify such link, it is assumed that this link is a one-way link and asymmetric development is allowed.

Results

Scenario 1: Baseline: Stated Decision Process

Table shows all Measures of Effectiveness and lane kilometers for each 5-year period until 2030. Figure and shows the predicted expansions for the baseline scenario for the state and counties respectively. The state will construct continuations of Highways 610 and 212 in the 2005 period (i.e. between 2005 and 2009). In the 2015 period there will be some expansion on sections of I-35E and on I-494 west of I-35W. Sections of Highway 100, I-94, TH62 and I-494 show some expansion by the 2020 period. There will be some expansions as well on I-35W from south of I-94 to south of Bloomington by the 2030 period. Highway 10 will also have some expansions over time. There will be some other small expansions spread across the region as well. In the 2015 and 2020 periods the demand for new construction is in the northwest part of the metropolitan area.

Scenario 2: Most Formal Process

In Scenario 2, Hennepin County's decision rules are applied to all the transportation network links. In this scenario the State would build Highways 610 and 212 by the 2005 period. It would also make some expansions on Highway 169 by the 2025 period. In the 2015 period, the state will expand I-494 from Highway 100 to I-35W, as well some expansion on I-35E north of St Paul. By 2020 there will be a major expansion on Highway 62 and Highway 100 (). At the county level there are some expansions across the region. County Road 10, which runs parallel south of Highway 10 will have expansions on the 2010 and 2015 periods. There will be new construction on the northwest outskirts of the metropolitan area ().

Table 17 shows the results for this scenario. At the state level, expansions under this scenario are very similar to the ones made under Scenario 1. A major difference is that there is no expansion on I-94 between Minneapolis and Saint Paul (unlike the base scenario). At the county level, this scenario is also similar to the base scenario; the main difference is the sequence of expansions. On both scenarios County Road 10 and Highway 10 get expanded, but under Scenario 2, it happens earlier.

Scenario 3: Least Formal Process

In Scenario 3, Scott County's decision rules are applied to all transportation links in the system. Even when these decisions are fairly simple, this scenario also produces the construction of the legacy links. One of the main differences between this scenario and the base scenario is the expansion of Highway 7 between Minnetonka and St Louis Park in the 2015 period. At the state level there are some major expansions on the south part of the Beltway, which includes I-494 between Highway 10 and Highway 77, and on I-35W south of I-494 to Burnsville (). At the county level there are some new links constructed by the 2020 period similar to the base scenario. This scenario shows more expansion in the 2030 period on the Saint Paul area than the base scenario. Expansions on County road 10 are done in the 2020 period (later than the base scenario suggests) (). Table shows the results for this scenario.

Scenario 4: Budget Change Sensitivity Analyses
It was found in every interview the same response when it came to investments: there is not enough money to invest on what the network requires. This research wanted to test how much more investment would be enough to provide a better transportation network.
For this scenario there are five different sub-scenarios. The budget allocated to each jurisdiction is increased by 100%, 200% and 400%, or reduced the budget by 10% and 25%, for every time interval. Results for this scenario can be seen in Tables 19-23 and .

A noticeable expansion is made by the State under the +400% scenario (the other expansion scenarios are between the base and +400%). It appears that in the 2005 period, expansion happens inside the beltway, in the 2010 period expansion occurs on links that connect the center of the area with the beltway, in the 2015 period expansion happens on links that connect the beltway with the outer side of the area, and in the 2020 period, the expansion would occur on the beltway itself (). At the county few clear trends emerge ().

It is a different story when the budget is decreased by a 25% shows that Highway 610 would not get constructed until the 2010 period while Highway 212 is still constructed in the 2005 period. There is some expansion on Highway 169 similar to the base scenario. Under this scenario expansions would occur at approximately the same time as the base scenario for both the state and counties ().

If the State were to increase the available budget by 400%, according to Figure 11, all the new construction projects (legacy links) would be completed by the 2005 period (2005-2009), and no more new construction would occur under that scenario in the following years. In contrast, if the state adopted the 25% budget decrease scenario, a total of 120 lane kilometers would be constructed in the 2005 period and 40 more lane kilometers in the 2010 period.

shows how the counties would invest over time on new link construction under different scenarios. As well as the state, if the seven counties increase the budget by 400%, a total of 100 lane kilometers of "legacy links" projects would be done by 2005. If there is a decrease of 25% on their budget, it would take until 2030 to construct the last 18 lane kilometers of new link construction. () show how the State (counties) would expand over time depending under each scenario.

Scenario 5: More New Construction
This scenario changes the allocation of the new construction-expansion budget to a 25-75% split. At the state level, this split affects when new link construction occurs. In the base scenario legacy links are constructed in the 2005 period while under this scenario the construction is pushed until the 2010 period (). shows that counties' new construction scheduled on the base scenario for a specific year is postponed under this scenario for 5 years in the future. For expansion, this scenario provides similar results to the base scenario, there are only a couple of links that are expanded in an earlier period of time under this scenario. shows the results for this scenario.

Scenario 6: Revealed Decision Rules, Restricted New Construction Choice Set
Revealed decision rules were developed from statistical estimation of actual investment decisions. Under this scenario, there is new construction at the same time as the base scenario suggested. In the 2015 period there will be important expansion on Highway 10 crossing Coon Rapids, in this year there is also expansion on I-35W from I-35E to where it merges with

Highway 10. In the 2010 period, Highway 212 is expanded going west. In the 2020 period, I-94 going east towards Wisconsin is expanded as well (). At the county level there are significant continuous sections of roads that are expanded, most of them are in the south part of the Metro Area (). shows results for this scenario.

Scenario 7: Revealed Decision Rules, Unrestricted New Construction Choice Set

For this scenario at the state level there is no clear pattern either for expansion or new construction. It occurs across the region on different years (). Several hot-spots though include the area around I-394 west of Minneapolis and the I-94-I-35E Commons area in St. Paul. At the county level there is some new construction inside the beltway, especially in the 2025 and 2030 periods (). Numerical results for this scenario are shown in .

While this scenario would be investing in less than 10 lane kilometers of new projects per period, the investment would be continuous over 25 years, and not end after the set of legacy links was exhausted. By and large, these investments would not occur on the legacy links.

6. Summary and Conclusions

Performance Measures

A desirable characteristic of a transportation system is to be operationally efficient. There are concerns about travel times, safety, congestion, and delays. Although perceptions are not always accurate, they indicate whether the system is working as well as it should be. Any transportation system has to have the goal of maximizing the community's benefits, the difficulty is defining what those benefits are.

Each performance measure has its strengths and weaknesses, but each one provides an important element in understanding how the transportation network is working and where it is heading in the future.

Good measures of effectiveness have a number of characteristics that make them easy to understand, simple, compatible and multidimensional (usable across time and at a different geographic scales). Data should be observable and at the same time be feasible, allowing a valid cross modal comparison at the right level of detail.

It is reasonable to recognize that although performance measures will not make politics disappear from the decision making process, they can ensure better and more efficient transportation systems because performance measures are dynamic tools that provide a good type of monitoring. At the same time they can compare elements that are an important part of the decision-making process and ensure that the investments made are in the most appropriate way.

This research aims to provide performance measures in a more realistic and practical way, in order to have a complete view of the transportation system as a whole.

This research, perhaps for the first time, made forecasts of changes in transportation networks as a function of empirically derived models, using a travel demand model based on economic theory and observed information. While one must treat with caution any specific results, the exercise is valuable.

The performance measures obtained from different scenarios are shown graphically in the following figures: shows the accessibility that the system provides to the users. In general every scenario that was compared in this figure provides better accessibility in the year 2030 than in the year 2005.

The following scenarios were tested:

1) Baseline: Stated Decision Process to all counties for existing links.
2) Most structured decision rules (Hennepin County rules) in all counties
3) Least structured decision rules (Scott County rules) in all counties
4) Budget changes (a) +100%, (b) +200% and (c) +400% (d) -10% and (e) -25%.
5) Change split between budget expansion and new construction to 25-75.
6) Revealed Decision Process: Levinson-Karamalaputi (LK) model for expansion and new construction (with only legacy links available for new construction).
7) Revealed Decision Process: Levinson-Karamalaputi (LK) model for expansion and new construction (with full set of potential new links available for new construction).

There is no major difference between scenarios. This is largely driven by two factors, first, the land use distribution is the same in each scenario (i.e. there is no land use response to network changes in the model), and second, the vast majority of the network is the same in each scenario, the total amount of change to the network is relatively small compared to the size of the network as a whole.

According to , between the scenarios that are being compared, Scenario 1 provides the highest trip time by 2030, and the Scenario 4c (Budget increase by 400%) provides the lowest trip time. It is interesting that even Scenario 3 (Least Structured decision process) would result in less trip time than the base scenario.

While the relative positions of trip times across the scenarios are plausible, the steep increases in trip times over the years may be exaggerated (if historical changes are any guide). We believe this is related to a variety of modeling assumptions, most significantly, the land use assumptions, which are not likely reasonable in forecast years, the lack of peak spreading in the model, the relative insensitivity in the gravity model to changes in travel time, as well as changes in travel demand at external stations, for which we have a very simplistic forecasting procedure.

As the budget rises, the Vehicle Kilometers of Travel (VKT) rises (
Figure). In the scenarios where the budget is expanded, the network expands, accessibility increases (), and consequently users will spend less time on the road () (and systemwide Vehicle Hours of Travel (VHT) declines ()).

One measure of effectiveness is the average travel time per trip (). For 2030, Scenario 4c (with a 400% budget increase) provides the lowest trip time between all scenarios. It is around 8 minutes less per trips than Scenario1 (base). Scenario 2 (with the most structured rules) provides 6 minutes less as well. Scenario 3 (with the least structured rules) and Scenario 5 (favoring new investment early on) have 5 minutes less than the base scenario. Similarly, by 2030 all scenarios provide less vehicle hour travel than the base scenario. If these travel time reductions could be given a monetary value, all users together would be saving millions of dollars per year (considering drivers time on the road has a price).

Scenario 4c (which increases the budget by 400%) provides the highest accessibility of all scenarios every period of time. Scenario 6 (Revealed decision rules) provides the least accessibility. The other scenarios were very similar to Scenario 1 (the base).

shows measures of effectiveness for the year 2030. It compares vehicle hour travel, vehicle kilometer travel, trip length, trip times and accessibility between the seven different scenarios. If all scenarios are compared to the base scenario, scenario 4c provides the greatest benefits.

In the modeling process, we assumed that “legacy links”, those links that are on state plans but unbuilt would be built under almost every scenario (Scenario 7 excepted). Thus Highways 610 and 212 will be constructed in either 2005 (i.e. 2005-2009) or 2010 (i.e. 2010-2014).

Only one scenario provided freedom to construct new links that had not been predesignated on plans (Scenario 7). Even though this scenario was the most distinct, even the overall results here were fairly similar to the other scenarios because budgets constrained how much new capacity could be built. It would be valuable to examine the kinds of changes to the network that might occur if more new construction could take place, and it were less confined to existing plans. The legacy links will soon be completed, it is unclear whether this means there will be no additional new links on the network.

This research finds that in order to provide a significantly better transportation network given the system’s mature stage, there is a need for investment. According to this research, greater investment resulted in lower travel times and as result higher accessibility. Specific decision rules applied to the network only make marginal changes in network performance compared with changes in total investment.

Decision-Making

To document the process of network investment decision-making; starting from an idea of a project, its evaluation, its results and finally its construction, this research interviewed a number of engineers, managers, planners and staff members from a variety of jurisdictions.

This research found a gap between how staff perceives the decision-making process and how official documents suggest it happens. Most of the interviewed persons at different levels of government refer to official documents, saying that the selection process takes into consideration different issues, as safety, capacity, pavement conditions, and so on, but they did not give a clear answer on how projects that are in those official documents get selected. There could be a number of reasons for this, budget issues, many different types of funding, delivery readiness or simply politics. It seems that the process is more complicated than a straightforward selection criteria. Staff members know broadly what projects are needed on the transportation network, but they are not sure how their priority is given and specific projects emerge from the process.

The findings suggest that in the past, projects were basically selected depending on the engineers' perception of the transportation system. However, safety issues, road conditions and capacity were present in the engineers' minds when selecting projects. The decision-making process may not be the same from 50, 20, or 10 years ago, but the lead variables used to identify a transportation problem have not changed much over time.

Presently, even at levels of government that do not have a ranking system, the main criterion is based on performance measures, safety being the most important among them.

The findings indicate that counties that are around the main core of the Twin Cities do not have a ranking point system structured, while Hennepin and Ramsey Counties, containing Minneapolis and St. Paul, do. But each one of them has some type of criteria when selecting projects. And the more developed counties that contain the center of the Metropolitan Area have a more formal decision-making process and a ranking system. The Metropolitan Council also has a formal process for their solicitation.

MnDOT does not use a formal process, such as the one described in the 1997 Transportation System Plan and now prefers to use a more informal, less quantitative process. While this process decreases transparency in the system, the public is invited to participate fully in the Transportation Systems Plan planning process.

Some jurisdictions declined to endorse the flowchart presented and did not provide any other alternative. The main reason for that was political concern because there is an implication that such a "restrictive" process could bring some controversy and issues between the community, the jurisdiction and politicians. Because all levels of government face limited budgets and irregular ways of funding, having a more quantitative approach to the selection process may help to provide the best solution for different transportation issues.

Future research should make a comparative detailed analysis of decision-making rules between different metropolitan areas. This analysis would have the purpose of pairing measures of effectiveness with those decision-making rules of each area, which would produce a more realistic way to identify what users want and perhaps be able to establish a correlation between investment policies and community characteristics.

Modeling

From a modeling perspective, improvements can proceed in several directions. First, the step length between iterations can be reduced from a five-year model to a one-year model. One of the reasons for wanting to change from five-year model to one-year model is to test an evolutionary model of network growth. Only a fraction (say 20%) of all work trips change destinations in a given year. In an evolutionary one-year model, this means that 80% of trips in previous year would not change, only 20% of OD demand in that year and additional OD demand this year will be redistributed according to the congested travel time calculated at the end of the previous year.

Clearly, improvements can be made to the investment models; particularly in the way resources are allocated between new construction and expansion of existing facilities. The available information in those cases is different, resulting in different criteria used to prioritize those types of decisions. Additionally, better models of total revenue, and revenue available for investment, should be aimed for. Assuming a fixed share of total revenue is invested is unlikely, as the network grows and matures, we expect an increasingly large share would be associated with maintenance and preservation, though the data from the past decade do not point to any clear trends

Overall

A major criterion we were unable to model was pavement condition, due to a lack of geographically accurate and complete data on the current pavement condition across the regional network. Should this data become available, it would be useful to re-introduce this variable as a factor affecting the timing of investments.

One of the great benefits of a modeling exercise such as that conducted in this research is not simply the predictions, it is that the process, which requires coding decisions into a computer program in a logical way forces the specifications of all of the assumptions that are often expressed vaguely in typical spoken and written human communication. There are many parts of the decision-making process that are underspecified in written documents, leaving ambiguity and opportunities for special-case politics rather than systematic consideration and evaluation of decisions according to agreed upon principles. While that ambiguity may be intentional, it reduces transparency in the system and opens it up for manipulation.

Over time, the process of decision-making may change but the lead variables used to identify the problem (congestion, safety, environment, pavement condition) and hence the decisions to expand are fundamentally the same. The weights associated with those variables do change. A more quantitative approach, with a formal process, may help to refine the selection process given limited budgets, but the impact on the system of different quantitative weights is relatively small so long as the budget is insufficient to make large investments. Furthermore, irregular funding will not make it easy to plan projects, and may cause projects to be selected that are "ready" (e.g. have passed EIS) rather than those that are best. The primary effect of irregularity of budgets, however, is likely to be in the timing of projects rather than the sequence.

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Tables and Figures

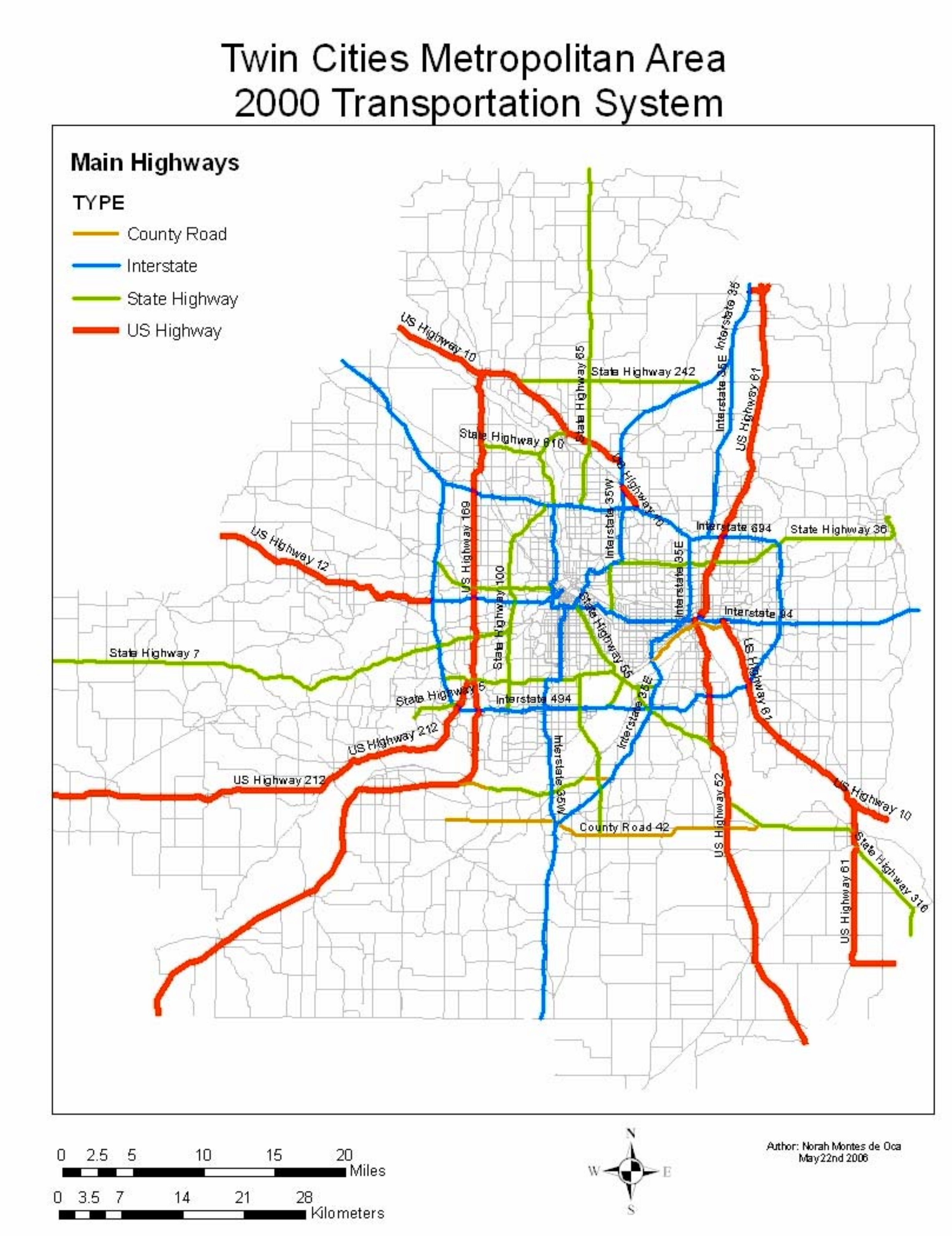


Figure 1: Twin Cities Metropolitan Area Transportation System

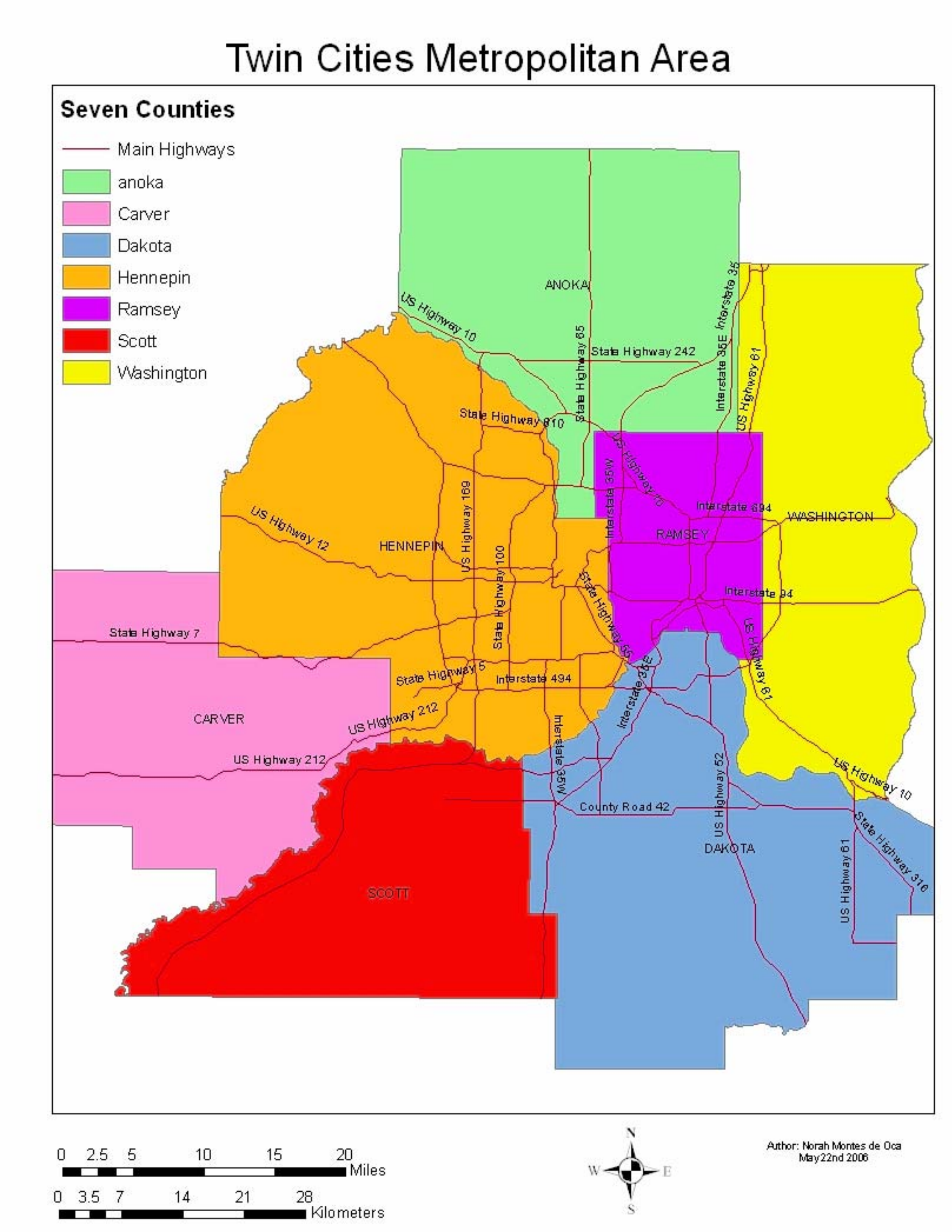


Figure 2: Twin Cities Metropolitan Area - Seven Counties

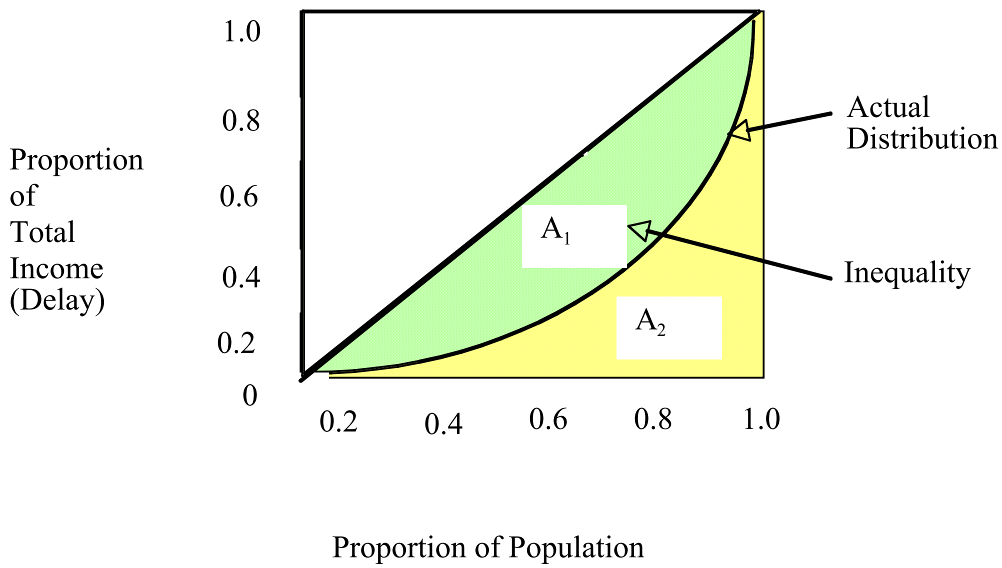


Figure 3: Gini Coefficient and Lorenz Curve

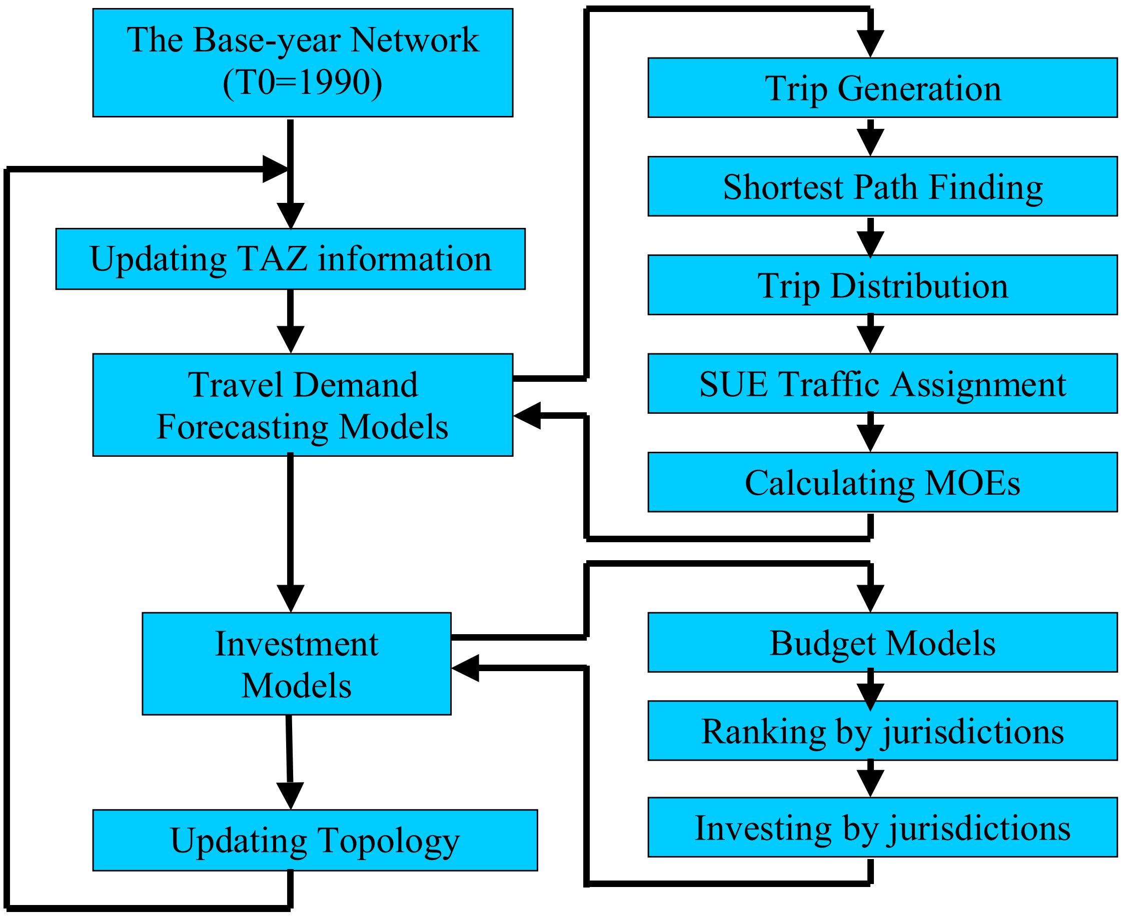


Figure 4: Detailed Program Process – SONG 2.0

The Flowchart of the Investment Models

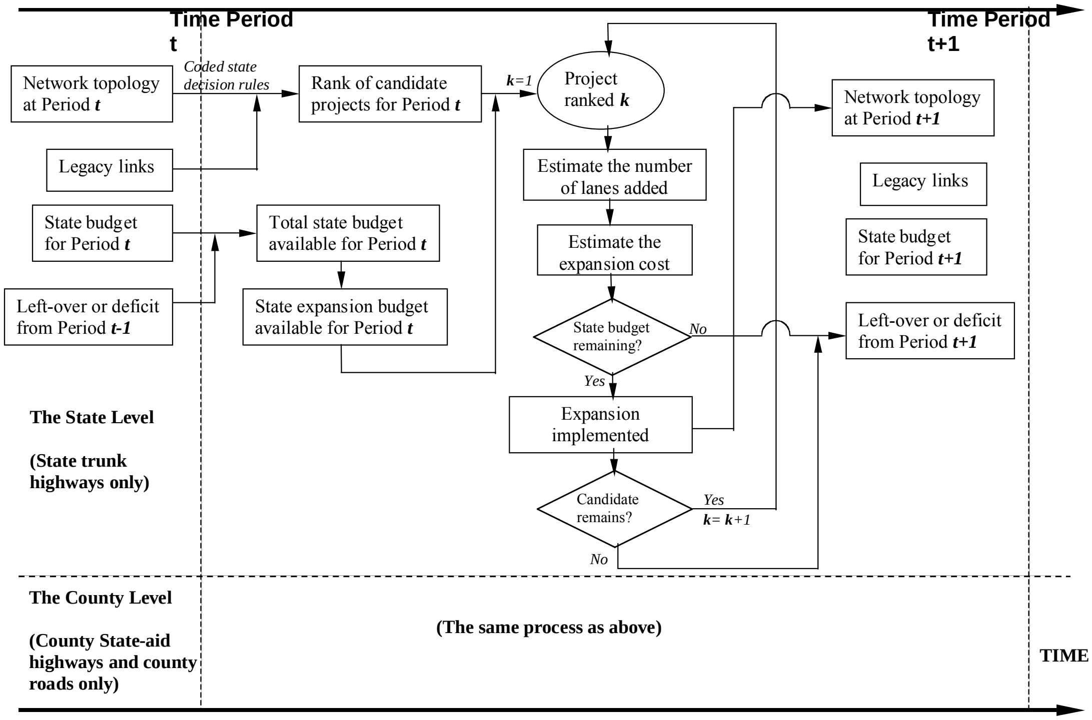


Figure 5: Investment Model Process

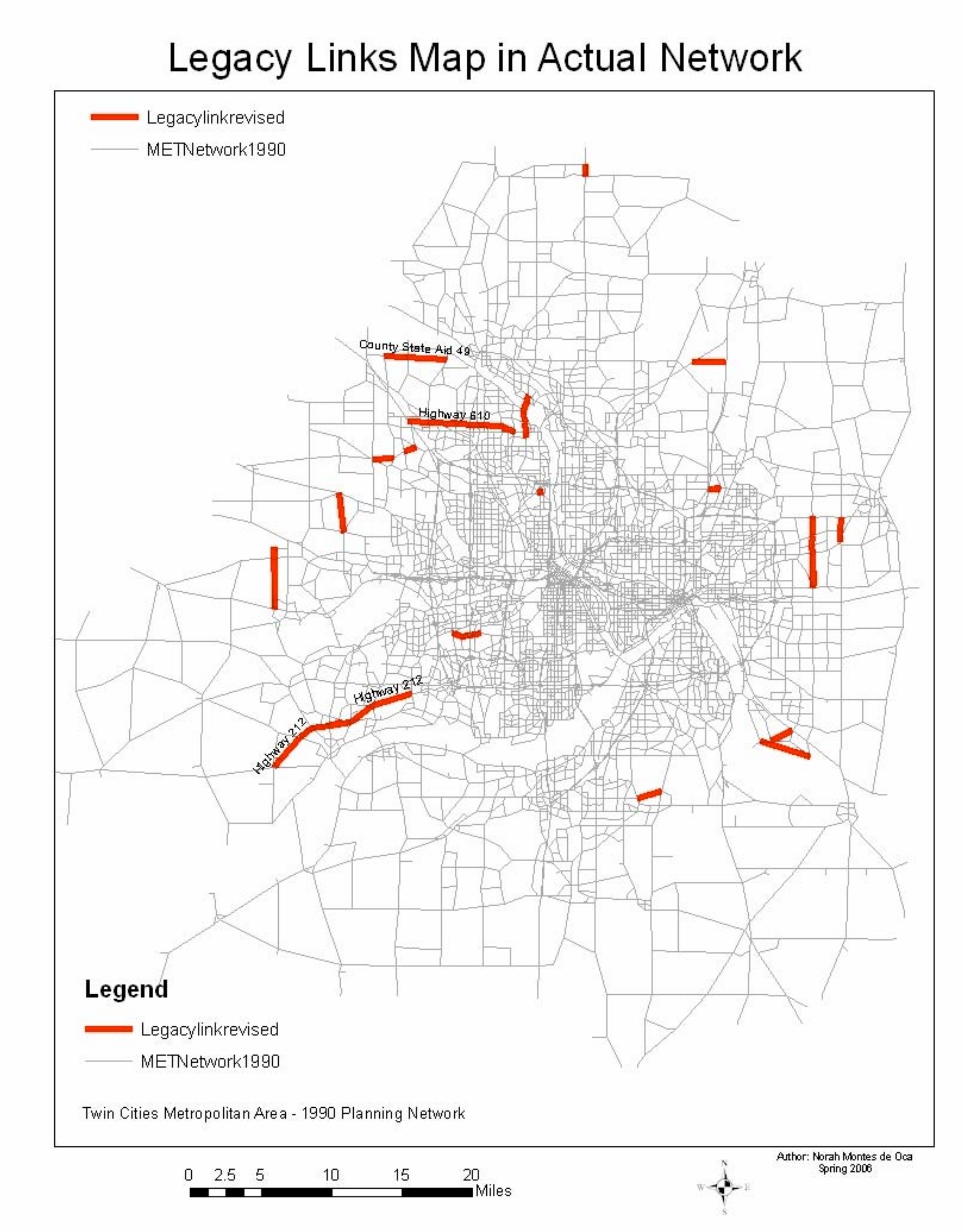


Figure 6: Legacy Links Map – GIS version

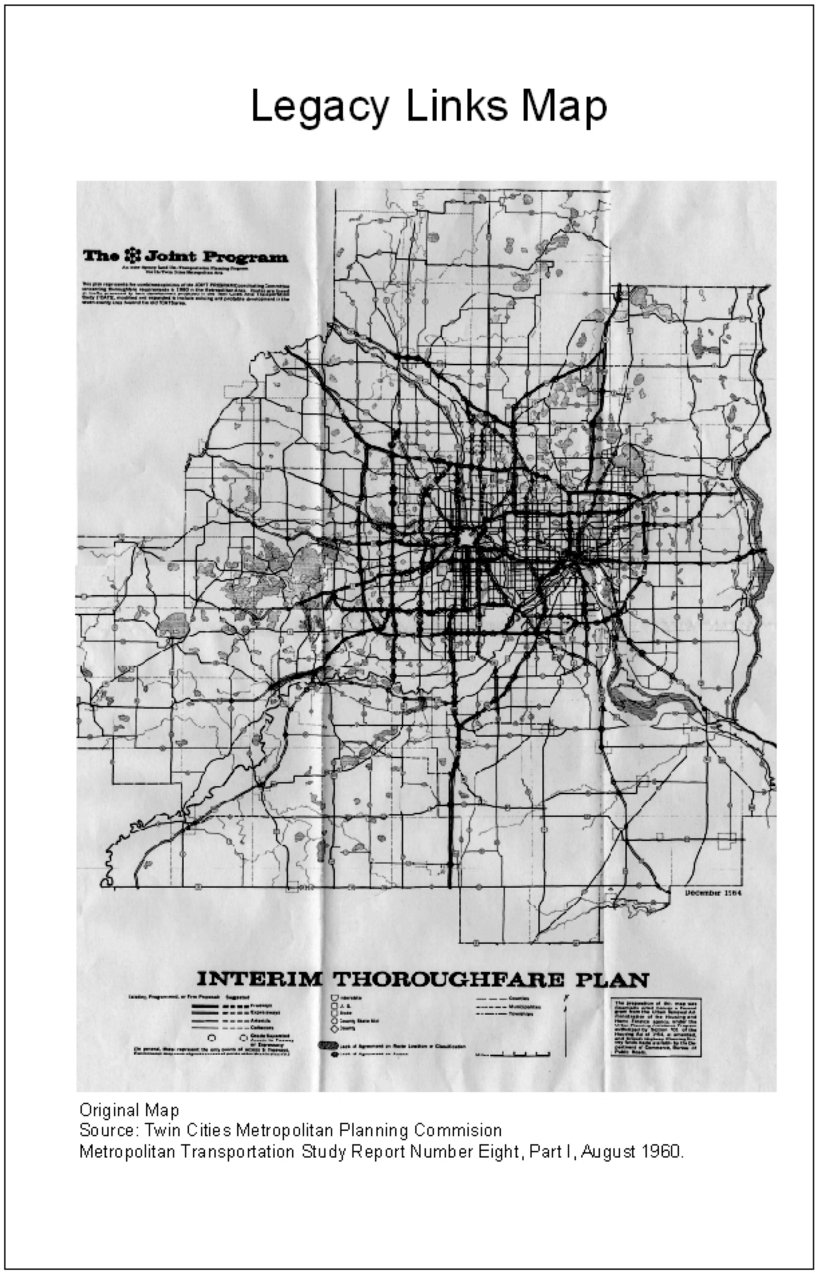


Figure 7: Legacy Link Original Map

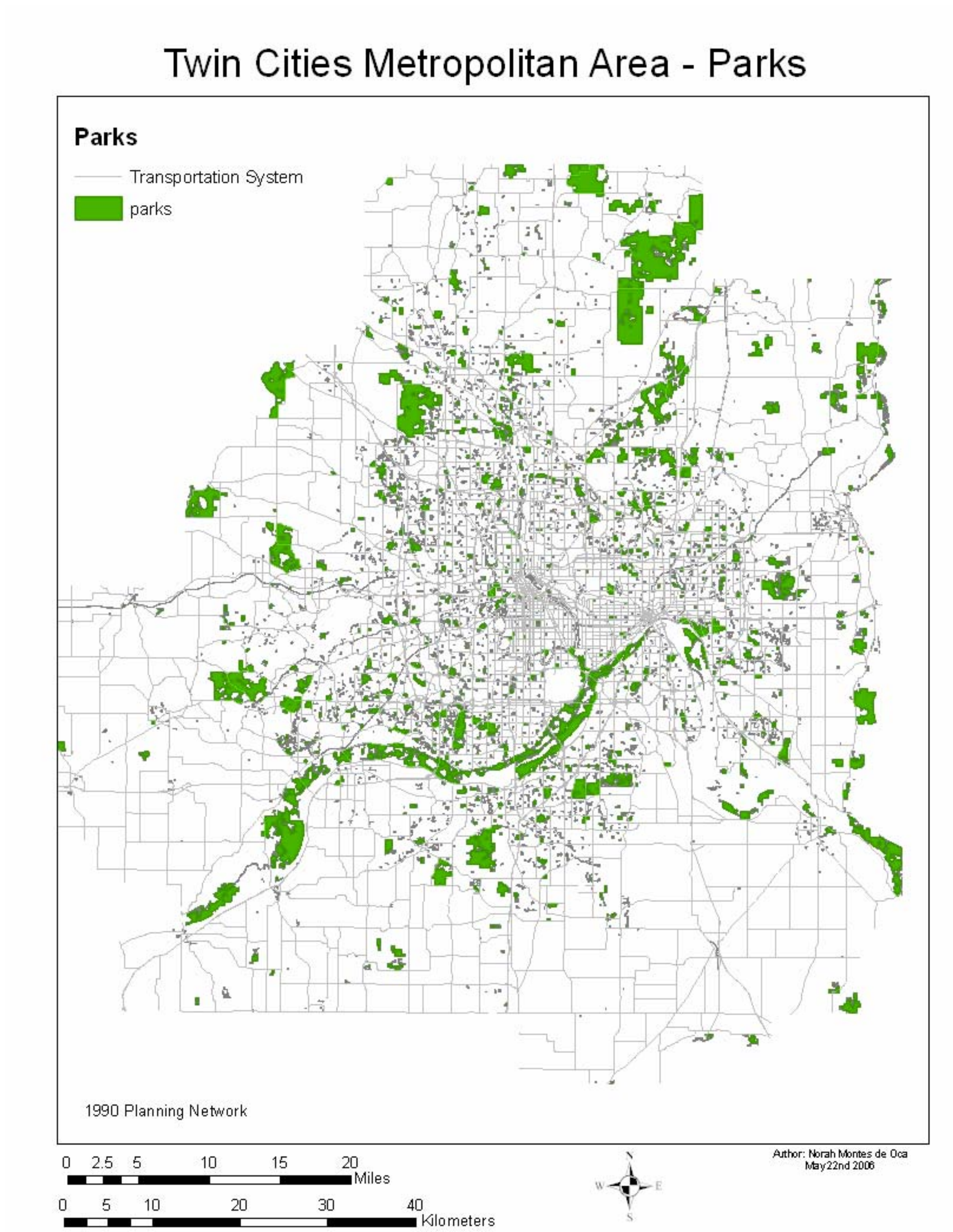


Figure 8: Twin Cities Metropolitan Area – Parks

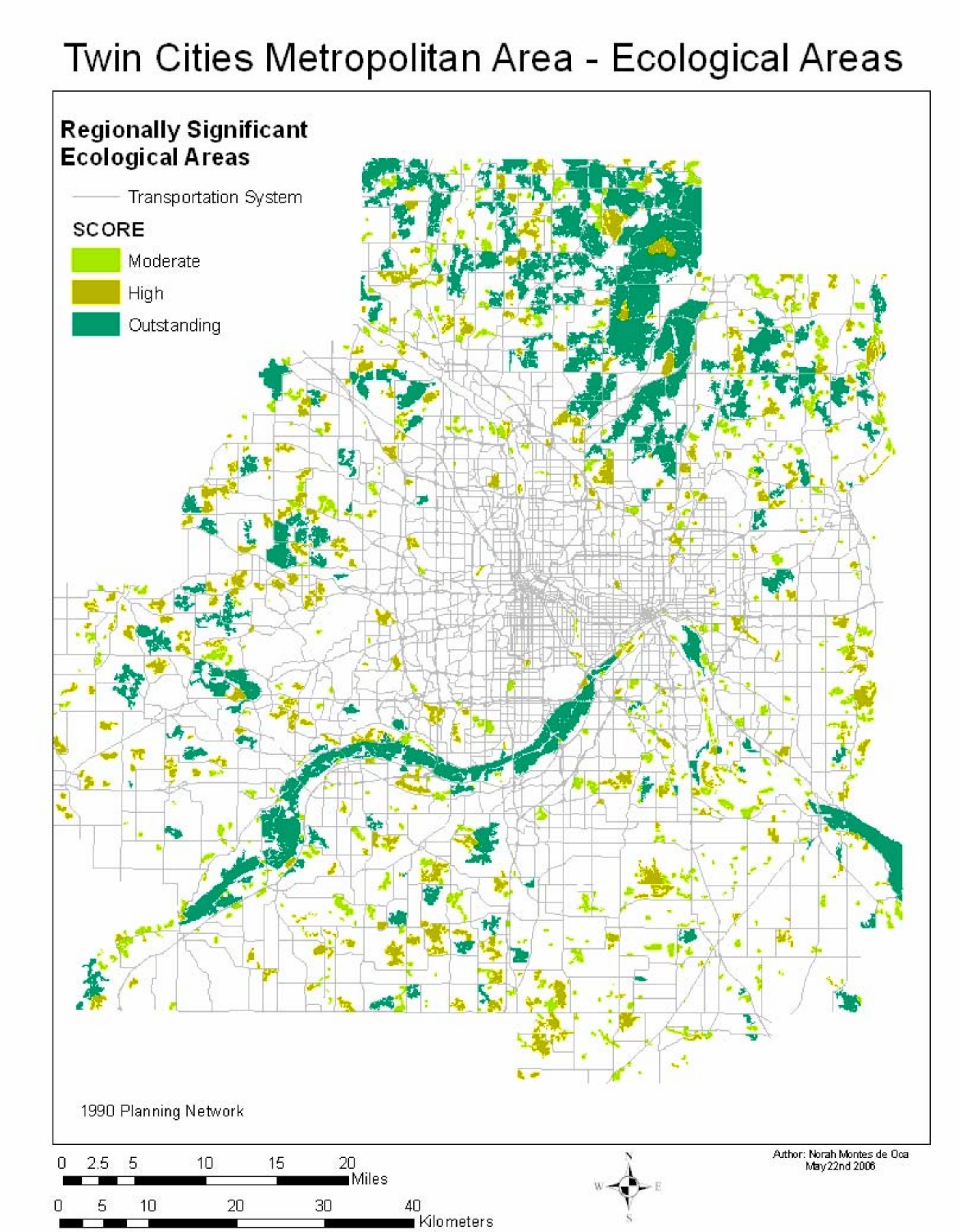


Figure 9: Twin Cities Metropolitan Area – Ecological Areas

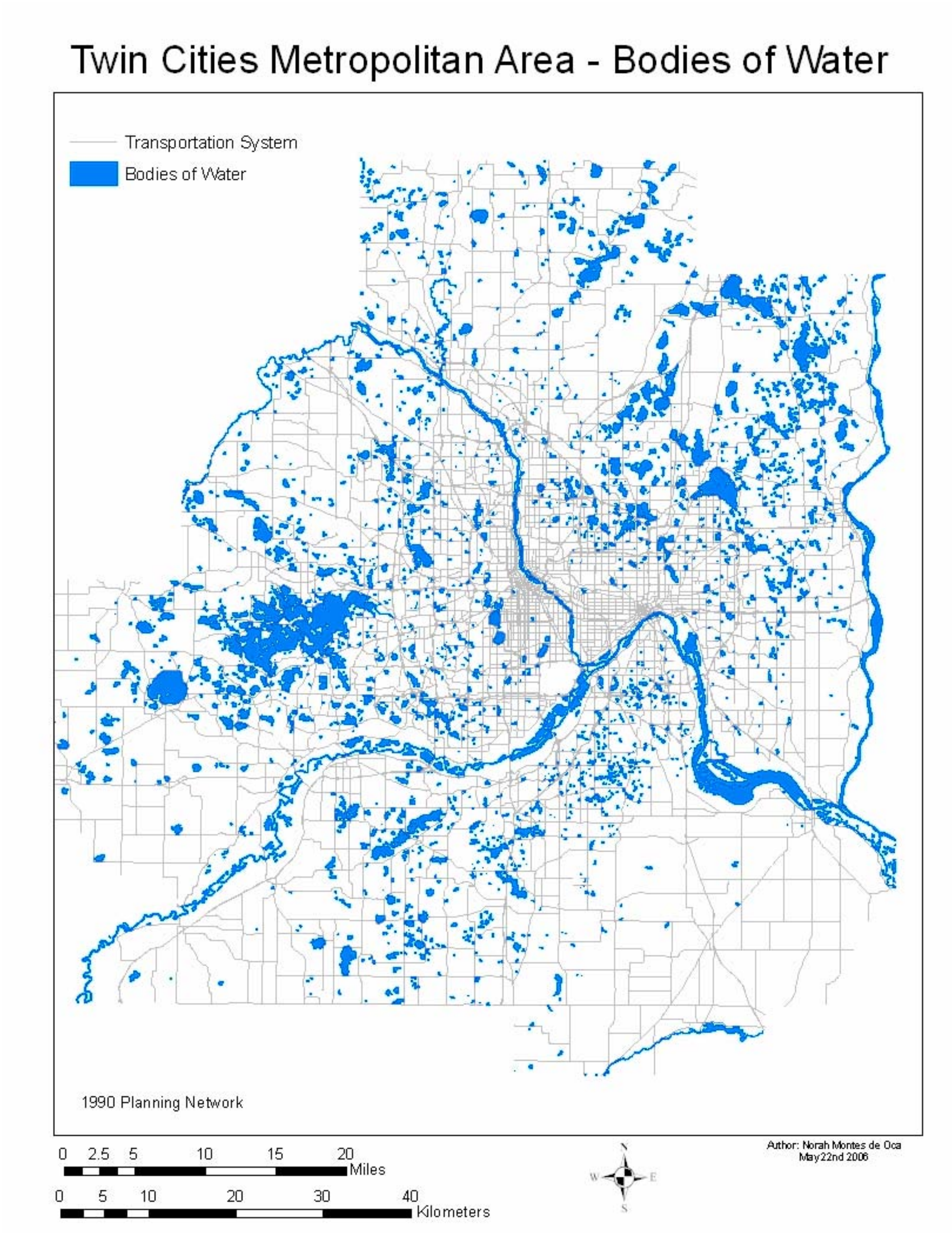


Figure 10: Twin Cities Metropolitan Area – Bodies of Water

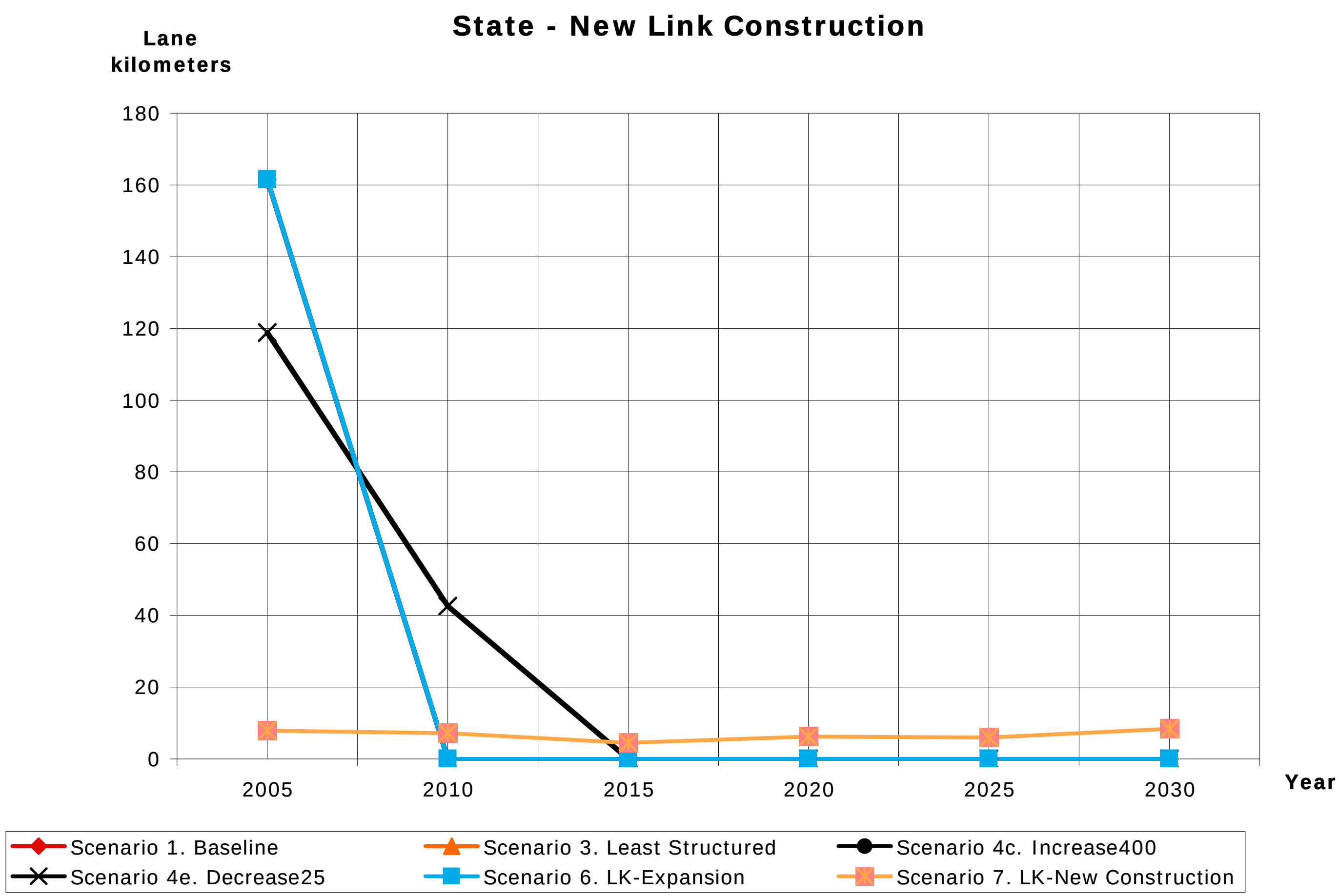


Figure 11: New Construction by the State for different scenarios

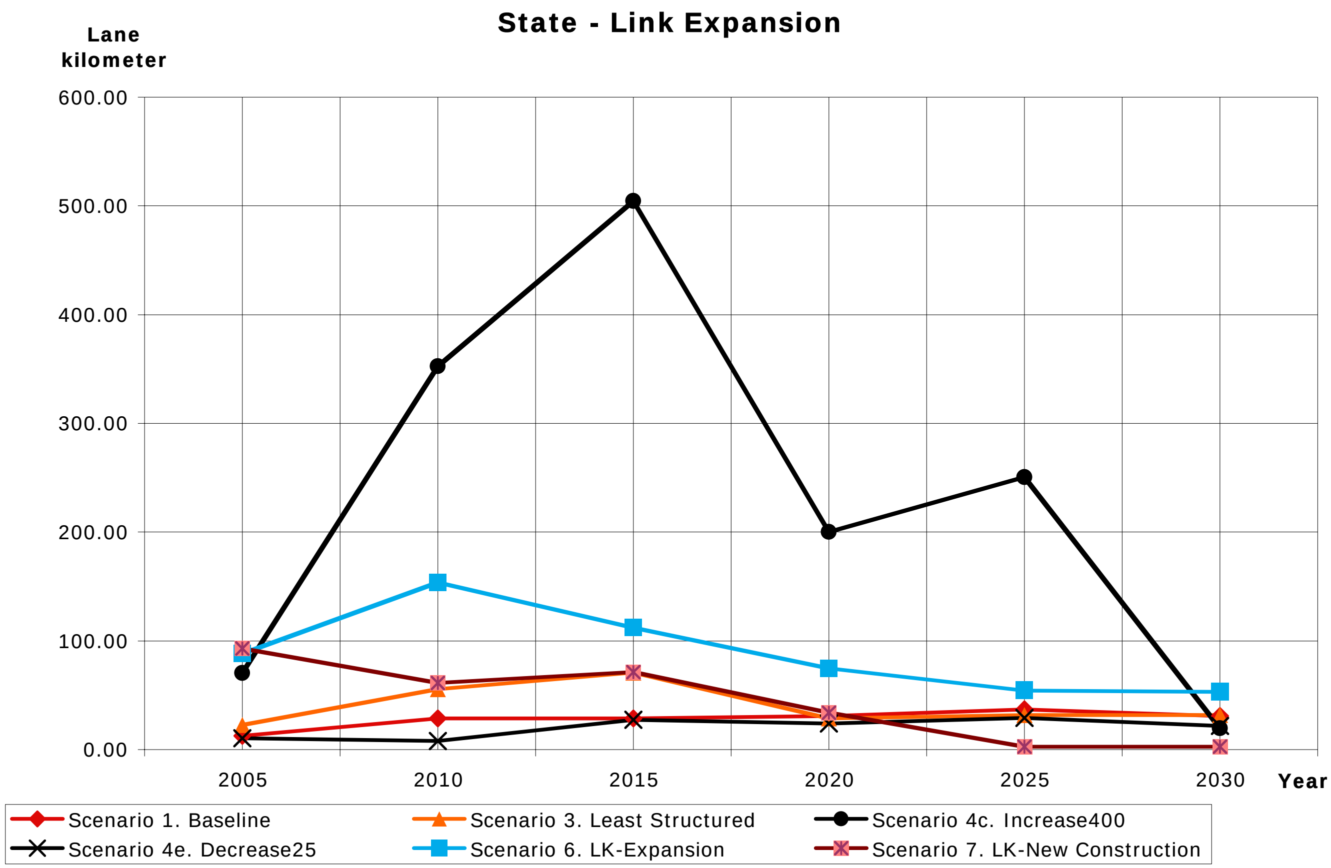


Figure 12: Link Expansion by the State for different scenario

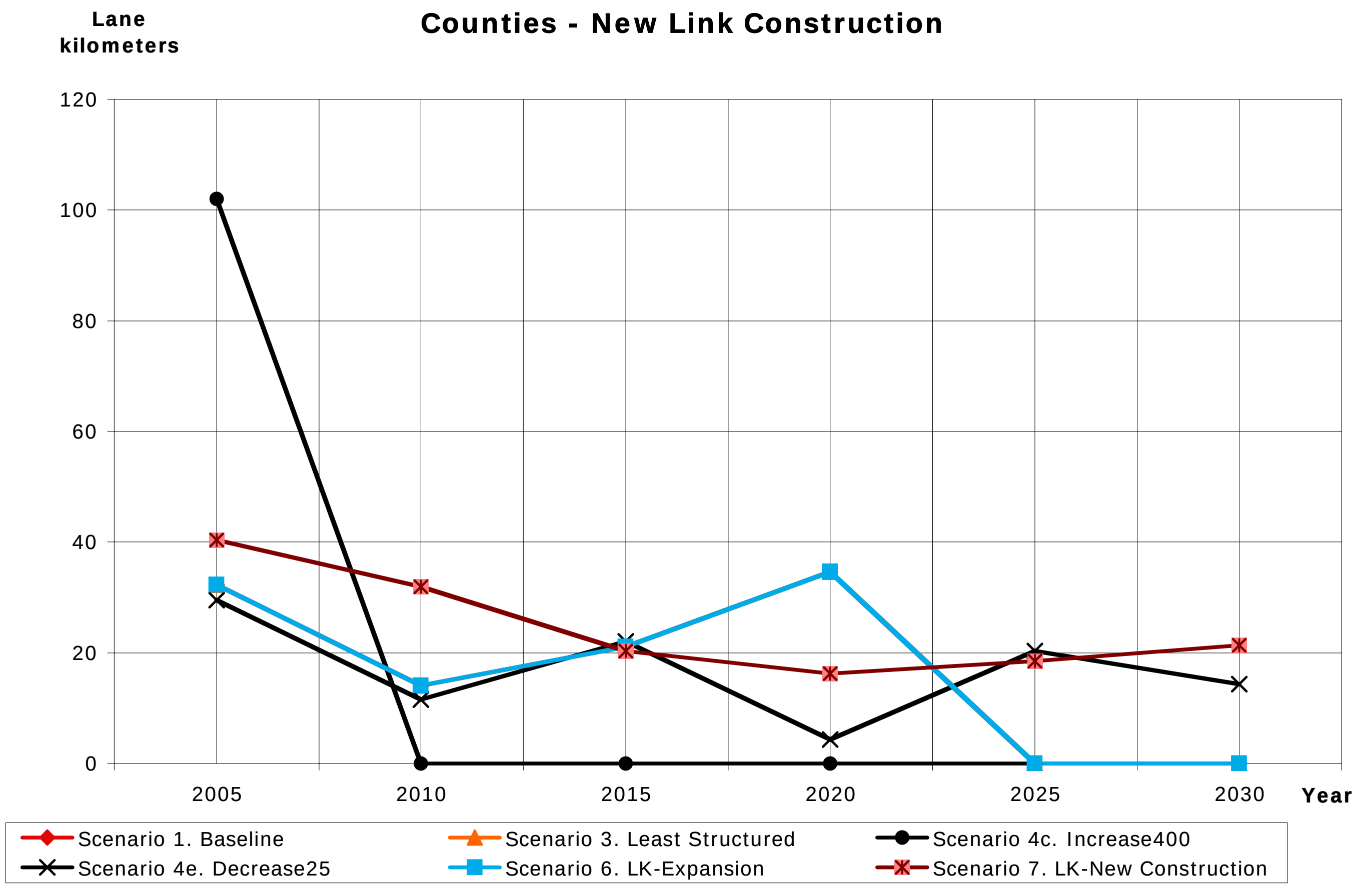


Figure 13: New Link Construction by the Counties for different scenarios

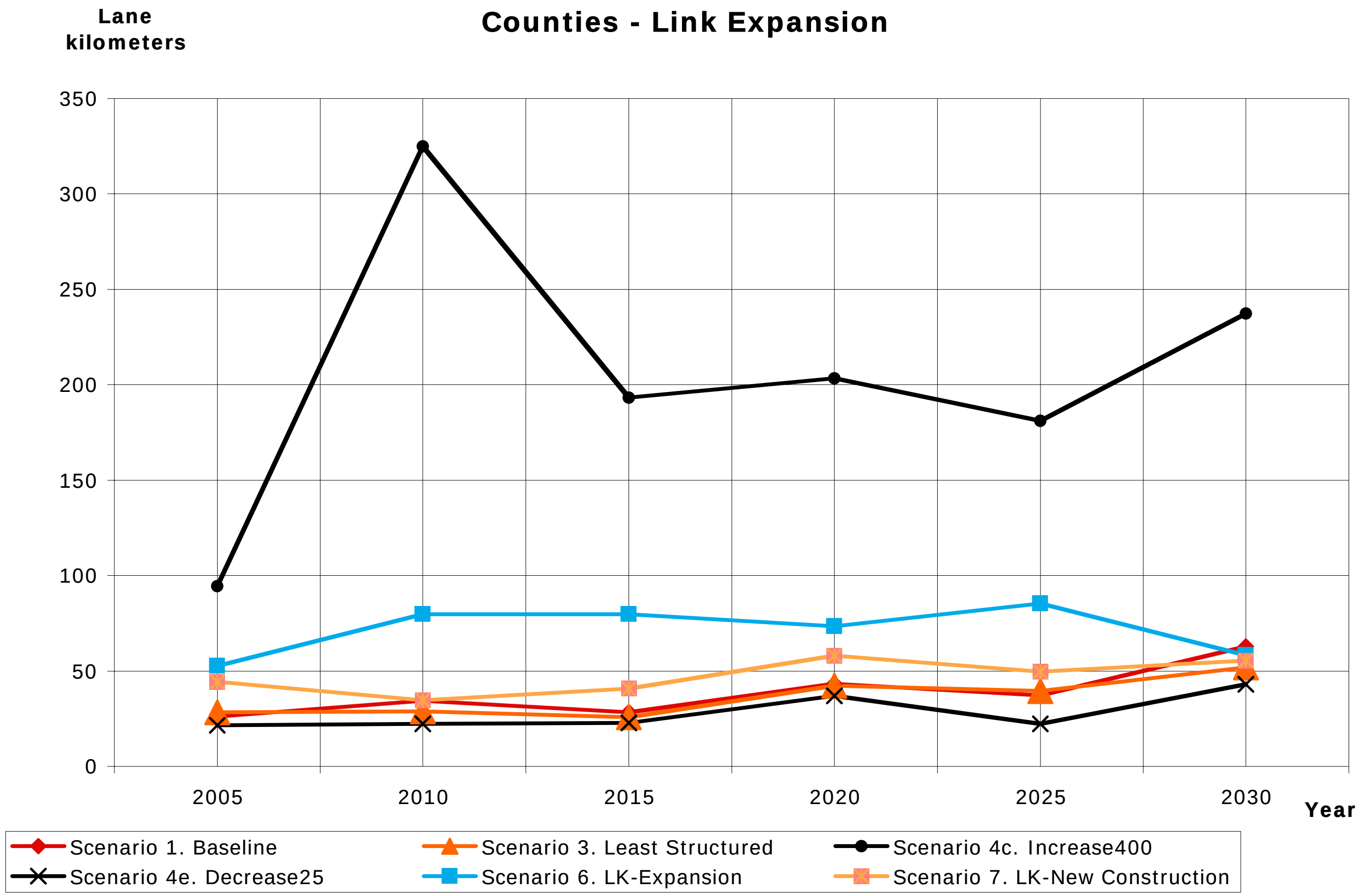


Figure 14: Link Expansion by the Counties for different scenarios

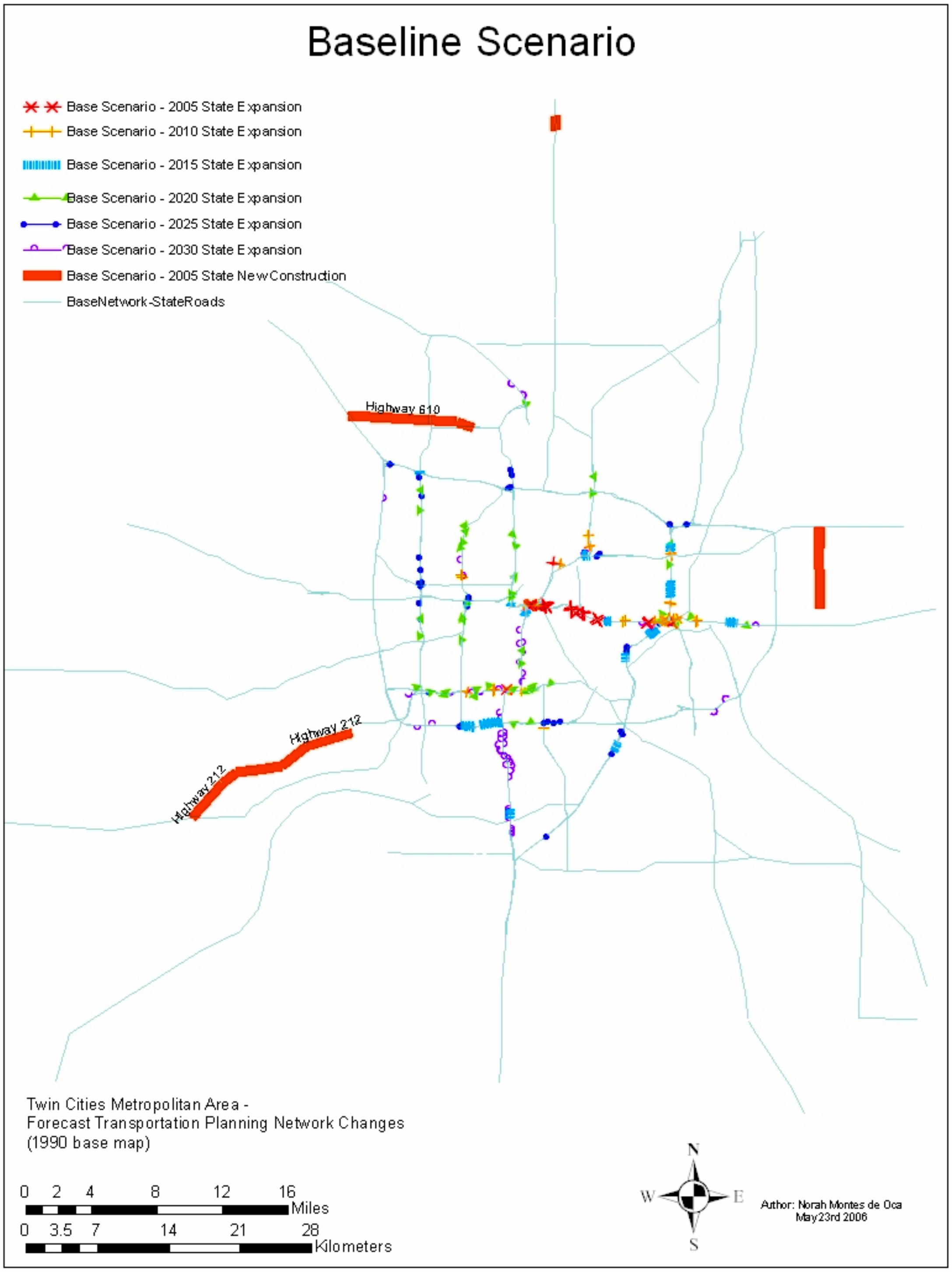


Figure 15: Scenario 1. Baseline - State

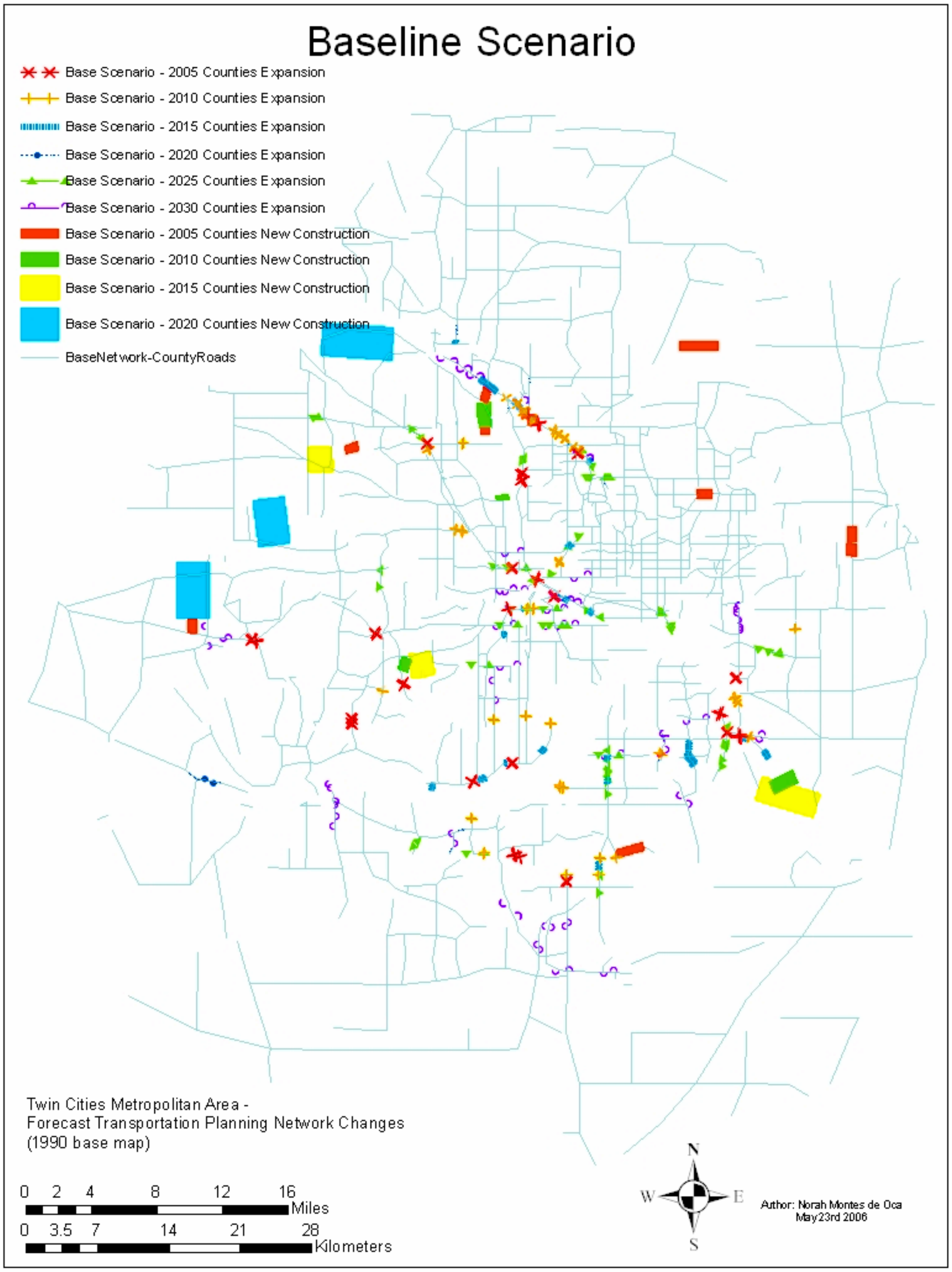


Figure 16: Scenario 1 Baseline - Counties

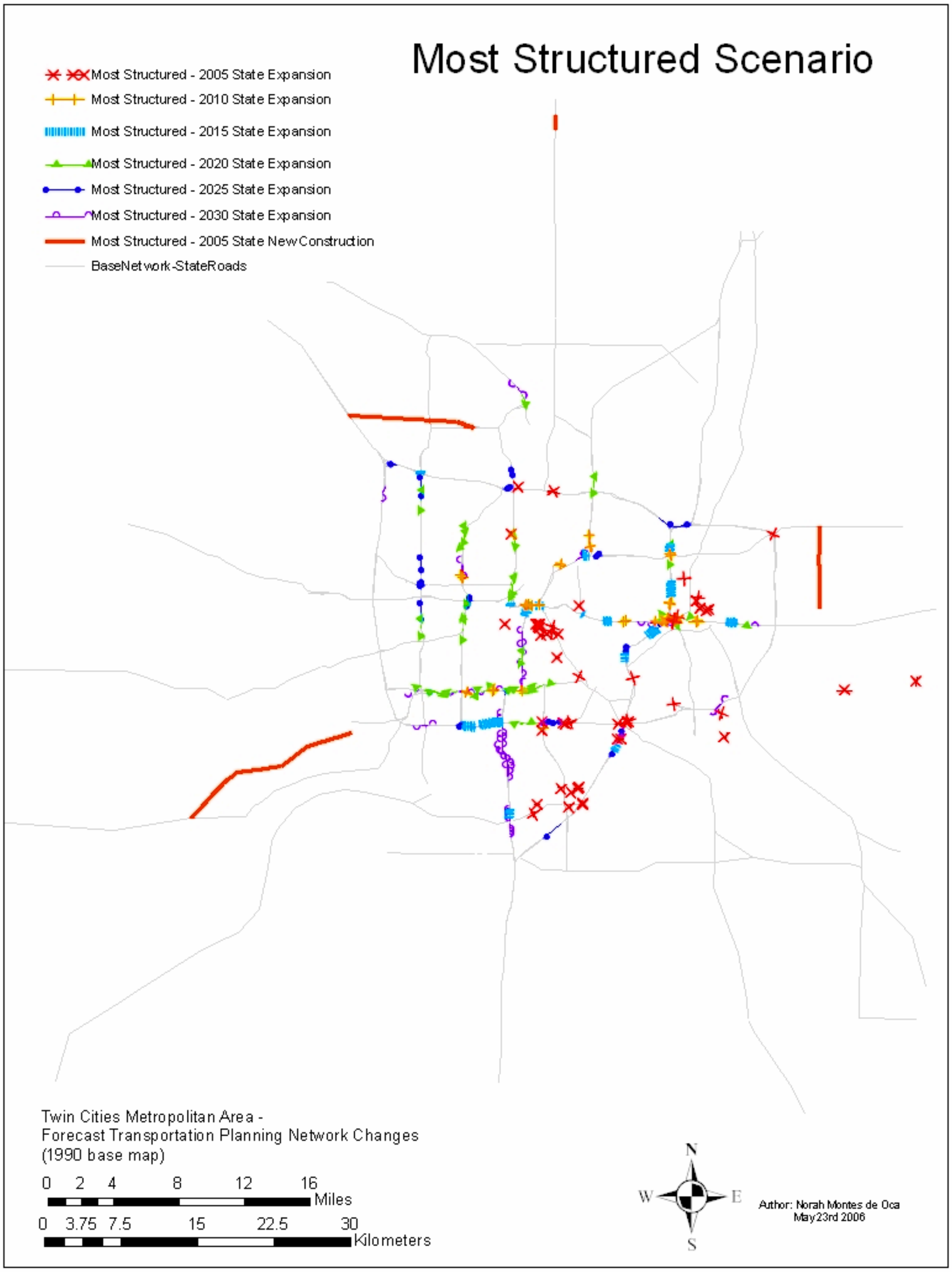


Figure 17: Scenario 2. Most Structured - State

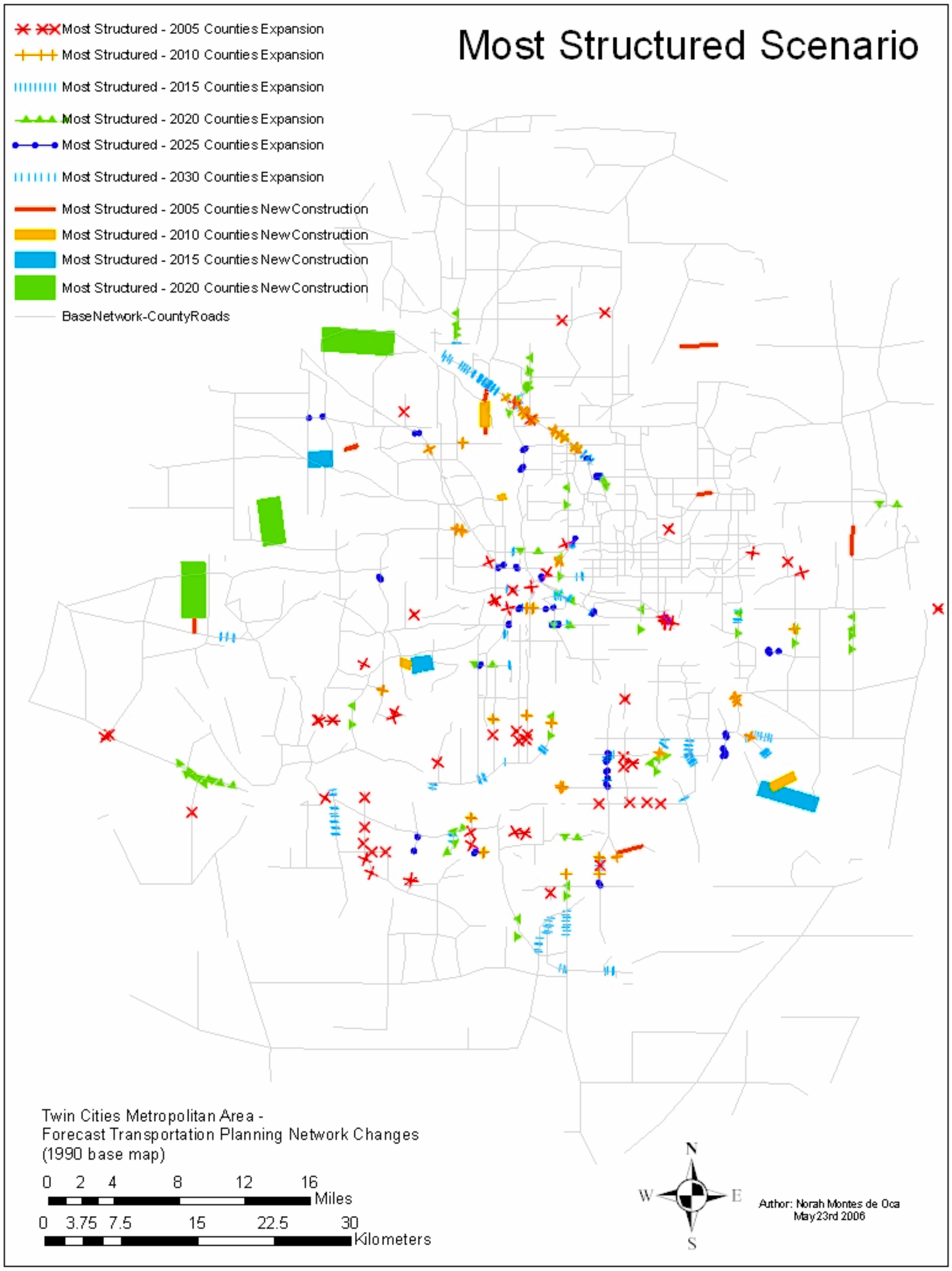


Figure 18: Scenario 2. Most Structured - Counties

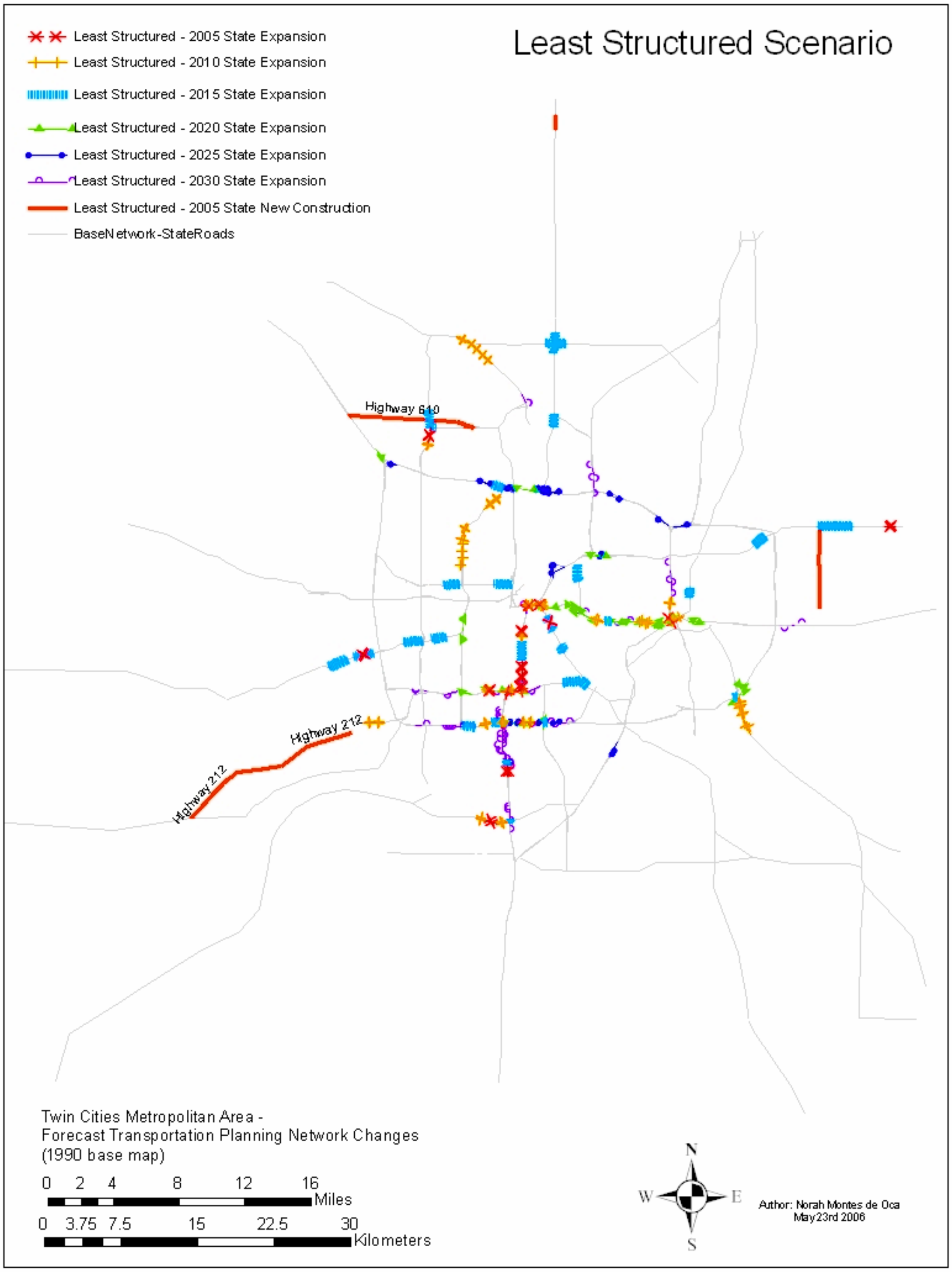


Figure 19: Scenario 3. Least Structured - State

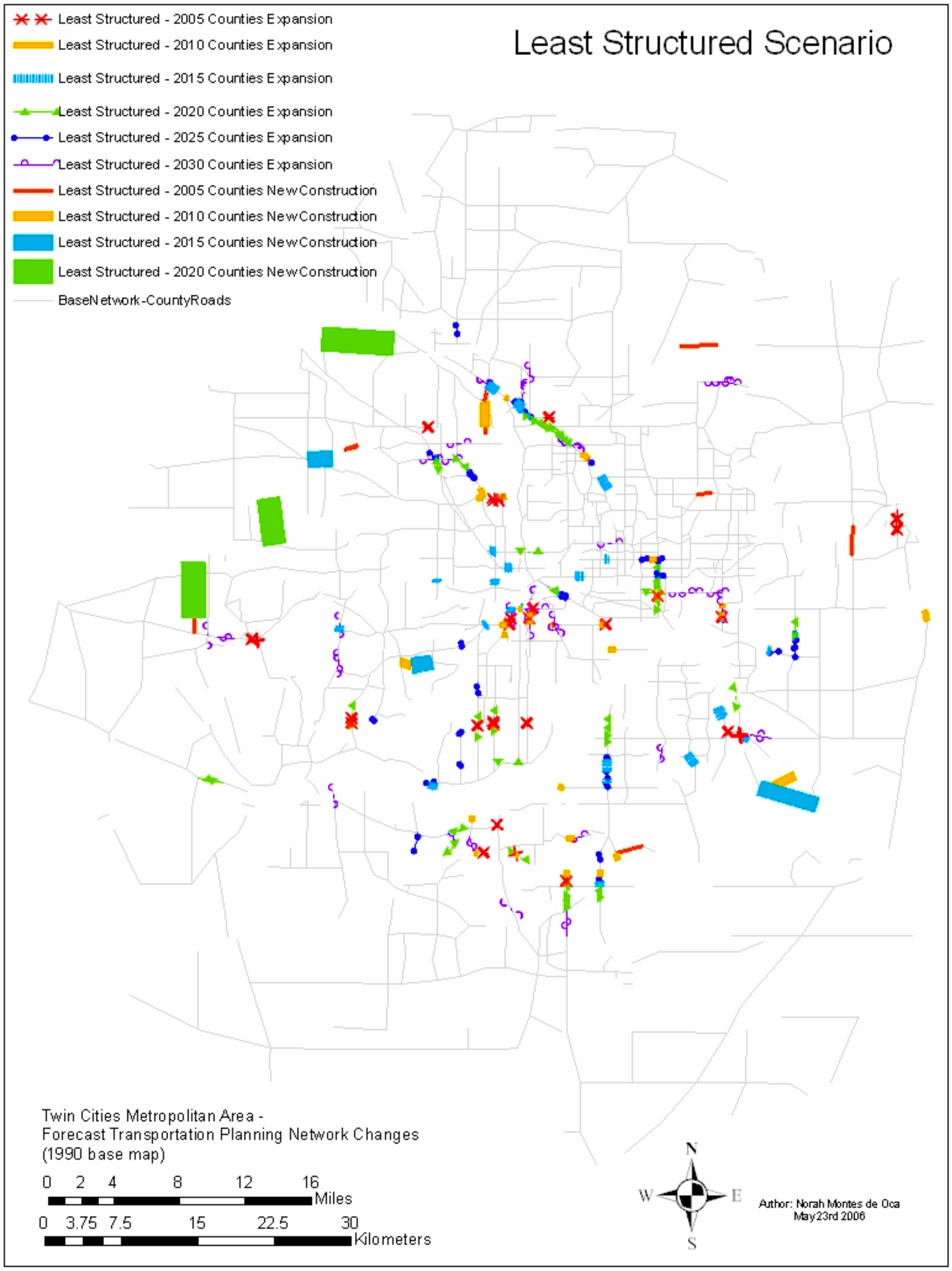


Figure 20: Scenario 3. Least Structured - Counties

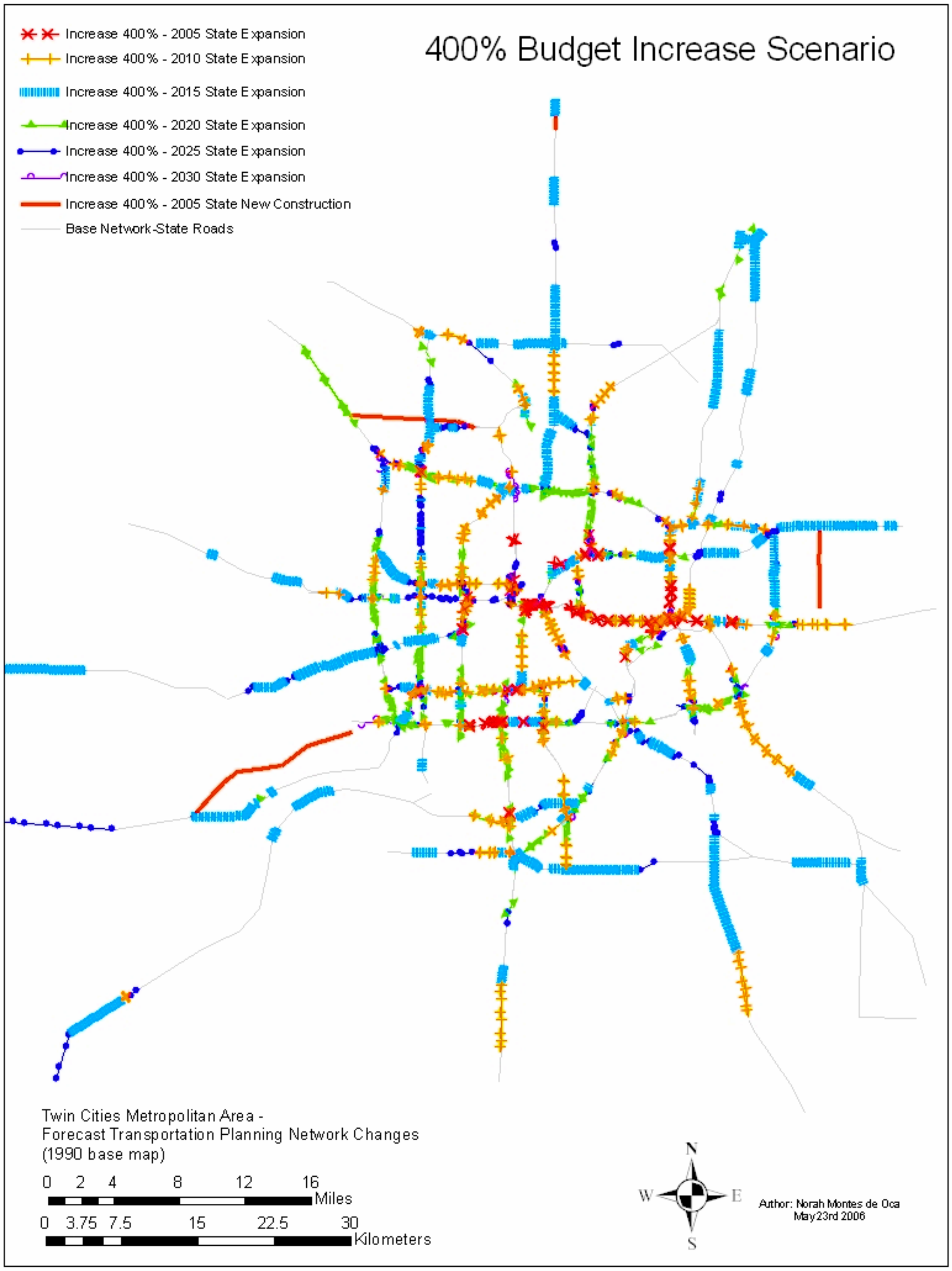


Figure 21: Scenario 4c. Budget increase by 400% – State

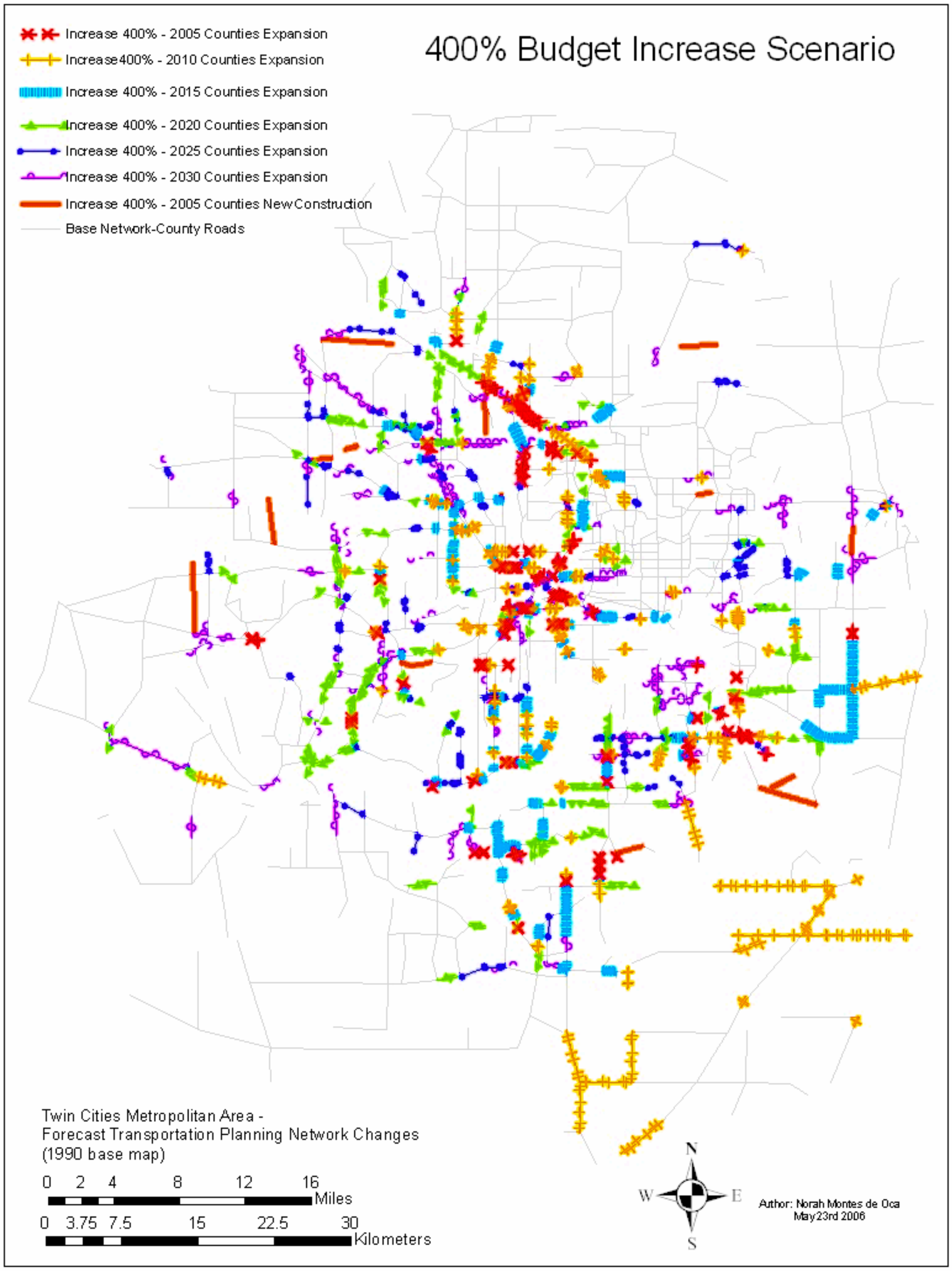


Figure 22: Scenario 4c. Budget increase by 400% – Counties

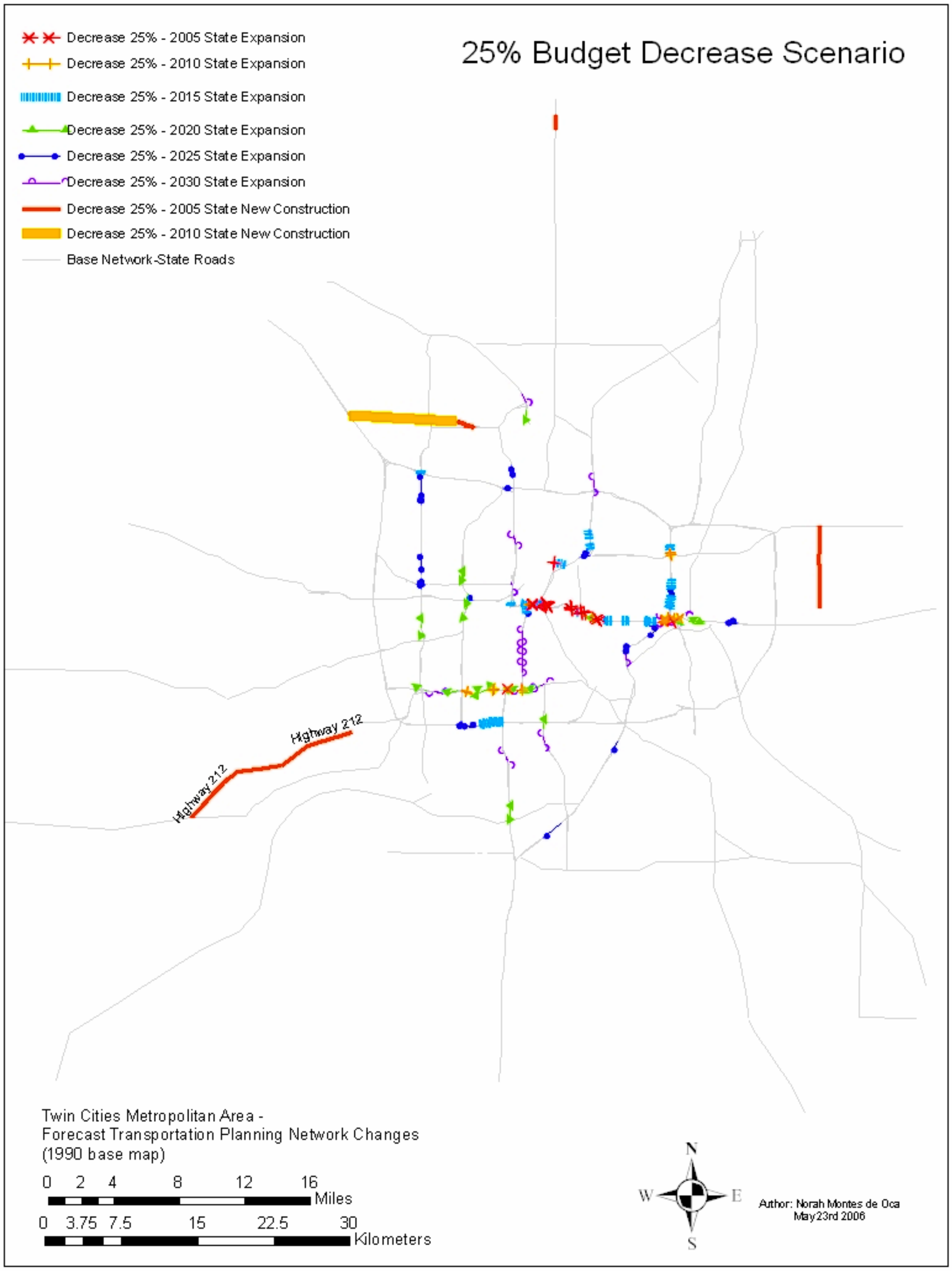


Figure 23: Scenario 4c. Budget decrease by 25% - State

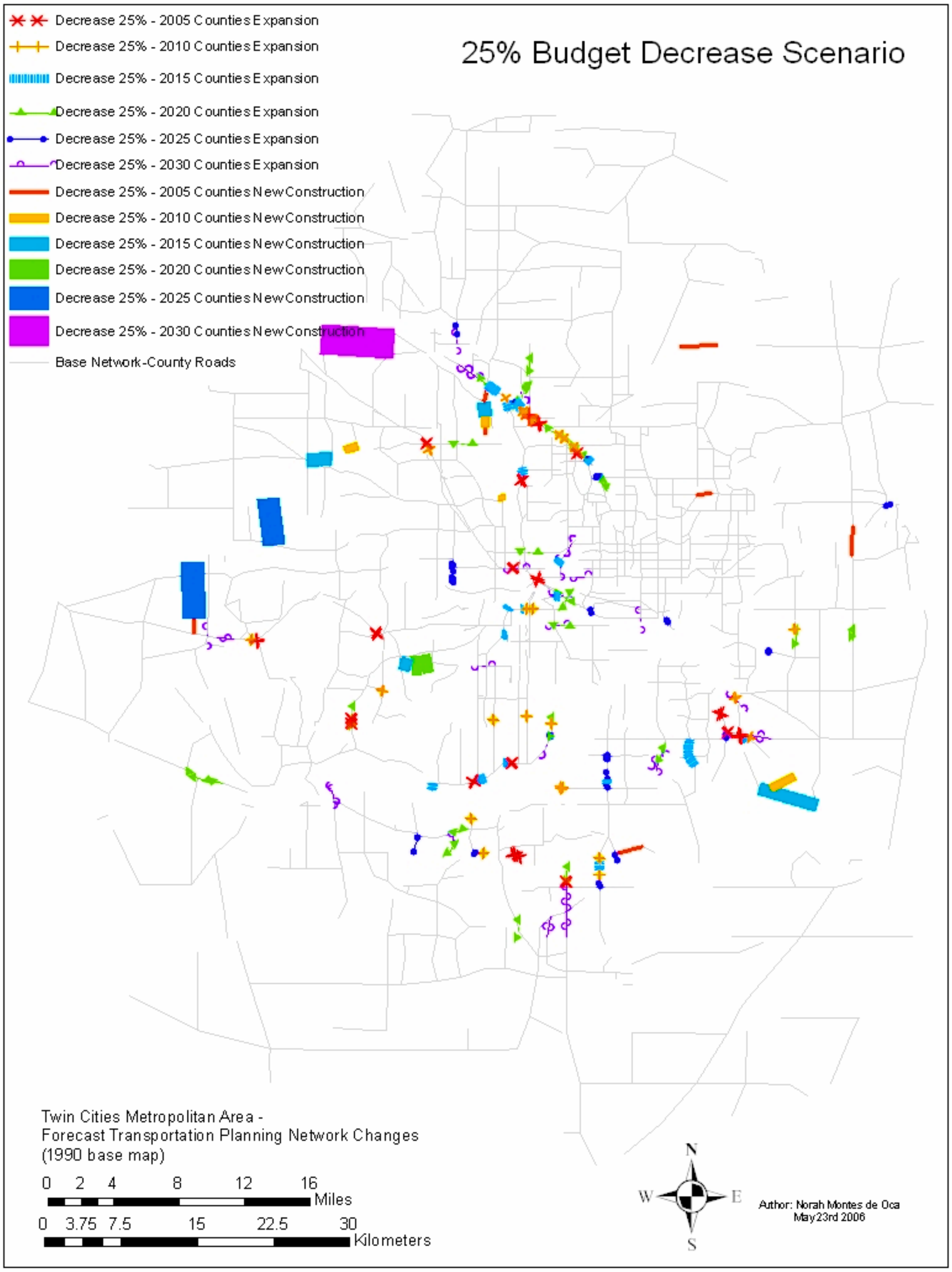


Figure 24: Scenario 4e. Budget decrease by 25% – Counties

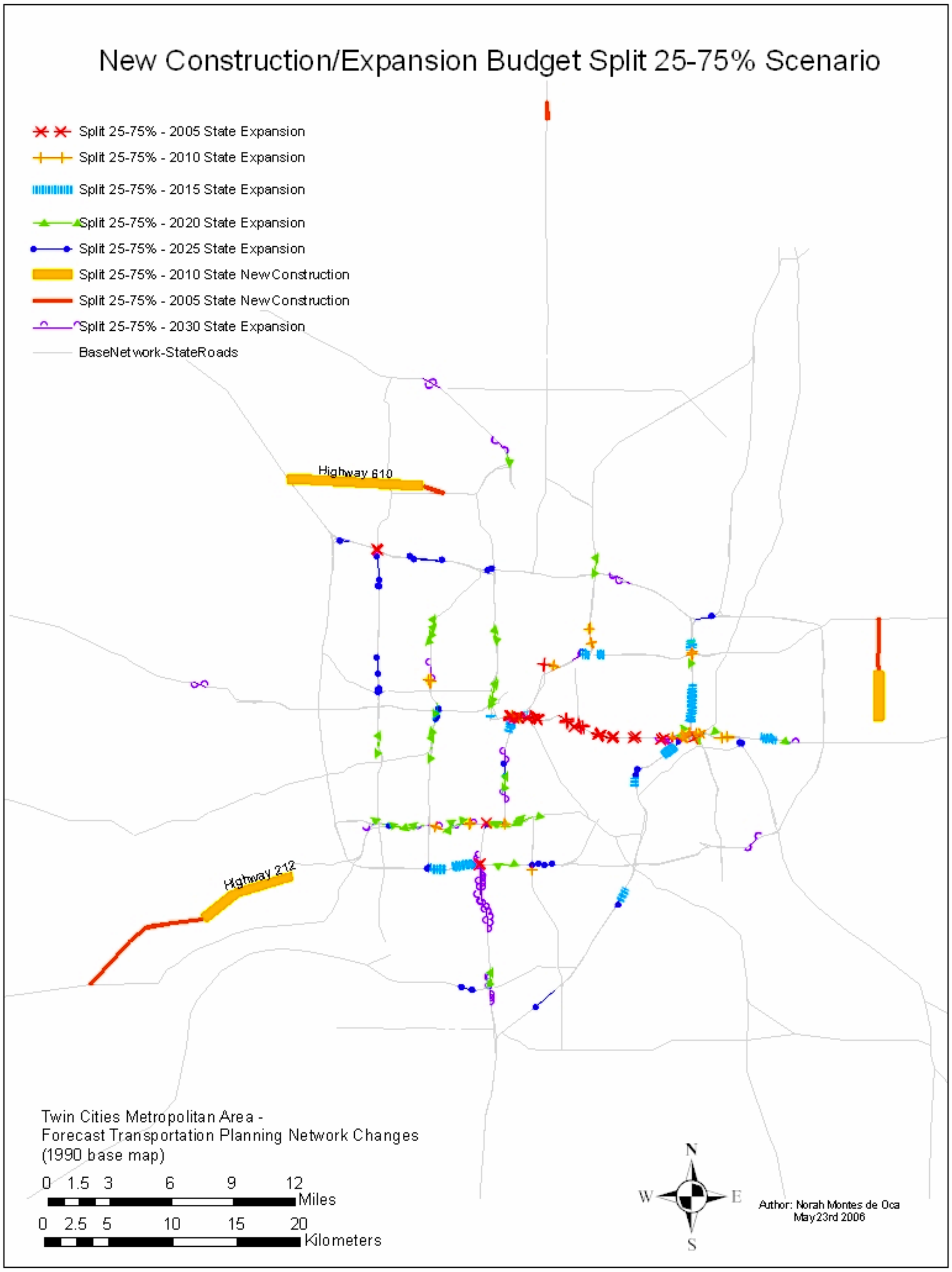


Figure 25: Scenario 5. Budget Split between new construction and expansion (25-75) – State

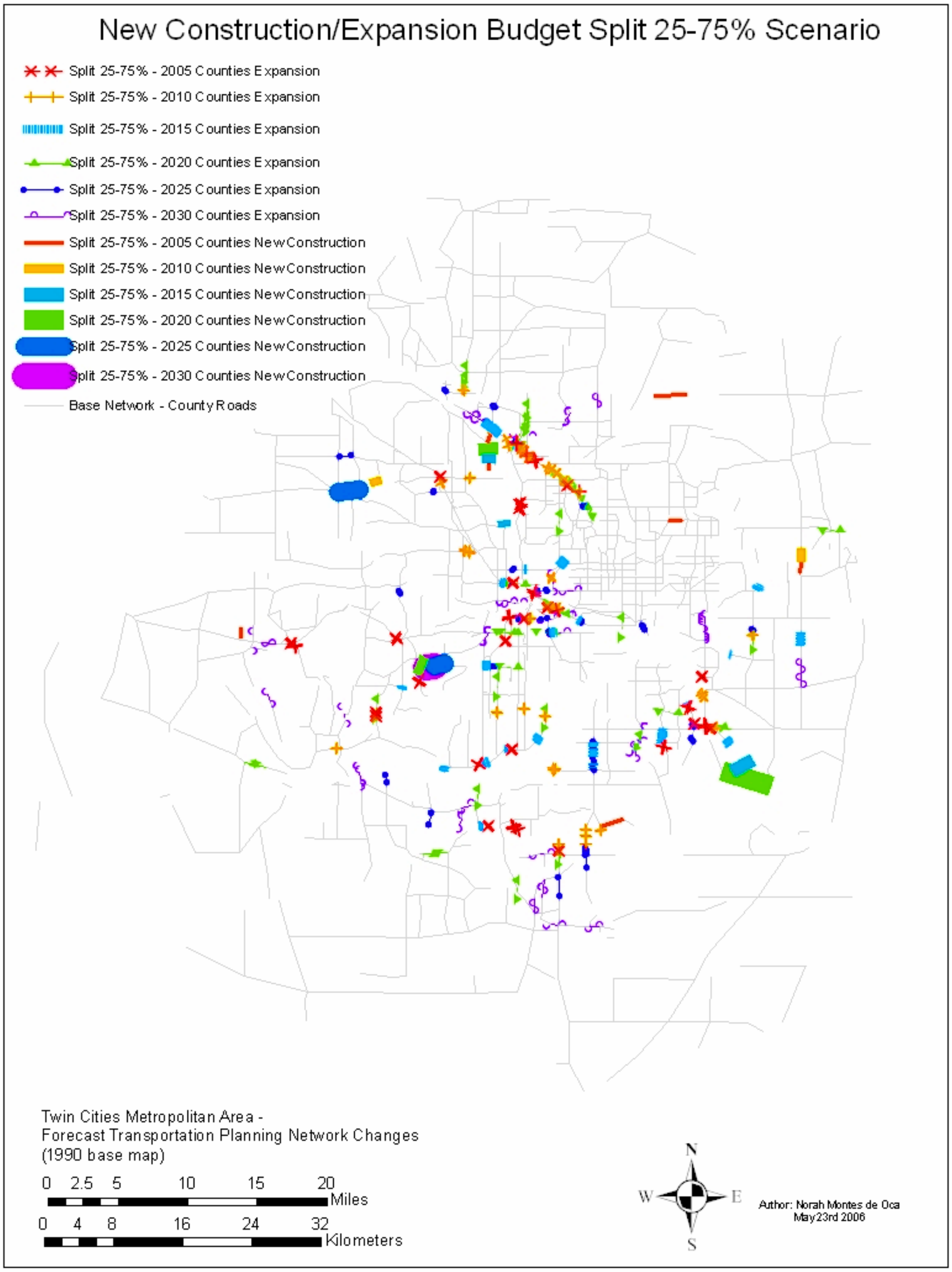


Figure 26: Scenario 5. Budget split between new construction and expansion (25-75) – Counties

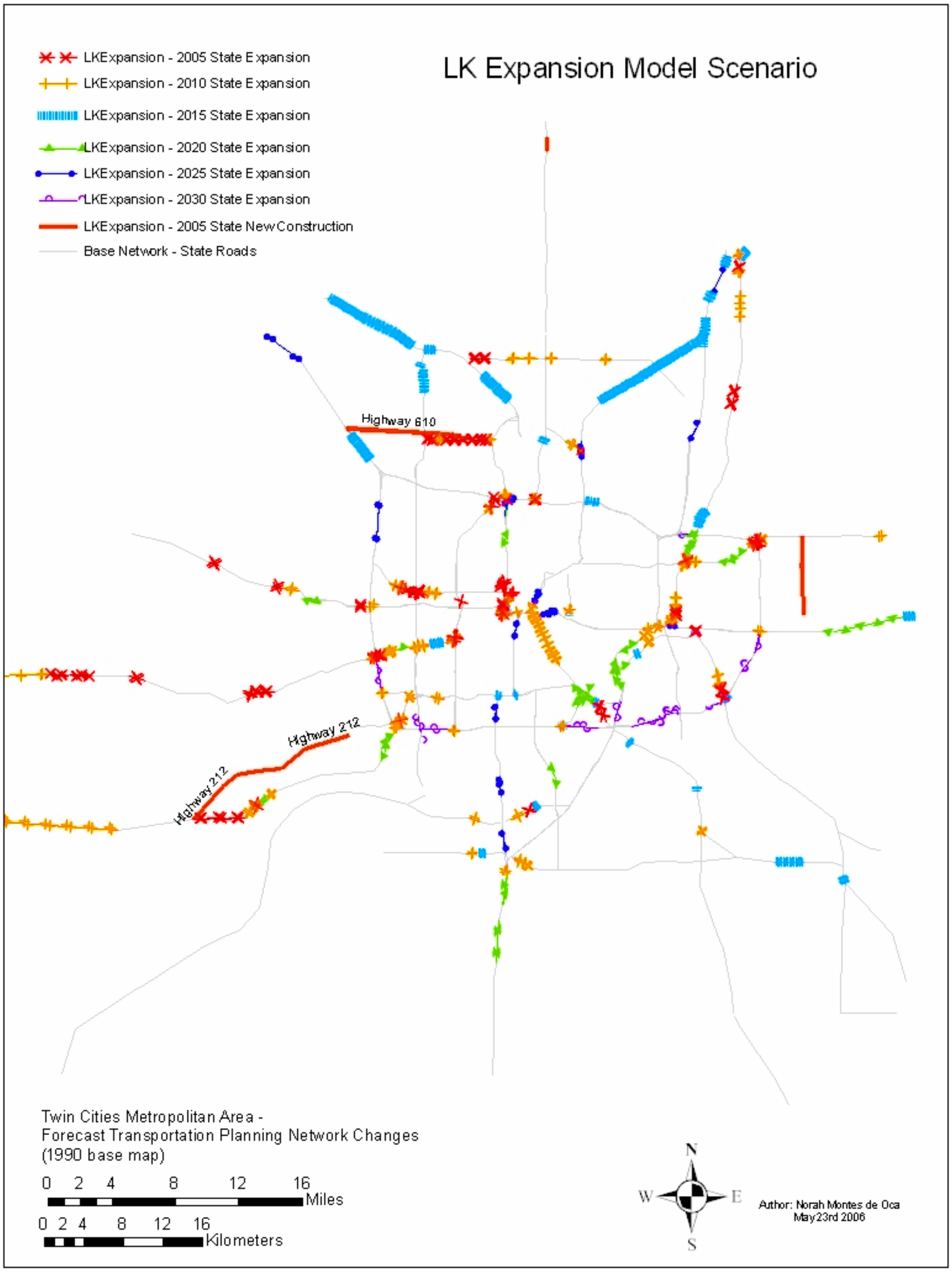


Figure 27: Scenario 6. LK Expansion Model - State

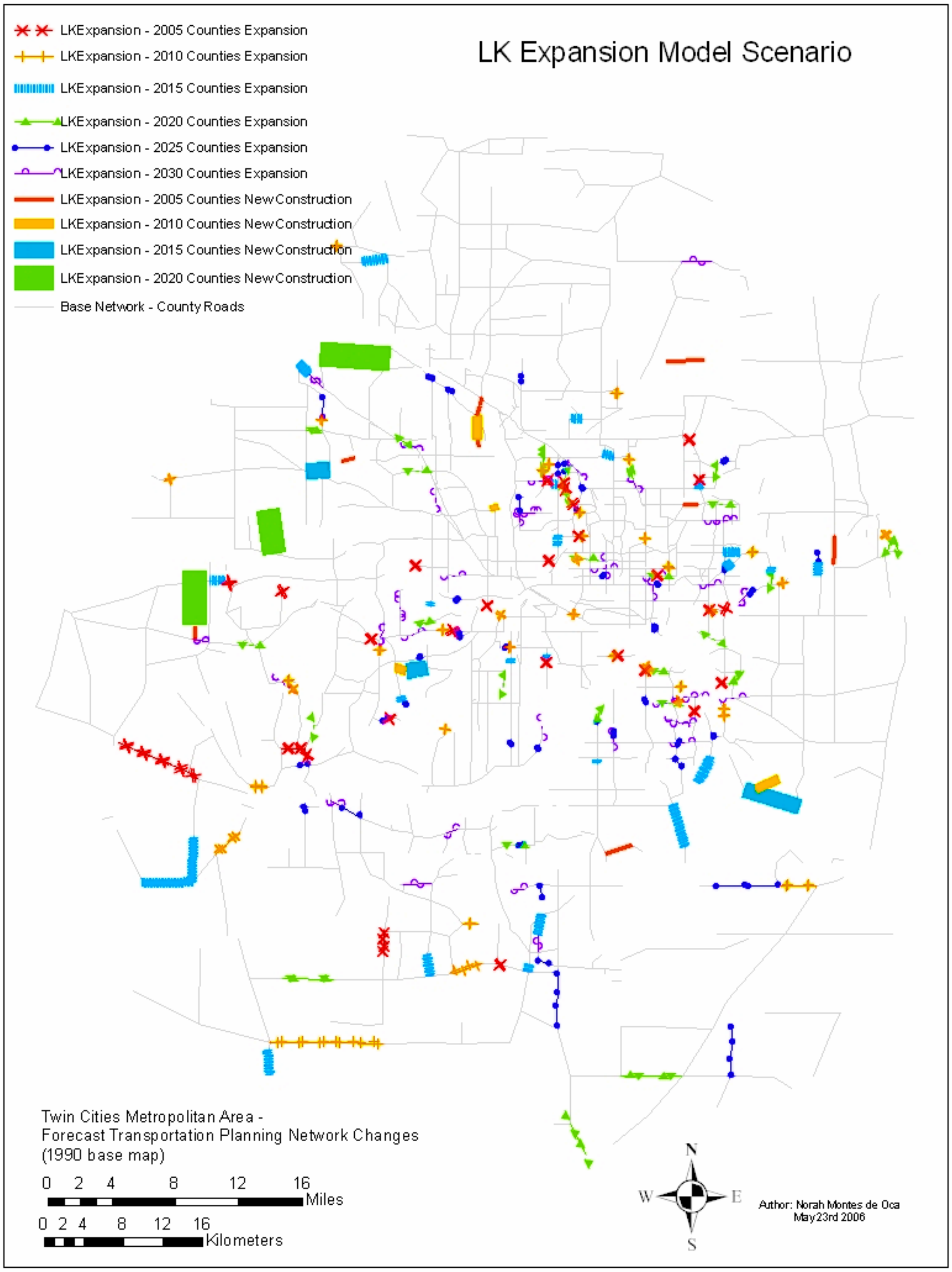


Figure 28: Scenario 6. LK Expansion – Counties

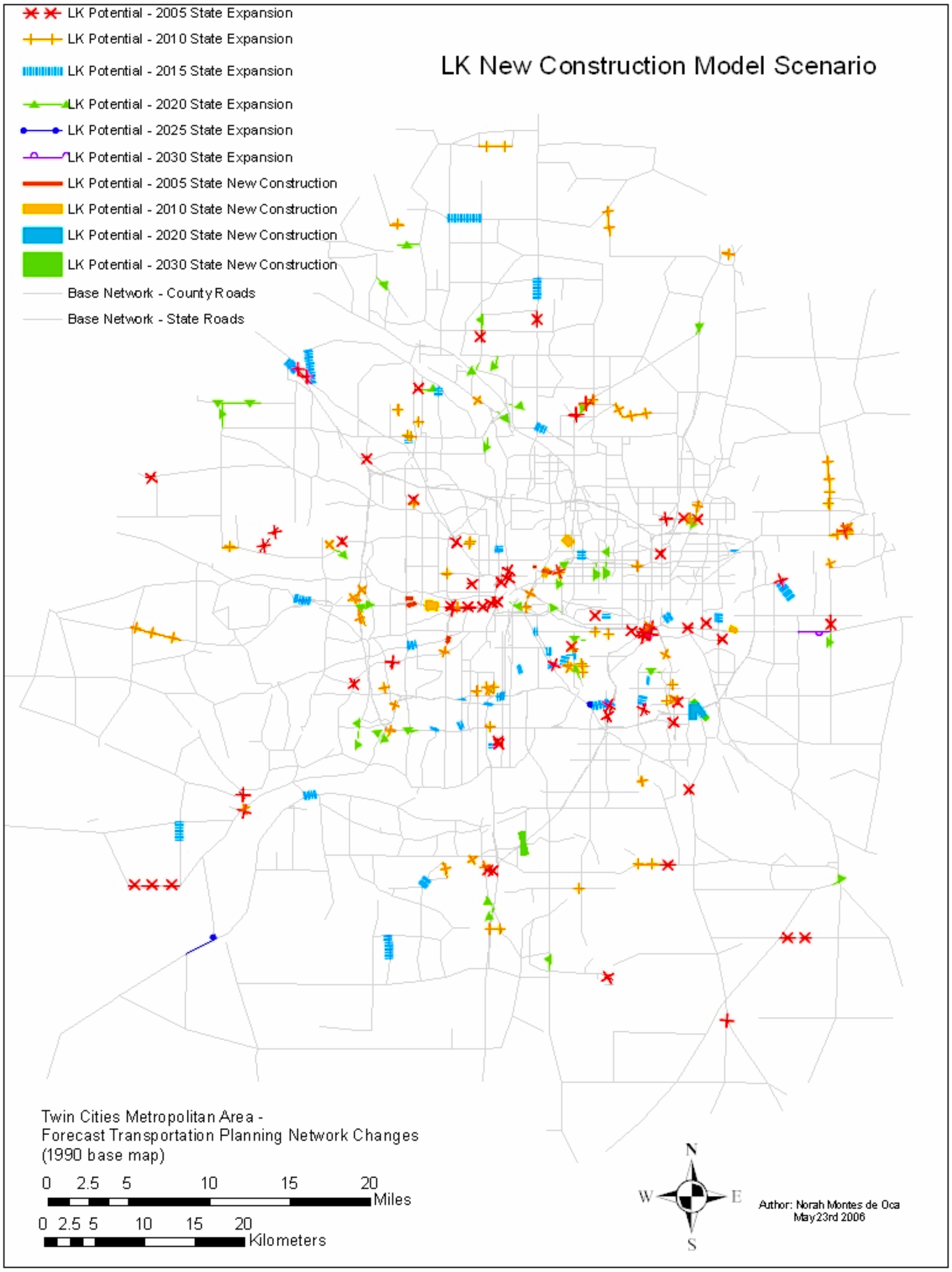


Figure 29: Scenario 7. LK New Construction Model – State

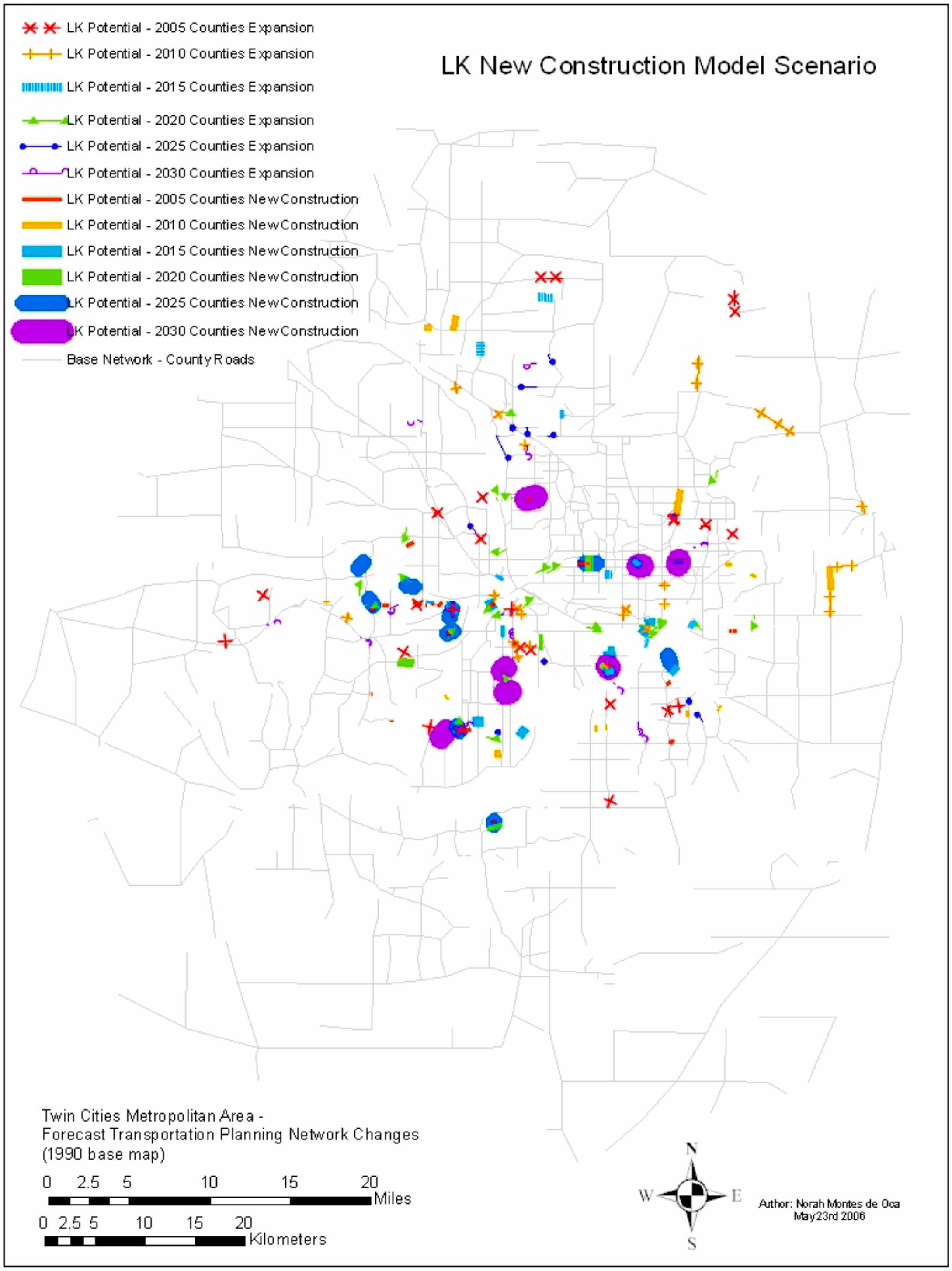


Figure 30: Scenario 7. LK New Construction Model– Counties

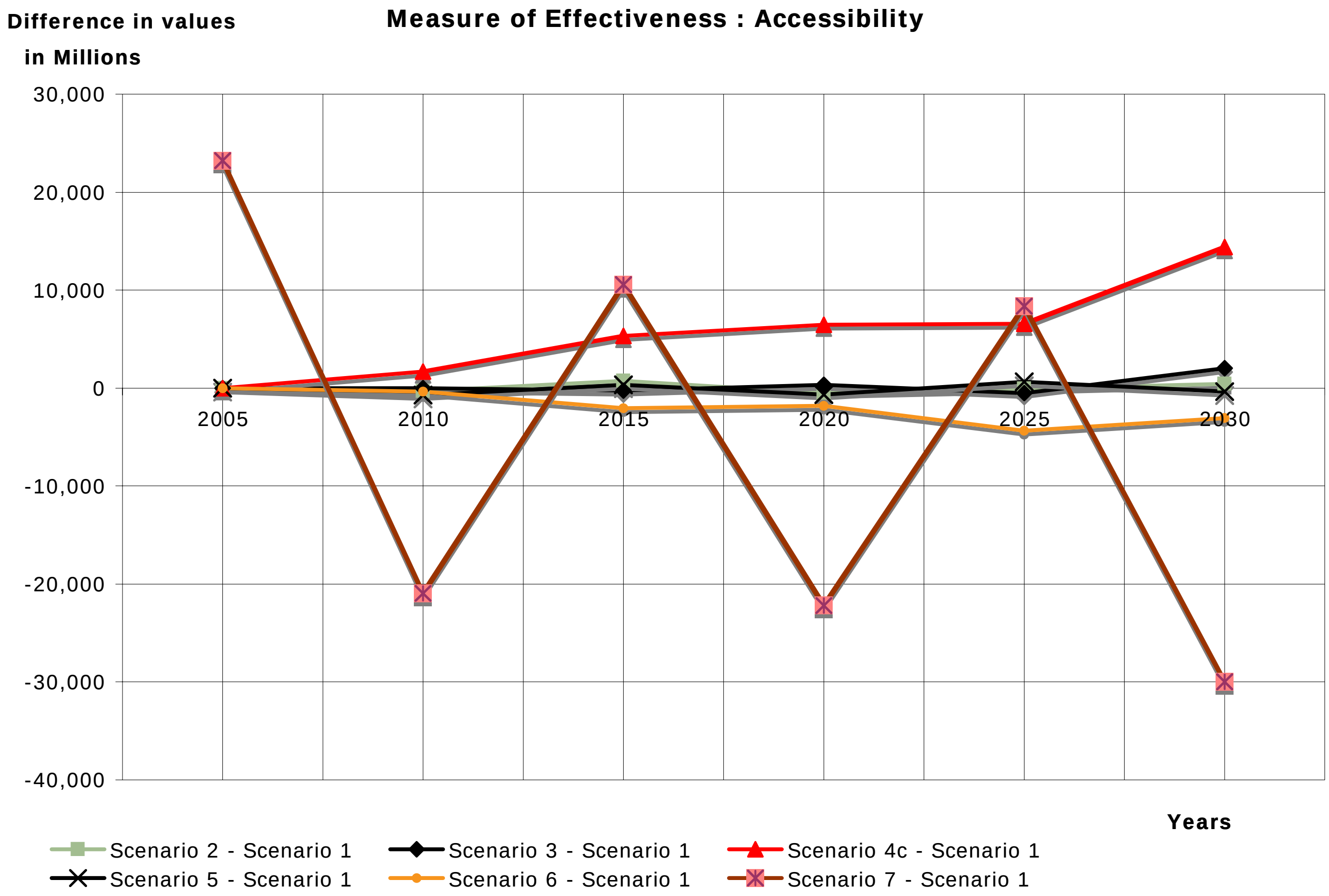


Figure 31: Measure of Effectiveness-Accessibility

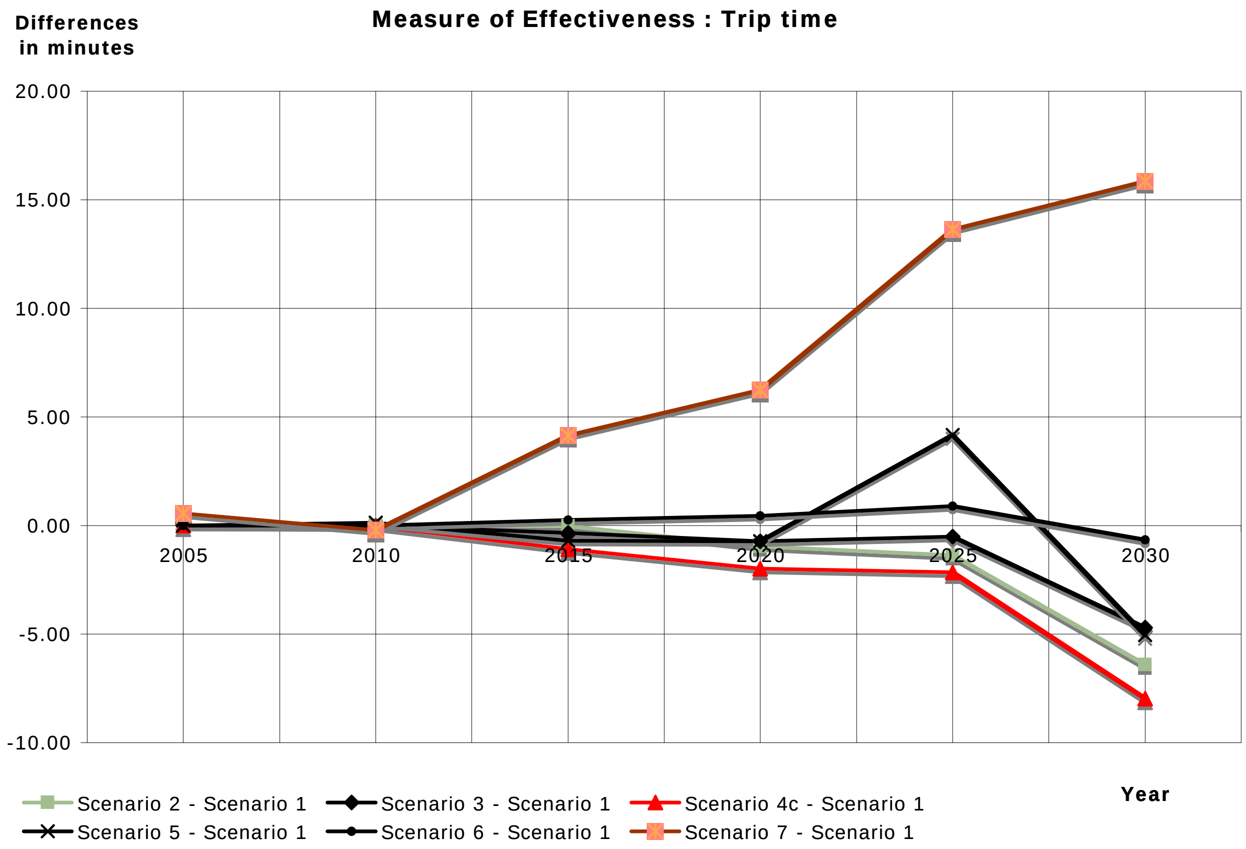


Figure 32: Measure of Effectiveness - Trip time (minutes)

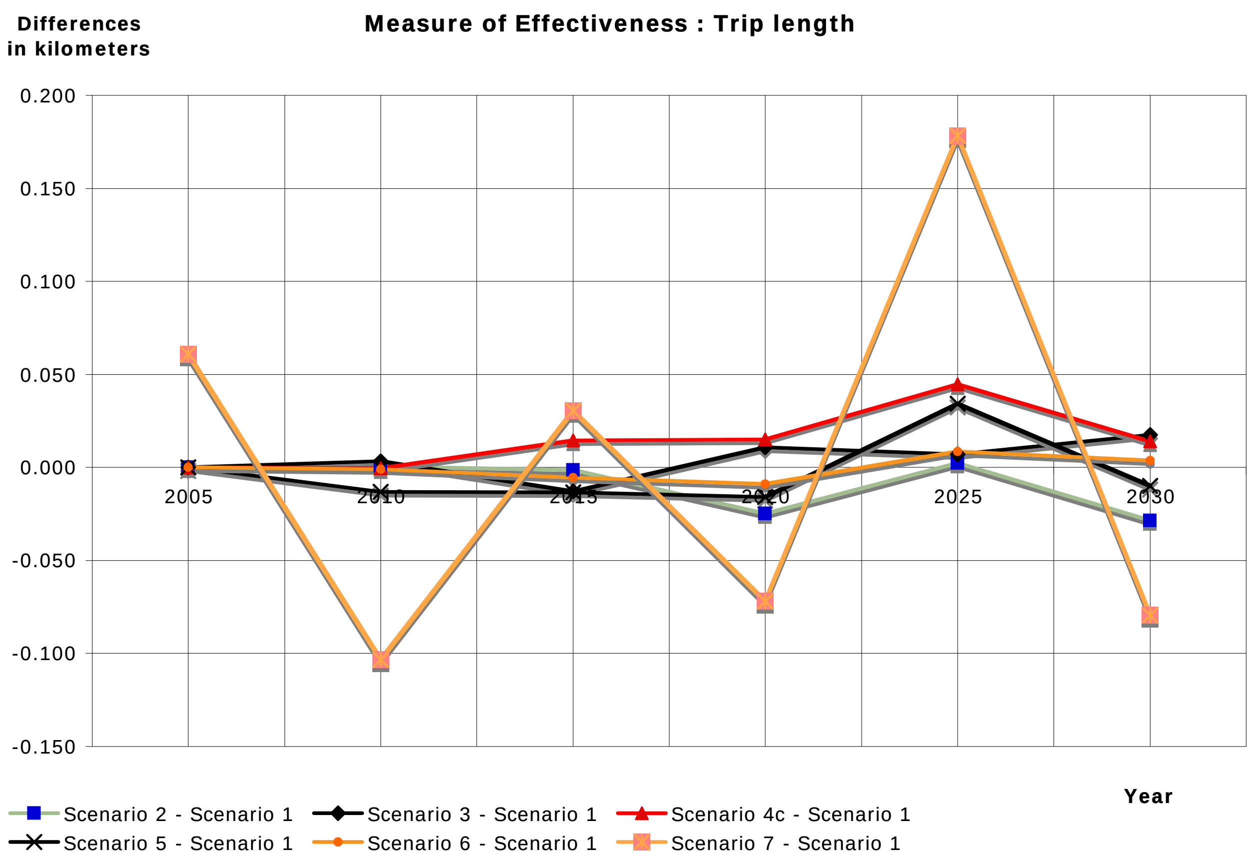


Figure 33: Measure of Effectiveness - Trip length (kilometers)

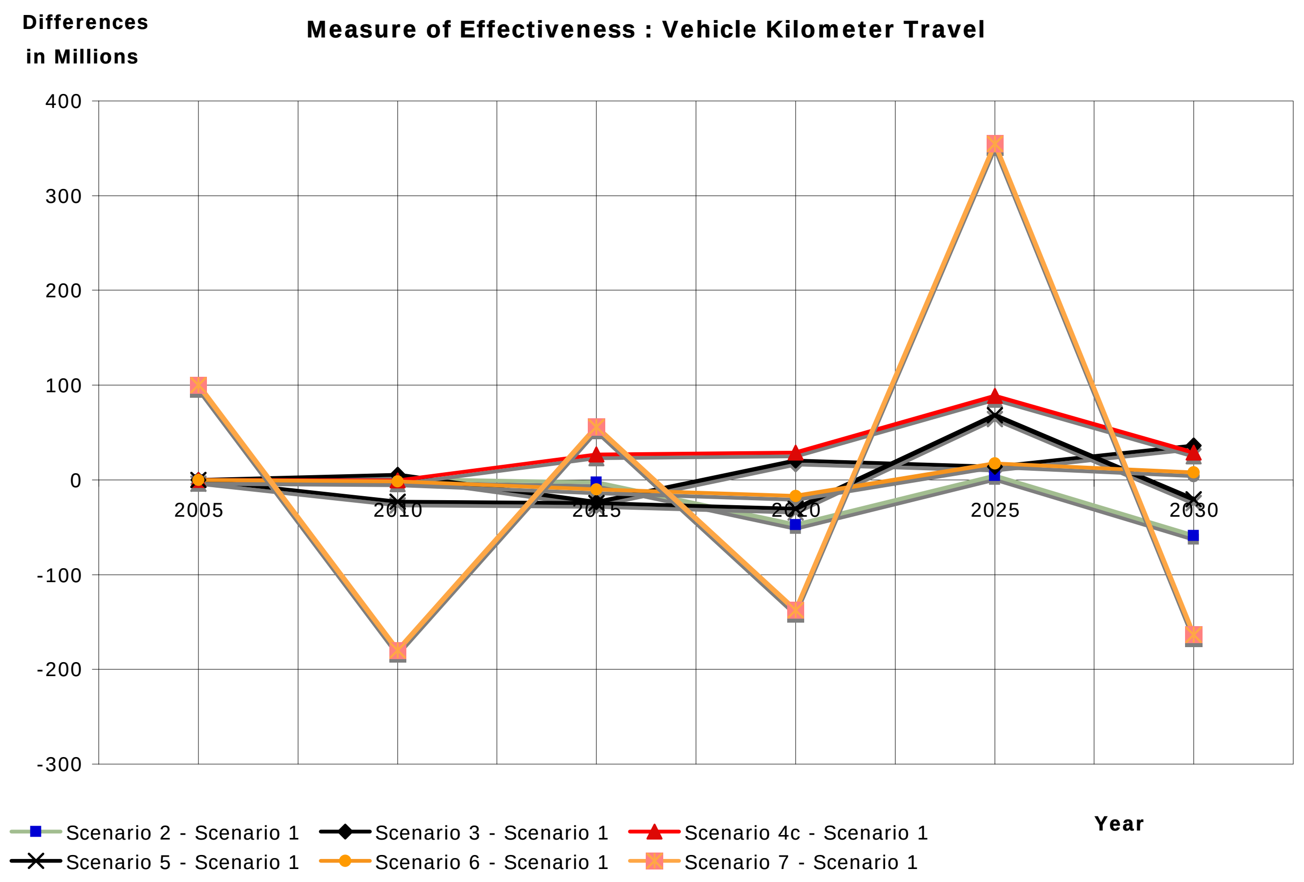


Figure 34: Measure of Effectiveness - Vehicle Kilometers of Travel

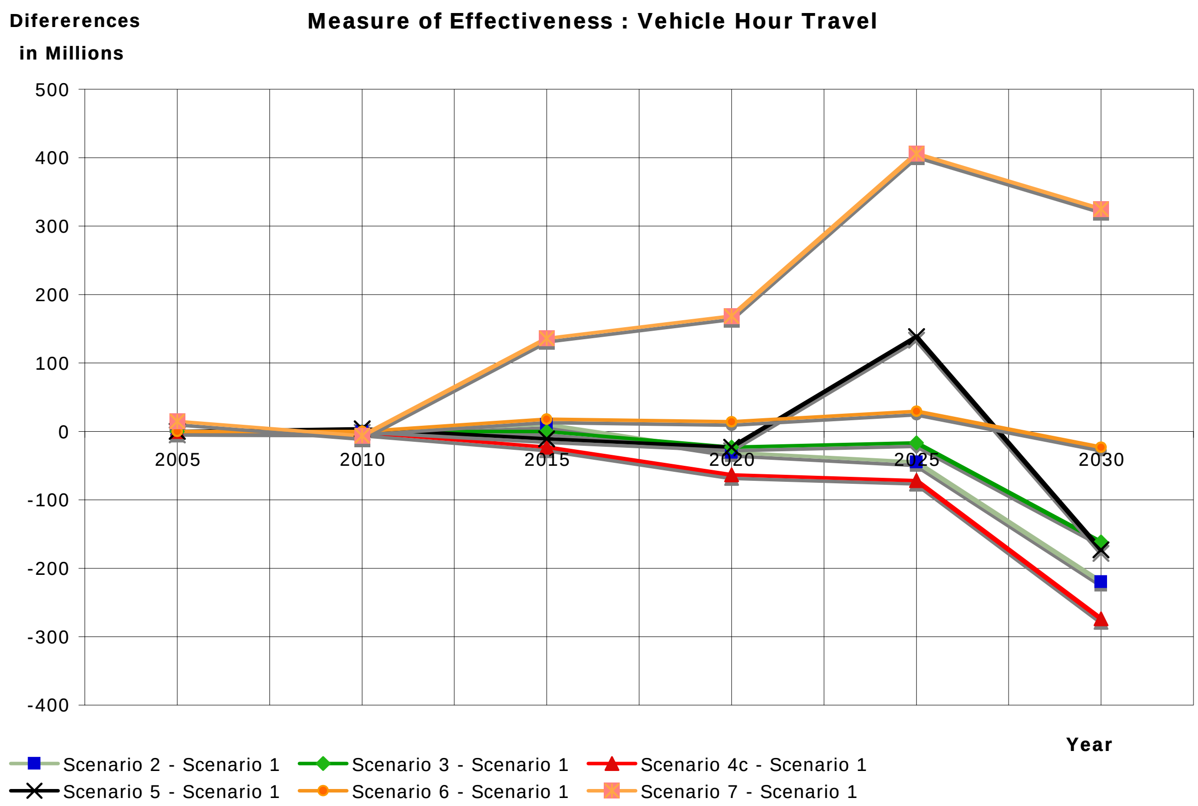


Figure 35: Measure of Effectiveness - Vehicle Hours of Travel

Table 1: State highway budget model

Regression Statistics	Multiple R = 0.9072 R-square = 0.8230 Adjusted R-square = 0.8176 Standard Error = 15451478.8 Observations = 35

	Coef.	Std. Err.	t Stat	P-value
Intercept	22146206.1	3986497.14	5.55530465	3.5803E-06
Total VMT	0.01012081	0.00081703	12.3873636	5.8937E-14

Table 2: State Budget – Correlation results

	Expenditures	Total VMT
Expenditures	1.00	
Total VMT	0.91	1.00

Table 3: County highway budget model

Regression Statistics	Multiple R = 0.9574 R-square = 0.9166 Adjusted R-square = 0.8976 Standard Error = 4920 Observations = 28

	Coef.	Std. Err.	t Stat	P-value
Intercept	10289970.76	2546068.811	4.0415	0.0005
Households	-78.0026	39.3296	-1.9833	0.0599
Total VMT	0.0078	0.0019	4.1598	0.0004
Dummy for 1990	-11552700.9	3169562.041	-3.6449	0.0014
Dummy for 1995	-5900211.09	2903788.393	-2.0319	0.0544
Dummy for 2000	-3491842.33	2541778.176	-1.3218	0.1998

Table 4: County Budget – Correlation results

	Expenditures	Households	Total VMT
Expenditures	1.00		
Households	0.79	1.00	
Total VMT	0.88	0.98	1.00

Table 5: State Expenditures by Road Class in 2000

Category		Dollar Amount
Municipal-State Aid Highway		89,548,000
County-State Aid Highway		381,774,000
Trunk Highway Fund		1,369,021,000
Highway User Tax Distribution Fund (HUTDF) (5% Legislative Allocation)		17,898,000
	Total	1,858,241,000

Source: House Fiscal Analysis Department

Table 6: Allocation of State Highway User Tax Distribution Fund

	Kilometers (Miles)	Dollar amount	$/kilometer ($/mile)
Trunk Highways	19,202	1,379,562,922	7,184.47
	(11,932)		(11,561.87)
County Roads	73,065	387,599,799	5,304.86
	(45,401)		(8,537.21)
Municipal Roads	29,921	91,078,279	3,043.96
	(18,592)		(4,898.67)
Township Roads	90,838	272,944	3.00
	(56,444)		(4.83)
Total	213,027		8,724.31
	(132,369)	1,858,513,944	(14,040.40)

Source: Minnesota House of Representatives Research Department

Table 7: State expenditures-all operating funds

COUNTY	Dollar amount Legislature	Dollar amount Reported	Percent difference
ANOKA	21,942,938	23,392,084	6.2 %
CARVER	43,870,238	9,171,894	79.1 %
DAKOTA	33,492,021	32,119,551	4.1 %
HENNEPIN	55,149,034	49,396,288	10.4 %
RAMSEY	24,591,089	23,610,251	4.0 %
SCOTT	14,465,030	13,405,387	7.3 %
WASHINGTON	23,673,945	14,887,552	37.1 %
Total	217,184,295	165,983,007	

Source: Minnesota House of Representatives. Fiscal Analysis Department. Minnesota State Budget.

Table 8: Coefficients of Regression for Cost Models

$Ln(E_{ij})$		Model 2	
Description of the Variable	**Variable**	**Coef.**	**Std. Dev**
Lane kilometers of Construction	$Ln(L_{ij}*\Delta C_{ij})$	0.50	0.118*
Dummy for new constructions	N	0.39	0.187*
Dummy for Interstate roads	Inter	1.97	0.300*
Dummy for State Roads	TH	0.56	0.226*
Year-1979	Y	-	-
Log of year-1979	Ln(Y)	0.75	0.110*
Log of duration of construction	Ln(D)	0.16	0.142
Distance from nearest downtown	X	-0.03	0.016*
	_cons	5.56	0.329*
	Number of Observations	76	
	Adj. R-squared	0.77	

* Significant at 10% confidence level

- Variable not present in that model

Source: Levinson and Karamalaputi, Ramachandra. 2003. Journal of Transportation and Statistics Vol 6 (2/3) 81-89. Predicting the Construction of New Highway Links

Table 9: City of Minneapolis Capital Long-Range Improvement Program Rating Form

Project ID Number		
	Points	
Project Priority		
Level of Need		
Critical	51-60	
Significant	41-50	
Important	21-40	
Desirable	0-20	
In adopted Five Year Plan		
2006	30	
2007-2009	20	
2010	10	
New for 2006-2009	0	
Integrated Project	10	
Sub-Total Project Priority		
Contributions to City Goals/Objectives		
Strong Contribution	46-70	
Moderate Contribution	16-45	
Little or No Contribution	0-15	
Operating Costs:	-25 to +25	
Sub-Total Goals & Operating Costs		
Qualitative Criteria:		
Neighborhood Livability & Safety	0-15	
Public Benefit	0-15	
Capital Cost/Customer Service Delivery	0-15	
Environmental Quality	0-15	
Collaboration & Leveraging	0-15	
Effect on Tax Base & Job Creation	0-15	
Intellectual & Cultural Implications	0-15	
Sub-Total Qualitative		
Total Rating Points	300 Possible	

Source: Capital Long Range Improvement Committee. 2005 Capital Guidelines.

Table 10: Hennepin County's project selection scoring

Performance Measure	Points	Details
Capacity V/C ratio	100	Ratio of 10% AADT to current capacity = (AADT x 0.10)/Capacity For Example: AADT = 11,900 Current capacity/hr = 1,200 Ratio = 0.99 Normalized score = 65 1.52 = 100 points 0.67 = 44 points
Pavement	100	Pavement Condition Index Present Service-ability rating rideability Pavement quality index (PQI)
Safety	100	Ratio of project crash rate to county average > 5 = 100 points, ratio >3=90, ratio >20=80…ratio <.50=0
Municipal support	100	City approves preliminary design and commits to cost share greater than required by county policy………………….100 City council resolution supports ISTEA application………………………….50 City staff gives verbal support for project………………………………20

Table 11: Sources of Transportation Funds

Funding Category	Project Selection Process Followed
Title I Federal Funds (Traditional Highway Fund)	
• STP Urban Guarantees, Enhancement, Congestion Mitigation/Air Quality, Bridge	Competitive Regional Solicitation Process conducted by the Transportation Advisory Board (TAB)
• Improvement/Replacement, Railroad Surface and Signals, and Hazard Elimination/Safety funds	Competitive regional solicitation process conducted by Mn/DOT and TAB
• National Highway System Interstate Maintenance, STP, Non-Urban Guarantee, Intelligent Transportation System	Mn/DOT/Metro Division Process with assistance from Capital Improvement Committee (CIC)
Federal Title III Funds	
• Sections 5307 and 5309	Metropolitan Transit Selected
• Section 5310	Mn/DOT Office of Transit/Statewide Competitive Process
• Section 5311	Mn/DOT Office of Transit/Categorical Allocation
State Trunk Highway Funds	Mn/DOT Metro Division Process with CIC assistance
Regional Capital Transit Bond Funds	Competitive Regional Solicitation Process conducted by the Metropolitan Council
State Transportation Revolving Loan Fund (TRLF)	Statewide competitive solicitation process conducted by Mn/DOT

Source: Transportation Improvement Plan by the Metropolitan Council. Chapter 3.

Table 12: Regional Solicitation Process under the Surface Transportation Program (STP) by Transportation Advisory Board (TAB)

	Reliever	Expander	Connector	Augmenter	Non-Freeway Principal Arterial
A. Relative Importance of the route	0-100	0-100	0-100	0-150	0-100
B. Deficiencies and Solutions on category	425	425	425	375	425
1. Crash reduction	-	0-150	0-150	0-100	0-150
On Principal arterial	0-50	-	-	-	-
On the reliever	0-50	-	-	-	-
2. Access Management	0-125	0-175	0-125	0-125	0-175
3. Air quality	0-100	0-50	Good movement 0-75	0-100	0-50
4. Congestion Reduction	-	0-50	Shoulder Improvement 0-75	0-50	0-50
On principal arterial	0-50	-	-	-	-
On the reliever	0-50	-	-	-	-
C. Cost effectiveness	275	275	275	275	275
1. Crash reduction	0-125	0-125	0-125	0-125	0-125
2. Congestion reduction	0-75	0-75	good movement 0-75	0-75	0-75
3. Air Quality	0-75	0-75	Shoulder Improvement 0-75	0-75	0-75
D. Development Framework Implementation	300	300	300	300	300
1. Employment, housing and transportation integration	0-200	0-200	0-200	0-200	0-200
a) Intensity	60	60	60	60	60
b) Linkages	60	60	60	60	60
c) Brownfields & Natural Resources	40	40	40	40	40
d) Affordable/Life Cycle housing	40	40	40	40	40
2. Integration of modes	0-100	0-100	0-100	0-100	0-100
E. Maturity of project concept	0-100	0-100	0-100	0-100	0-100
TOTAL	1,200	1,200	1,200	1,200	1,200

Table 13: Regional Solicitation Process under the Congestion Mitigation and Air Quality Improvement Program (CMAQ) by Transportation Advisory Board

	Transit expansion	Demand or System Management
A. Reduction in carbon monoxide (CO), nitrogen oxide (Nox), and volatile organic compound (VOC) emissions	475	550
1. Reduction in SOV trips and/or VMT	0-75	0-100
2. Reduction of vehicle emissions	0-100	0-150
3. Measure of project effectiveness	0-300	0-300
B. Congestion Mitigation	200	350
1. Congestion/increase hourly person reduction	0-100	0-175
2. Traffic congestion reduction	0-100	0-175
C. Service Efficiency and productivity	250	-
1. Service efficiency	0-125	-
2. Productivity	0-125	-
D. Regional Transit Priorities	300	-
1. Corridor priority (as ranked in 2030 TPP)	0-100	-
2. Location suitability & market area demand	0-100	-
3. Integration with existing infrastructure	0-100	-
E. Development Framework Implementation	200	200
1. Employment, housing and transportation integration	0-200	0-200
a) Intensity	60	75
b) Linkages	60	75
c) Brownfields & Natural Resources	40	50
d) Affordable/Life Cycle housing	40	-
F. Maturity of project concept	100	100
TOTAL	1,525	1,200

Table 14: Regional Solicitation Process under the Transportation Enhancement Program (TEP) by Transportation Advisory Board

	Scenic and Environmental Group	Bicycle and pedestrian Group	Historic and Archaeological Group
Transportation Enhancement Category Criteria	500	500	500
1. Urgency	150	150	150
2. Readiness	75	75	75
3. Impact	125	125	125
4. Context	100	100	100
5. Relationship between categories	50	50	50
General/Integrative Criteria	600	600	600
1. Relationship to Intermodal/Multimodal Transportation System.	150	150	150
2. Extent of Public benefit from the project	150	150	150
3. Development Framework Implementation (employment, housing and transportation integration)	200	200	200
4. Maturity of project concept	100	100	100
TOTAL	1,100	1,100	1,100

Table 15: Top priority criteria's percentages by different jurisdictions

Jurisdiction \ Priorities	Safety /Crash reduction (%)	Capacity, ADT (%)	Cost Effectiveness (%)	Air/Environmental quality (%)	Pavement Maintenance (%)	Community Involvement (%)	Access Management (%)	Endorsed by jurisdiction?	Point allocation
State	-	47	-	-	52	-	-	Pending	Formal
Anoka	33	-	33	-	33	-	-	No	Informal
Hennepin	25	25	-	-	25	25	-	Yes	Formal
Carver	-	-	-	-	-	-	-	-	-
Dakota	-	35	-	-	65	-	-	Pending	Informal
Scott	50	50	-	-	-	-	-	No	Informal
Washington	33	33	-	-	33	-	-	Yes	Informal
Ramsey	20	10	-	-	20	30	10	Yes	Formal
City of Minneapolis	21	-	58	21	-	-	-	Pending	Formal
Metropolitan Council	35	19	-	23	-	-	23	Pending	Formal

Table 16: Scenario 1. Baseline - Results

Base Scenario						
	2005	2010	2015	2020	2025	2030
Trips generated	359,190	380,920	400,210	419,500	435,430	451,360
Trips attracted	359,190	380,920	400,210	419,500	435,430	451,360
VHT	408,646,016	491,202,784	609,838,530	744,627,710	932,851,260	1,296,098,050
VKT	25,855,578,100	29,596,145,700	32,852,269,100	36,783,690,000	39,457,071,000	43,357,884,000
Trip length (kilometers)	15.7769	17.0291	17.9916	19.2183	19.8611	21.0546
Trip time (minutes)	0.2494	0.2826	0.3397	0.3890	0.4696	0.6294
Accessibility	1,014,928,310,000	1,157,286,590,000	1,238,549,920,000	1,345,951,370,000	1,404,922,100,000	1,499,779,960,000
Expansion - State (Lane km)	12.68	28.54	28.87	30.97	36.77	30.84
Expansion - Anoka (Lane km)	3.93	6.02	7.18	6.85	6.55	12.74
Expansion – Carver	4.12	0.74	0.80	5.89	3.28	3.70
Expansion – Dakota	4.54	10.75	8.33	8.82	6.69	11.55
Expansion – Hennepin	5.28	5.63	6.15	4.44	7.63	9.24
Expansion – Scott	4.05	7.43	3.60	6.44	4.41	5.12
Expansion – Ramsey	1.64	1.13	0.00	6.92	3.86	8.50
Expansion – Washington	2.45	2.64	2.35	4.05	4.89	11.94
New Construction -	161.54	0.00	0.00	0.00	0.00	0.00

State (Lane km)						
New Construction - Anoka (Lane km)	7.59	0.00	0.00	0.00	0.00	0.00
New Construction - Carver (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Dakota (Lane km)	5.53	0.00	0.00	0.00	0.00	0.00
New Construction - Hennepin (Lane km)	10.43	8.69	9.17	34.63	0.00	0.00
New Construction - Ramsey (Lane km)	2.99	0.00	0.00	0.00	0.00	0.00
New Construction - Scott (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Washington (Lane km)	5.76	5.37	11.91	0.00	0.00	0.00

Table 17: Scenario 2. Most Structured - Results

Most Structured Scenario						
	2005	2010	2015	2020	2025	2030
Trips generated	359,190	380,920	400,210	419,500	435,430	451,360
Trips attracted	359,190	380,920	400,210	419,500	435,430	451,360
VHT	408,646,016	491,380,416	619,944,510	714,071,360	887,739,010	1,076,424,960
VKT	25,855,578,100	29,597,030,400	32,849,510,400	36,736,307,000	39,461,626,000	43,298,865,000
Trip length (kilometers)	15.7769	17.0297	17.9901	19.1936	19.8634	21.0259
Trip time (minutes)	0.2494	0.2827	0.3395	0.3731	0.4469	0.5227
Accessibility	1,014,928,310,000	1,156,979,880,000	1,239,267,540,000	1,345,450,670,000	1,404,869,410,000	1,500,221,150,000
Expansion - State (Lane km)	37.71	43.88	86.50	62.28	63.31	55.19
Expansion - Anoka (Lane km)	7.59	7.30	6.40	6.63	5.82	5.21
Expansion – Carver	7.79	4.28	6.34	10.07	1.90	7.85
Expansion – Dakota	4.31	9.14	6.60	6.15	8.50	10.17
Expansion – Hennepin	5.28	5.63	4.41	4.34	8.33	8.30
Expansion – Scott	1.80	5.92	4.31	6.92	3.86	6.60
Expansion – Ramsey	6.76	5.95	7.18	6.24	10.62	21.79
Expansion – Washington	2.25	3.57	2.35	2.32	4.79	4.04
New	161.54	0.00	0.00	0.00	0.00	0.00

Construction - State (Lane km)						
New Construction - Anoka (Lane km)	7.59	0.00	0.00	0.00	0.00	0.00
New Construction - Carver (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Dakota (Lane km)	5.53	0.00	0.00	0.00	0.00	0.00
New Construction - Hennepin (Lane km)	10.43	8.69	9.17	34.63	0.00	0.00
New Construction - Ramsey (Lane km)	2.99	0.00	0.00	0.00	0.00	0.00
New ConstructionScott (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction Washington (Lane km)	5.76	5.37	11.91	0.00	0.00	0.00

Table 18: Scenario 3. Least Structure - Results

Least Structured Scenario						
	2005	2010	2015	2020	2025	2030
Trips generated	359,190	380,920	400,210	419,500	435,430	451,360
Trips attracted	359,190	380,920	400,210	419,500	435,430	451,360
VHT	408,646,016	490,647,168	609,972,860	721,324,800	916,146,240	1,134,627,070
VKT	25,855,578,100	29,601,652,700	30,282,901,610	36,804,289,000	39,471,063,000	43,394,052,000
Trip length (kilometers)	15.7769	17.0323	17.9788	19.2291	19.8681	21.0721
Trip time (minutes)	0.2494	0.2823	0.3341	0.3769	0.4612	0.5510
Accessibility	1,014,928,310,000	1,157,270,210,000	1,238,263,140,000	1,346,269,090,000	1,404,390,740,000	1,501,825,470,000
Expansion - State (Lane km)	22.41	55.64	70.92	28.59	31.76	31.83
Expansion - Anoka (Lane km)	4.38	6.28	6.21	6.69	6.56	9.75
Expansion – Carver	4.12	0.74	0.80	5.89	0.00	3.70
Expansion – Dakota	5.50	8.59	7.53	11.01	7.56	10.56
Expansion – Hennepin	4.63	3.64	4.83	6.23	9.14	12.55
Expansion – Scott	2.80	6.56	3.89	6.02	5.99	4.22
Expansion – Ramsey	1.64	1.13	0.00	4.25	3.67	3.19
Expansion – Washington	5.18	2.01	2.61	2.32	6.69	7.92
New Construction	161.54	0.00	0.00	0.00	0.00	0.00

- State (Lane km)						
New Construction - Anoka (Lane km)	7.59	0.00	0.00	0.00	0.00	0.00
New Construction - Carver (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Dakota (Lane km)	5.53	0.00	0.00	0.00	0.00	0.00
New Construction - Hennepin (Lane km)	10.43	8.69	9.17	34.63	0.00	0.00
New Construction - Ramsey (Lane km)	2.99	0.00	0.00	0.00	0.00	0.00
New Construction - Scott (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Washington (Lane km)	5.76	5.37	11.91	0.00	0.00	0.00

Table 19: Scenario 4a. Increase 100% Budget - Results

Budget Increase - 100% Scenario						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Trips generated	359,190	380,920	400,210	419,500	435,430	451,360
Trips attracted	359,190	380,920	400,210	419,500	435,430	451,360
vht	408,646,016	490,515,840	605,001,410	729,409,220	929,688,900	1,110,125,700
vkt	25,855,579,100	29,589,289,000	32,862,087,200	36,806,046,000	39,445,537,000	43,336,135,000
Trip length (kilometers)	15.7769	17.0252	17.9970	19.2300	19.8553	21.0440
Trip time (minutes)	0.2494	0.2822	0.3313	0.3811	0.4680	0.5391
Accessibility	1,014,928,310,000	1,157,717,030,000	1,241,117,880,000	1,348,187,980,000	1,408,412,680,000	1,504,630,010,000
Expansion - State (Lane km)	27.50	72.76	90.02	95.33	122.33	115.83
Expansion - Anoka (Lane km)	7.18	15.01	17.31	20.63	14.37	18.37
Expansion - Carver	5.66	0.00	0.00	0.58	3.28	3.70
Expansion - Dakota	9.42	27.71	13.45	20.85	20.02	29.73
Expansion – Hennepin	9.18	9.81	17.89	21.91	21.17	24.81
Expansion - Scott	6.08	14.16	8.95	9.12	10.39	10.94
Expansion - Ramsey	1.64	0.00	0.00	3.80	3.86	14.00
Expansion - Washington	5.53	6.89	15.09	18.31	27.10	17.31
New Construction - State (Lane km)	161.54	0.00	0.00	0.00	0.00	0.00
New Construction - Anoka (Lane km)	7.59	0.00	0.00	0.00	0.00	0.00

New Construction - Carver (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Dakota (Lane km)	5.53	0.00	0.00	0.00	0.00	0.00
New Construction - Hennepin (Lane km)	19.11	43.80	0.00	0.00	0.00	0.00
New Construction - Ramsey (Lane km)	2.99	0.00	0.00	0.00	0.00	0.00
New Construction - Scott (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Washington (Lane km)	11.13	11.91	0.00	0.00	0.00	0.00

Table 20: Scenario 4b. Budget Increase by 200% - Results

Budget increase - 200% Scenario						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Trips generated	359,190	380,920	400,210	419,500	435,430	451,360
Trips attracted	359,190	380,920	400,210	419,500	435,430	451,360
VHT	408,601,600	490,596,928	604,346,300	716,765,120	894,338,110	1,037,843,970
VKT	25,855,578,100	29,590,339,600	32,884,103,200	36,818,911,000	39,463,395,000	43,366,945,000
Trip length (kilometers)	15.7769	17.0258	18.0091	19.2363	19.8643	21.0590
Trip time (minutes)	0.2494	0.2823	0.3310	0.3745	0.4501	0.5040
Accessibility	1,014,928,310,000	1,157,999,620,000	1,242,416,550,000	1,349,997,950,000	1,410,427,390,000	1,507,121,300,000
Expansion - State (Lane km)	41.58	138.33	156.49	198.78	393.43	119.07
Expansion - Anoka (Lane km)	12.55	25.70	22.59	21.40	11.94	28.51
Expansion – Carver	5.66	0.00	0.00	0.58	3.28	3.70
Expansion – Dakota	14.26	69.89	36.52	55.19	43.19	56.67
Expansion – Hennepin	13.81	13.64	41.13	34.24	36.20	45.12
Expansion – Scott	8.82	21.79	13.42	13.53	15.16	8.14
Expansion – Ramsey	1.64	0.00	0.00	3.80	5.86	7.37
Expansion – Washington	10.23	14.64	22.69	36.07	30.86	19.37
New	161.54	0.00	0.00	0.00	0.00	0.00

Construction - State (Lane km)						
New Construction - Anoka (Lane km)	7.59	0.00	0.00	0.00	0.00	0.00
New Construction - Carver (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Dakota (Lane km)	5.53	0.00	0.00	0.00	0.00	0.00
New Construction - Hennepin (Lane km)	28.29	34.63	0.00	0.00	0.00	0.00
New Construction - Ramsey (Lane km)	2.99	0.00	0.00	0.00	0.00	0.00
New Construction - Scott (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction Washington (Lane km)	23.04	0.00	0.00	0.00	0.00	0.00

Table 21: Scenario 4c. Budget Increase by 400% - Results

Budget Increase - 400% Scenario						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Trips generated	359,190	380,920	400,210	419,500	435,430	451,360
Trips attracted	359,190	380,920	400,210	419,500	435,430	451,360
VHT	408,646,016	489,951,680	586,864,900	681,110,980	861,262,590	1,022,548,480
VKT	25,855,578,100	29,595,455,500	32,878,985,200	36,812,534,000	39,545,688,000	43,386,839,000
Trip length (kilometers)	15.7769	17.0287	18.0062	19.2334	19.9057	21.0686
Trip time (minutes)	0.2494	0.2819	0.3214	0.3559	0.4335	0.4965
Accessibility	1,014,928,310,000	1,158,965,120,000	1,243,877,080,000	1,352,427,240,000	1,411,494,963,000	1,514,157,510,000
Expansion - State (Lane km)	70.25	352.64	504.31	200.03	250.54	19.53
Expansion - Anoka (Lane km)	18.02	28.79	17.35	16.80	4.41	19.66
Expansion - Carver	5.66	0.00	0.00	0.58	6.21	4.51
Expansion - Dakota	21.11	163.73	52.26	55.09	53.13	37.10
Expansion – Hennepin	22.30	58.25	56.28	90.36	83.27	124.60
Expansion – Scott	12.61	29.11	19.95	0.55	5.31	8.04
Expansion – Ramsey	1.64	0.00	0.00	9.56	3.67	5.05
Expansion – Washington	13.19	44.99	47.30	30.44	24.97	38.46
New Construction - State (Lane km)	161.54	0.00	0.00	0.00	0.00	0.00
New Construction -	7.59	0.00	0.00	0.00	0.00	0.00

Anoka (Lane km)						
New Construction - Carver (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New ConstructionDakota (Lane km)	5.53	0.00	0.00	0.00	0.00	0.00
New Construction - Hennepin (Lane km)	62.91	0.00	0.00	0.00	0.00	0.00
New Construction - Ramsey (Lane km)	2.99	0.00	0.00	0.00	0.00	0.00
New Construction - Scott (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction Washington (Lane km)	23.04	0.00	0.00	0.00	0.00	0.00

Table 22: Scenario 4d. Budget Decrease by 10% - Results

Budget decrease - 10% Scenario						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Trips generated	359,190	380,920	400,210	419,500	435,430	451,360
Trips attracted	359,190	380,920	400,210	419,500	435,430	451,360
VHT	408,646,016	491,203,392	610,502,530	746,256,700	934,907,200	1,247,846,400
VKT	25,855,579,100	29,596,129,300	32,851,613,700	36,776,657,000	39,436,784,000	43,357,209,000
Trip length (kilometers)	15.7769	17.0291	17.9913	19.2146	19.8509	21.0542
Trip time (minutes)	0.2494	0.2826	0.3343	0.3899	0.4706	0.6060
Accessibility	1,014,928,310,000	1,157,277,940,000	1,238,339,810,000	1,345,325,110,000	1,404,520,760,000	1,499,419,900,000
Expansion – State (Lane km)	11.57	22.41	26.60	25.62	33.81	29.36
Expansion – Anoka (Lane km)	3.93	5.08	5.28	6.11	4.84	10.94
Expansion - Carver	4.12	0.74	0.80	5.89	3.28	3.70
Expansion - Dakota	4.54	8.43	8.33	7.98	6.47	8.82
Expansion – Hennepin	5.15	4.54	5.50	4.28	3.99	9.30
Expansion – Scott	2.70	7.69	3.89	5.79	4.28	4.15
Expansion – Ramsey	1.64	1.13	0.00	6.92	3.86	3.99
Expansion – Washington	2.45	1.54	3.09	3.12	5.08	5.50
New Construction -	161.54	0.00	0.00	0.00	0.00	0.00

State (Lane km)						
New Construction - Anoka (Lane km)	7.59	0.00	0.00	0.00	0.00	0.00
New Construction - Carver (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Dakota (Lane km)	5.53	0.00	0.00	0.00	0.00	0.00
New Construction - Hennepin (Lane km)	10.43	6.31	9.49	22.40	14.28	0.00
New Construction - Ramsey (Lane km)	2.99	0.00	0.00	0.00	0.00	0.00
New Construction - Scott (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction Washington (Lane km)	5.76	5.37	11.91	0.00	0.00	0.00

Table 23: Scenario 4e. Budget decrease by 25% - Results

Budget decrease - 25% Scenario						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Trips generated	359,190	380,920	400,210	419,500	435,430	451,360
Trips attracted	359,190	380,920	400,210	419,500	435,430	451,360
VHT	408,646,016	490,433,312	611,413,950	748,244,800	937,831,380	1,280,469,760
VKT	25,855,578,100	29,575,428,100	32,833,540,100	36,781,482,000	39,423,611,000	43,377,095,000
Trip length (kilometers)	15.7769	17.0172	17.9814	19.2172	19.8443	21.0639
Trip time (minutes)	0.2494	0.2822	0.3348	0.3909	0.4721	0.6218
Accessibility	1,014,928,310,000	1,157,132,980,000	1,237,995,360,000	1,344,704,610,000	1,402,984,070,000	1,497,617,660,000
Expansion - State (Lane km)	10.51	8.00	27.29	23.94	28.90	21.62
Expansion - Anoka (Lane km)	3.93	3.54	4.70	4.96	3.91	10.94
Expansion - Carver	3.15	1.71	0.80	5.89	0.00	3.70
Expansion - Dakota	4.54	5.37	6.89	6.28	5.99	7.56
Expansion - Hennepin	4.02	3.54	4.89	2.93	4.38	3.38
Expansion – Scott	2.57	5.50	3.22	6.92	2.32	3.54
Expansion – Ramsey	1.64	1.13	0.00	6.92	3.86	8.50
Expansion – Washington	1.61	1.54	2.35	3.12	1.93	5.50
New Construction - State (Lane km)	118.94	42.61	0.00	0.00	0.00	0.00
New Construction - Anoka (Lane km)	7.59	0.00	0.00	0.00	0.00	0.00
New Construction - Carver (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Dakota (Lane km)	5.53	0.00	0.00	0.00	0.00	0.00
New Construction -	7.66	6.15	10.14	4.34	20.34	14.29

Hennepin (Lane km)						
New Construction - Ramsey (Lane km)	2.99	0.00	0.00	0.00	0.00	0.00
New Construction - Scott (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New ConstructionWashington (Lane km)	5.7602	5.37	11.91	0.00	0.00	0.00

Table 24: Scenario 5. New Construction/Expansion Budget Split 25-75% - Results

Budget Split 25-75%						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Trips generated	359,190	380,920	400,210	419,500	435,430	451,360
Trips attracted	359,190	380,920	400,210	419,500	435,430	451,360
VHT	408,646,016	494,786,368	598,817,790	721,701,180	1,071,163,260	1,123,229,820
VKT	25,855,578,100	29,573,060,600	32,827,981,800	36,753,048,000	39,525,274,000	43,337,593,000
Trip length Kilometers)	15.7769	17.0159	17.9783	19.2023	19.8954	21.0447
Trip time (minutes)	0.2494	0.2847	0.3279	0.3771	0.5392	0.5454
Accessibility	1,014,928,310,000	1,156,571,990,000	1,238,861,870,000	1,345,272,150,000	1,405,542,600,000	1,499,426,980,000
Expansion - State (Lane km)	18.78	22.08	28.58	31.28	38.81	33.56
Expansion - Anoka (Lane km)	5.50	5.57	5.31	7.85	7.88	11.01
Expansion – Carver	4.12	2.70	0.80	0.58	3.28	7.18
Expansion – Dakota	6.56	9.07	7.82	12.20	8.72	10.97
Expansion – Hennepin	7.11	8.11	8.82	5.76	7.98	6.85
Expansion – Scott	4.28	5.95	4.51	7.24	4.15	4.67
Expansion - Ramsey	1.64	0.00	0.00	6.89	6.05	10.36
Expansion – Washington	4.79	2.64	5.28	7.35	1.42	6.47
New Construction - State (Lane km)	72.15	89.40	0.00	0.00	0.00	0.00
New Construction - Anoka (Lane km)	7.59	0.00	0.00	0.00	0.00	0.00
New Construction - Carver (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Dakota (Lane	5.53	0.00	0.00	0.00	0.00	0.00

km)						
New Construction - Hennepin (Lane km)	6.24	4.18	3.38	5.31	7.11	2.06
New Construction - Ramsey (Lane km)	2.99	0.00	0.00	0.00	0.00	0.00
New Construction - Scott (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Washington (Lane km)	2.57	3.19	5.37	11.91	0.00	0.00

Table 25: Scenario 6. Levinson-Karamalaputi (LK) Model for expansion - Results

LK-Expansion Mode						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Trips generated	359,190	380,920	400,210	419,500	435,430	451,360
Trips attracted	359,190	380,920	400,210	419,500	435,430	451,360
VHT	408,646,016	491,167,232	628,052,290	759,037,700	962,253,820	1,273,041,020
VKT	25,855,578,100	29,594,521,600	32,842,135,600	36,766,437,000	39,474,237,000	43,365,863,000
Trip length (kilometers)	15.7769	17.0282	17.9861	19.2093	19.8697	21.0584
Trip time (minutes)	0.2494	0.2826	0.3440	0.3966	0.4844	0.6182
Accessibility	1,014,928,310,000	1,156,902,680,000	1,236,485,930,000	1,344,146,240,000	1,400,576,280,000	1,496,741,970,000
Expansion - State (Lane km)	88.22	153.51	112.00	74.82	54.34	53.16
Expansion - Anoka (Lane km)	2.06	9.09	9.81	6.60	10.01	14.93
Expansion – Carver	8.98	15.06	19.21	5.05	17.92	0.93
Expansion – Dakota	2.06	11.30	18.05	16.48	19.08	5.66
Expansion – Hennepin	22.82	7.82	8.59	10.88	12.12	16.96
Expansion – Scott	4.44	17.70	6.66	17.83	14.55	6.53
Expansion – Ramsey	10.01	15.89	15.29	12.94	6.63	10.59
Expansion – Washington	2.32	2.83	2.25	3.70	4.92	2.65
New Construction - State (Lane km)	161.54	0.00	0.00	0.00	0.00	0.00
New Construction - Anoka (Lane km)	7.59	0.00	0.00	0.00	0.00	0.00
New Construction - Carver (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00
New Construction - Dakota (Lane km)	5.53	0.00	0.00	0.00	0.00	0.00
New Construction - Hennepin (Lane km)	10.43	8.69	9.17	34.63	0.00	0.00
New Construction Ramsey (Lane km)	2.99	0.00	0.00	0.00	0.00	0.00
New Construction Scott (Lane km)	0.00	0.00	0.00	0.00	0.00	0.00

New Construction Washington (Lane km)	5.76	5.37	11.91	0.00	0.00	0.00

Table 26: Scenario 7. Levinson-Karamalaputi (LK) Model for new construction - Results

LK-New Construction Model						
	2005	**2010**	**2015**	**2020**	**2025**	**2030**
Trips generated	359,190	380,920	400,210	419,500	435,430	451,360
Trips attracted	359,190	380,920	400,210	419,500	435,430	451,360
VHT	423,568,960	484,890,400	745,975,680	913,379,580	1,338,797,180	1,620,939,140
VKT	25,955,416,100	29,416,329,200	32,907,954,200	36,645,990,000	39,811,539,000	43,194,352,000
Trip length (kilometers)	15.8379	16.9257	18.0221	19.1464	20.0395	20.9751
Trip time (minutes)	0.2585	0.2790	0.4085	0.4772	0.6739	0.7871
Accessibility	1,038,150,800,000	1,136,347,970,000	1,249,128,740,000	1,323,753,930,000	1,413,280,690,000	1,469,795,140,000
Expansion - State (Lane km)	92.86	61.30	71.12	33.69	2.70	2.80
Expansion - Anoka (Lane km)	2.06	5.47	3.57	2.96	3.89	2.77
Expansion – Carver	5.95	7.79	7.27	8.95	3.02	0.97
Expansion – Dakota	2.06	3.51	7.27	4.92	14.26	13.84
Expansion – Hennepin	22.82	7.82	8.17	15.09	8.56	14.95
Expansion – Scott	4.44	2.16	12.39	4.12	2.09	6.89
Expansion – Ramsey	4.76	5.25	0.00	12.74	16.54	13.42
Expansion – Washington	2.32	2.83	2.12	9.30	1.38	2.67
New Construction - State (Lane km)	7.82	7.14	4.41	6.24	5.95	8.37
New Construction - Anoka (Lane km)	4.70	1.47	3.93	1.29	5.98	1.61

New Construction - Carver (Lane km)	8.11	6.63	6.24	0.00	0.00	0.00
New Construction - Dakota (Lane km)	5.79	4.02	3.09	5.34	3.67	10.68
New Construction - Hennepin (Lane km)	4.51	3.38	4.51	4.67	5.63	5.37
New Construction - Ramsey (Lane km)	2.86	2.06	1.61	2.25	2.54	2.35
New Construction - Scott (Lane km)	11.26	11.26	0.00	0.00	0.00	0.00
New Construction - Washington (Lane km)	3.19	3.15	0.97	2.67	0.68	1.35

Table 27: Different Scenario Results for the year 2030

	Scenario 1.	Scenario 2.	Scenario 3.	Scenario 4 (a).	Scenario 4 (b).	Scenario 4 (c).	Scenario 4 (d).	Scenario 4 (e).	Scenario 5.	Scenario 6.	Scenario 7.
YEAR 2030	Base Scenario	Most Structured	Least Structured	Increase100	Increase200	Increase400	Decrease10	Decrease25	Split 25-75%	LK-Expansion Mode	LK-New Construction Model
VHT ('000)	1,296,098	1,076,424	1,134,627	1,110,125	1,037,843	1,022,548	1,247,846	1,280,469	1,123,229	1,273,041	1,620,939
VKT ('000)	43,357,884	43,298,865	43,394,052	43,336,135	43,366,945	43,386,839	43,357,209	43,377,095	43,337,593	43,365,863	43,194,352
Trip length	21.0546	21.0259	21.0721	21.0440	21.0590	21.0686	21.0542	21.0639	21.0447	21.0584	20.9751
Trip time	0.6294	0.5227	0.5510	0.5391	0.5040	0.4965	0.6060	0.6218	0.5454	0.6182	0.7871
Accessibility (millions)	1,499,779	1,500,221	1,501,825	1,504,630	1,507,121	1,514,157	1,499,419	1,497,617	1,499,426	1,496,741	1,469,795

Appendix A

Travel Demand Modeling – Main Framework Coding

BASIC TRAVEL DEMAND MODEL CODING

TRIP GENERATION

```
import java.text.*;

public class TGeneration {
	float TrafficProducedataNode[];   //// from a centroid
	float TrafficAttractedtoaNode[];    //// to a cnetroid
	int extTrips[];/// external stations
	double ext_Betas_1990[];///from 1990 to 2000
	int vertices;
	int centroids ;
	int taz;
	public double trip_gen_mutiplier=1.0;
	public float totaltrips=0;

	public TGeneration( DirectedGraph dgraph) {
		vertices=dgraph.Vertices() ;
		centroids=dgraph.Centroids() ;
		taz=dgraph.TAZ() ;
		TrafficProducedataNode=new float [centroids];
		TrafficAttractedtoaNode=new float [centroids];
		for(int i=0;i<centroids;i++){
			TrafficProducedataNode[i]=TrafficAttractedtoaNode[i]=0;
		}


		//1990 External Station AADT (From MetCouncil)
		extTrips=new int [centroids-taz];


	extTrips[0]=11300;extTrips[1]=4200;extTrips[2]=26500;extTrips[3]=6200;extTrips
[4]=13800;

	extTrips[5]=3600;extTrips[6]=15000;extTrips[7]=44000;extTrips[8]=9200;extTrips
[9]=4550;

	extTrips[10]=3700;extTrips[11]=1550;extTrips[12]=1750;extTrips[13]=11100;extT
rips[14]=1200;

	extTrips[15]=5000;extTrips[16]=1800;extTrips[17]=21000;extTrips[18]=3200;extT
rips[19]=3900;
```

```
	extTrips[20]=10100;extTrips[21]=2700;extTrips[22]=2400;extTrips[23]=5400;extT
rips[24]=5000;

	extTrips[25]=1450;extTrips[26]=11300;extTrips[27]=1600;extTrips[28]=11300;ext
Trips[29]=4800;

	extTrips[30]=36500;extTrips[31]=18000;extTrips[32]=20100;extTrips[33]=2650;ex
tTrips[34]=3300;
		//Betas
		ext_Betas_1990=new double[centroids-taz];
		for(int i=0;i<centroids-taz;i++)
			ext_Betas_1990[i]=0.02;

	//ext_Betas_1990[0]=0.034741501;ext_Betas_1990[1]=0.053903643;ext_Betas_199
0[2]=0.052011967;ext_Betas_1990[3]=0.070905976;ext_Betas_1990[4]=0.047742014;

	//ext_Betas_1990[5]=0.062488269;ext_Betas_1990[6]=0.005209496;ext_Betas_199
0[7]=0.046019164;ext_Betas_1990[8]=0.035179237;ext_Betas_1990[9]=0.003248794;

	//ext_Betas_1990[10]=0.065834151;ext_Betas_1990[11]=0.075181611;ext_Betas_1
990[12]=0.02991879;ext_Betas_1990[13]=0.052409779;ext_Betas_1990[14]=0.0442369
3;

	//ext_Betas_1990[15]=0.056951172;ext_Betas_1990[16]=0.045173892;ext_Betas_1
990[17]=0.050896583;ext_Betas_1990[18]=0.041379744;ext_Betas_1990[19]=0.034974
878;

	//ext_Betas_1990[20]=0.023171029;ext_Betas_1990[21]=0.030606578;ext_Betas_1
990[22]=0.030782916;ext_Betas_1990[23]=0.038779411;ext_Betas_1990[24]=0.038568
833;

	//ext_Betas_1990[25]=0.042570586;ext_Betas_1990[26]=0.01949209;ext_Betas_19
90[27]=0.034680474;ext_Betas_1990[28]=0.0470742;ext_Betas_1990[29]=0.037706069
;

	//ext_Betas_1990[30]=0.050959157;ext_Betas_1990[31]=0.060867355;ext_Betas_1
990[32]=0.044279046;ext_Betas_1990[33]=0.04959622;ext_Betas_1990[34]=0.0733863
95;
	}

	public void updateDemoInfo(DirectedGraph dgraph,int year){


	extTrips[0]=11300;extTrips[1]=4200;extTrips[2]=26500;extTrips[3]=6200;extTrips
[4]=13800;
```

```
        extTrips[5]=3600;extTrips[6]=15000;extTrips[7]=44000;extTrips[8]=9200;extTrips
[9]=4550;

        extTrips[10]=3700;extTrips[11]=1550;extTrips[12]=1750;extTrips[13]=11100;extT
rips[14]=1200;

        extTrips[15]=5000;extTrips[16]=1800;extTrips[17]=21000;extTrips[18]=3200;extT
rips[19]=3900;

        extTrips[20]=10100;extTrips[21]=2700;extTrips[22]=2400;extTrips[23]=5400;extT
rips[24]=5000;

        extTrips[25]=1450;extTrips[26]=11300;extTrips[27]=1600;extTrips[28]=11300;ext
Trips[29]=4800;

        extTrips[30]=36500;extTrips[31]=18000;extTrips[32]=20100;extTrips[33]=2650;ex
tTrips[34]=3300;

                //update the demographic data by TAZs
                int deltayear=year-1990;
                if (deltayear%10==0){
                        for (int i=0;i<taz;i++){
                                for (int j=0;j<9;j++){
                                        dgraph.TAZ_info[i][j]=dgraph.TAZ_info_forecasted
[i][j][(int)(deltayear/10)];
                                }
                        }

                }
                else{
                        int min=(int)(deltayear-deltayear%10)/10;
                        int max=min+1;
                        for (int i=0;i<taz;i++){
                                for (int j=0;j<9;j++){
                                        dgraph.TAZ_info[i][j]=(float)(dgraph.TAZ_info_forecasted
[i][j][min]*((10-deltayear%10)*0.1)+dgraph.TAZ_info_forecasted
[i][j][max]*((deltayear%10)*0.1));
                                }
                        }

                }


                //update the external station traffic
```

```
		for(int i=0;i<centroids-taz;i++){
			extTrips[i]*=Math.pow((1+ext_Betas_1990[i]),deltayear);
		}

	}

	public void tripGeneration(DirectedGraph dgraph) {
		float convertionratio=dgraph.convertionratio;
		//update the demographic data by Counties
		for (int i=0;i<8;i++){
			dgraph.juris_info[i][0]=0;
		}

		int m[];
		m=new int[8];
		for (int i=0;i<8;i++)
			m[i]=0;
		for (int i=0;i<taz;i++){
			int county=(int)dgraph.TAZ_info[i][6];
				//if(county<0)System.out.print("i="+i+"\tcounty="+county+"\n");
			//number of household
			dgraph.juris_info[0][0]+=dgraph.TAZ_info[i][0];//state
			dgraph.juris_info[county][0]+=dgraph.TAZ_info[i][0];//county
		}


	//version A:production and attraction combined
		//Intercept	35.93885022
		//POPULATION	0.12922701
		//RETAIL	0.232498334
		//NON RETAIL	0.149062479
		//RES DENSITY	-0.086487052
		//DISTANCE  0.00795244
		//DISTANCE SQ	-2.13347E-07

	//this regression model uses the total generation and attraction, so the calculated
number
	//should be divided by 2
	/*
		for(int i=0;i<taz;i++){
			//version A:
			TrafficProducedataNode[i]=(float)(35.9389+0.1292*dgraph.TAZ_info
[i][2]+0.2325*dgraph.TAZ_info [i][7]+0.1491*dgraph.TAZ_info [i][8])/2;
			TrafficProducedataNode[i]+=(float)(-0.086487*dgraph.TAZ_info
```

```
[i][3]+0.0079524*dgraph.TAZ_info [i][5]-2.13347E-7*Math.pow(dgraph.TAZ_info
[i][5],2))/2;

            if(TrafficProducedataNode[i]<0) TrafficProducedataNode[i]=0;

            TrafficProducedataNode[i]*=1.15;

            TrafficAttractedtoaNode[i]=TrafficProducedataNode[i];

            total_trips+=2*TrafficProducedataNode[i];
        }

        */
        //version B:production and attraction separated
        //Production
        //Intercept: -14.899933
        //POPULATION     0.108304451
        //RETAIL         0.03480615
        //NON RETAIL     0.011022643
        //RES DENSITY    -0.000320247
        //DISTANCE  0.005206677
        //DISTANCE SQ    -1.20079E-07

        //Atrraction
        //Intercept      50.83878331
        //POPULATION     0.020922559
        //RETAIL         0.197692184
        //NON RETAIL     0.138039836
        //RES DENSITY    -0.086166805
        //DISTANCE  0.002745763
        //DISTANCE SQ    -9.32674E-08

        float total_production=0,total_attraction=0;

        for(int i=0;i<taz;i++){
            //version B:
            TrafficProducedataNode[i]=(float)(-
14.899933+0.108304451*dgraph.TAZ_info [i][2]+0.03480615*dgraph.TAZ_info
[i][7]+0.011022643*dgraph.TAZ_info [i][8]);
            TrafficProducedataNode[i]+=(float)(-0.000320247*dgraph.TAZ_info
[i][3]+0.005206677*dgraph.TAZ_info [i][5]-1.20079E-07*Math.pow(dgraph.TAZ_info
[i][5],2));
            if(TrafficProducedataNode[i]<0) TrafficProducedataNode[i]=0;
            TrafficProducedataNode[i]*=trip_gen_mutiplier;
            total_production+=TrafficProducedataNode[i];
```

```
	TrafficAttractedtoaNode[i]=(float)(50.83878331+0.020922559*dgraph.TAZ_info
[i][2]+0.197692184*dgraph.TAZ_info [i][7]+0.138039836*dgraph.TAZ_info [i][8]);
			TrafficAttractedtoaNode[i]+=(float)(-0.086166805*dgraph.TAZ_info
[i][3]+0.002745763*dgraph.TAZ_info [i][5]-9.32674E-08*Math.pow(dgraph.TAZ_info
[i][5],2));
			if(TrafficAttractedtoaNode[i]<0) TrafficAttractedtoaNode[i]=0;
			TrafficAttractedtoaNode[i]*=trip_gen_mutiplier;
			total_attraction+=TrafficAttractedtoaNode[i];

		}

		//System.out.print(total_production+"\t"+total_attraction+"\n");
		if(total_production!=total_attraction){
			for(int i=0;i<taz;i++){

	TrafficAttractedtoaNode[i]=TrafficAttractedtoaNode[i]*(total_production/total_attra
ction);
			}
		}
		totaltrips=2*total_production;
		//System.out.print(total_trips);
		DecimalFormat myFormatter = new DecimalFormat("#######.00");
		System.out.print("\tTotal "+ myFormatter.format(
(float)total_production/1000)+" thousand trips are produced by
"+myFormatter.format(dgraph.juris_info[0][0]/1000) +" thousand households in the
seven-county region in the morning peak hour.\n\n");
		//System.out.print(TrafficProducedataNode[189]+"\n");
		int trip_generation_juris[]=new int [8];
		for (int i=0;i<=7;i++){
			trip_generation_juris[i]=0;
		}
		for(int i=0;i<taz;i++){
			int county=(int)dgraph.TAZ_info [i][6];
			trip_generation_juris[county]+=TrafficProducedataNode[i];
			trip_generation_juris[0]+=TrafficProducedataNode[i];
		}
		//for (int i=0;i<=7;i++){

			//System.out.print("County "+i+":\t"+dgraph.juris_info
[i][0]+"\t"+trip_generation_juris[i]+"\n");
		//}

		//External Stations
```

```
		for (int i=0;i<centroids-taz;i++){

	TrafficProducedataNode[taz+i]=(float)((extTrips[i]/convertionratio)/2);//convert
aadt to peak hour data
			TrafficAttractedtoaNode[taz+i]=TrafficProducedataNode[taz+i];//???
		}

		/*
		System.out.print("#Trips generated (Zones 1-1200):\n");
		for (int i=0;i<centroids;i++){
			System.out.print((int)TrafficProducedataNode[i]+"\t");
			if((i+1)%12==0)System.out.print("\n");
		}
		System.out.print("\n");
		*/
	}



}
```

TRIP DISTRIBUTION

```
import java.io.*;

public class TDistribution {
	float TrafficProducedataNode[];   //// at a network node
	float TrafficAttractedtoaNode[];    //// at a network node
	float Attraction[],oldAttraction[],newAttraction[];   ////// the resulting attraction
function for each node
	double denom[];    //// its the resulting denominator in the gravity
model.......denom[i] = sum(j) (Attraction[j] * f(i, j))
	public double coeff = 0.048*60;// coefficent in friction function//0.1 is commonly
used for friction factor, with travel in minutes


	public TDistribution( DirectedGraph dgraph) {
		int vertices=dgraph.Vertices() ;
	}

	public void tripDistribution(DirectedGraph dgraph, TGeneration tgen, DijkstrasAlgo
dalgo) {

		int edges= dgraph.Edges();
```

```
		int vertices = dgraph.Vertices();
		int centroids=dgraph.Centroids();
		TrafficProducedataNode=new float [centroids];   //// at a network centroid
		TrafficAttractedtoaNode=new float [centroids];    //// at a network centroid
		TrafficProducedataNode=tgen.TrafficProducedataNode;
		TrafficAttractedtoaNode=tgen.TrafficAttractedtoaNode;
		Attraction=new float[centroids];
		oldAttraction=new float[centroids];
		newAttraction=new float[centroids];
		denom=new double[centroids];


		///////   Trip_Distribution
			float error = 2;

			//System.out.println("Starting Trip Distribution");

			for(int i=0; i<centroids; i++)
				Attraction[i] = newAttraction[i] = TrafficAttractedtoaNode[i];
			int iterationCounter = 0;

			while(error> 0.5) {

				iterationCounter++;
				error = 0;

				//// step 1:   set denom =0; and oldattraction = newattraction
				for(int i=0; i<centroids; i++) {
					denom[i] = 0;
					oldAttraction[i] = newAttraction[i];
					newAttraction[i] = 0;
					//System.out.print(oldAttraction[i] + "  ");
				}
				//System.out.println();

				//// step 2:  calculate the new Attractions using the previous
oldAttraction
				for(int i=0; i<centroids; i++)
					{
						if(oldAttraction[i]>0)
						Attraction[i] =
TrafficAttractedtoaNode[i]*Attraction[i]/oldAttraction[i];

					}
```

```
            //// step 3:  calculate denom with the new Attractions
            for(int i=0; i<centroids; i++)
                for(int j=0; j<centroids; j++)
                    if(i!=j && dalgo.pLabel(i+1, j+1)<dgraph.INF )
                    denom[i] +=Attraction[j]*Math.exp( -
coeff*dalgo.pLabel(i+1, j+1) );

            //// step 4:  calculate newAttraction using denom and Attraction
            for(int j=0; j<centroids; j++) {
                for(int i=0; i<centroids; i++)
                    if( i!= j && denom[i]>0 && dalgo.pLabel(i+1,
j+1)<dgraph.INF )
                        newAttraction[j] +=
TrafficProducedataNode[i]*Math.exp( -coeff*dalgo.pLabel(i+1, j+1) )/denom[i];
                newAttraction[j] *= Attraction[j];
            }

            //// step 5:  calculate error. error = square root of sum of squares of
deviation rom previous results
            for(int i=0; i<centroids; i++)
                error += Math.pow( (oldAttraction[i] - newAttraction[i] ),  2);
            error = (float)Math.sqrt( error);
        }

        for(int i=0;i<centroids;i++){
            for (int j=0;j<centroids;j++){
                if(i!=j && denom[i]>0 && dalgo.d [i][j]<dalgo.INF )
                    {
                        dgraph.ODMatrix[i][j]= (float) Math.round
((TrafficProducedataNode[i] * Attraction[j]*Math.exp(-coeff*dalgo.d [i][j])/denom[i] ));

                    }
                else
                    dgraph.ODMatrix[i][j]=0;

            }
        }

    }

    public void printODMatrix(DirectedGraph dgraph){

        PrintWriter flowoutput=null;
        int centroids=dgraph.Centroids() ;
        try
```

```
			{
				flowoutput=new PrintWriter(new
FileOutputStream("TC1990_od1.txt"));
			}
		catch(IOException e)
			{
				System.out.print("Error opening the files!");
				System.exit(0);

			}
		flowoutput.print(centroids*centroids+"\n");
		for(int i=0;i<centroids;i++){

			for(int j=0;j<centroids;j++){

				flowoutput.print((i+1)+"\t");
				flowoutput.print((j+1)+"\t");
				flowoutput.print(dgraph.ODMatrix[i][j]+"\n");
			}
			//flowoutput.print("\n");
		}
		flowoutput.print("\n");

		flowoutput.close();
		System.out.print("ODMatrix created.\n");

	}

	public void printODCost(DirectedGraph dgraph,DijkstrasAlgo dalgo){

		PrintWriter flowoutput=null;
		int centroids=dgraph.Centroids() ;
		try
			{
				flowoutput=new PrintWriter(new FileOutputStream("odcost.txt"));
			}
		catch(IOException e)
			{
				System.out.print("Error opening the files!");
				System.exit(0);

			}
		for(int i=0;i<centroids;i++){

			for(int j=0;j<dgraph.Vertices() ;j++){
```

```
                    flowoutput.print((i+1)+"\t");
                    flowoutput.print((j+1)+"\t");
                    flowoutput.print(dalgo.d[i][j]+"\n");
                }
                //flowoutput.print("\n");
            }
            flowoutput.print("\n");

            flowoutput.close();
            System.out.print("ODCost created.\n");

        }
```

TRAFFIC ASSIGMENT

```
//import java.io.*;
import java.text.*;
public class TAssignment {
    public double x[];
    double xp[];
    double bprtt[];


    float INF;
    int edges;
    double theta=0.2*60;//0.2 is for travel time in minutes; .2*60 is for hours
    //The dispersion parameter theta is set at 0.2, following Leurent's (1995) work on
    //case studies in the Paris metropolitan area. This means that if one route is shorter
by five
    //minutes than another, then approximately three out of four drivers will choose the
first road.


    //variables used in dial's algorithm
    int vertices;
    int startnode,endnode,ed,linkid;//temporary variables
    double lk[],w[],x_org[],x_total[];
    double sumW[],sumX[];
    //sumW stores the sum of link weights (w) for all the links entering a node. if it is
the origin node, sumW=1
    //sumX will be used for backward pass
```

```
        int rank[];

//      FreeFlowTravelTime of OD for the calculation of Equity
        double odFFT[][];
        double odDelay[][];
//  OD travel time and OD flow for calculating Consummer Surplus
        double lastODQ[][];
        double lastODT[][];
        double accumulateCS;

        public TAssignment( DirectedGraph dgraph) {
                //System.out.print("!!theta="+theta/60+"\n\n");

                INF=dgraph.INF ;
                vertices=dgraph.Vertices() ;//total nodes
                edges=dgraph.Edges() ;//total links
                x = new double[edges];  //a vector to store the link flows
                bprtt= new double[edges];//a temporary array to store the bpr travel time of
links for each iteration of MSA
                xp =  new double [edges];//a temporary array to store the flow pattern derived
in the previous iteration of MSA
                lastODQ = new double[dgraph.Centroids()][dgraph.Centroids()]; // a temporary
matrix to store the OD flow in previous iteration of MSA
                lastODT = new double[dgraph.Centroids()][dgraph.Centroids()];// a temporary
matrix to store the OD travel time in previous iteration of MSA
                accumulateCS = 0; // variable to store the consumer surplus compared to base
year.

                for(int i=0; i<edges ; i++) {
                        x[i] =xp[i]=0;
                        bprtt[i]=dgraph.link_info [i][9];
                }

                edges=dgraph.Edges() ;
                double theta=0.2*60;//0.2 is for travel time in minutes; .2*60 is for hours
                //The dispersion parameter theta is set at 0.2, following Leurent's (1995) work
on
                //case studies in the Paris metropolitan area. This means that if one route is
shorter by five
                //minutes than a second, then approximately three out of four drivers will
choose the first road.

                vertices=dgraph.Vertices() ;
                lk=new double [edges];// link likelihood
                w=new double [edges]; //link weight used in forward pass
```

```
		//x=new float [edges];//total link flows summing up all o-d pairs

		sumW=new double [vertices];
		sumX=new double[vertices];

		x_total=new double [edges];
		x_org=new double [edges];//link flows calculated for a specific origin
(centroid) node

		rank=new int [vertices];
		for (int p=0;p<vertices;p++){
			rank[p]=p+1;//store node numbers
		}

	}


	public void trafficassignment(DirectedGraph dgraph, DijkstrasAlgo dal, int year) {
		dgraph.updateBPRtt() ;
		//All-or-nothing assignment

		/*
		int tempNode=0,leadingNode=0, followingNode=0;

		for(int i=0; i<dgraph.Centroids (); i++) {	//// for each node of the graph as
the origin of the shortest path
			for(int j=dgraph.Vertices()-1;j>=1; j--) {
				//// for each element from the end of the shortest path
				//// find its previously connected permanent node along the shortest
path until the orign ithNode is reached
				followingNode=dal.s[i][j];  //Node Number of the element in the
permanent vector
				//System.out.println(followingNode+"follow\n");
				if(followingNode<1){
				}

				else{
					leadingNode=dal.pi[i][followingNode-1];// the
predecessor,which is DIRECTLY connected to the node


					do
					{

						int K=-1;
```

```
                    a:    for(int k=0;k<dgraph.NoofLinks(leadingNode);k++){
                                if(dgraph.EndNodeNumbers( leadingNode, k+1
)==followingNode)
                                        {K=k;break a;}

                          }

                          //System.out.println("i+1="+(i+1)+"
following="+followingNode+" leadingNode="+leadingNode+" K="+K);

                                x[dgraph.linkID [leadingNode-1][K]-1]+=
dgraph.ODMatrix (i+1,dal.s[i][j]); ////

        //if(period==0)System.out.print("traffic="+TrafficonaLink[leadingNode-
1].access(K)+"\tODMatrix="+ODMatrix(i, dalgo.s[i][j]-1, (float)dalgo.pLabel(i+1,
dalgo.s[i][j]) )+"\tdenom="+denom[i]+"\n");
                                followingNode=leadingNode;
                                leadingNode=dal.pi[i][followingNode-1];


                    }
                    while(followingNode!=i+1);

                }
            }

        }

        System.out.print("F:\t");
        for(int p=0; p<dgraph.Edges() ; p++) {
            System.out.print(x[p]+"\t");
        }
        System.out.print("\n");
        */


    //Stochastic User Equilibrium (SUE)

        //initialization
        //int edges=dgraph.Edges() ;
        int startnode,endnode;//temporary variables
        //DijkstrasAlgo dal;
        //dal=new DijkstrasAlgo(dgraph);

        //Specify convergence requirement
```

```
int iternum=0,maxiternum=100;
double errorcrit=100.0;

if(year>2020){
      maxiternum=100;
      errorcrit=200;
}

double error[];
error=new double[maxiternum+1]; // a vector to store the error term (dependent
on definition),showing the trend of convergence
for(int i=0; i<=maxiternum ; i++) {
      error[i]=0;
}

//change2
for(int i=0; i<edges ; i++) {
      x[i]=dgraph.link_info [i][8];
      //if((i+1)%1000==0)System.out.print(x [i]+"\t");
      x[i]=Math.round( 100*x[i])/100;
      //if((i+1)%1000==0)System.out.print(x[i]+"\t");
}
System.out.print("\n");

//change3
for (int p=0;p<vertices;p++){
      rank[p]=p+1;//store node numbers
}

//System.out.print(" Initialization finished\n");
//Refer to Sheffi's book p.327
//0) Stochastic network loading based on a set of initial travel times

//System.out.print("Network loading before MSA...\n");

int linkno=-1;

do {

      iternum=iternum+1;
      //System.out.print("\nMSA: Iteration "+ iternum+"\n");
      //0) store the flow pattern at the begin of a MSA iteration
      for(int p=0; p<edges; p++) {
            xp[p]=x[p];
      }
```

```
//1) update link travel times
//According to the BPR function,link travel time=free flow travel
time*(1+0.15*(flow/capacity)**4)
for(int p=0; p<edges; p++) {
    double vcratio=0;
    if(bprtt[p]<INF && dgraph.link_info [p][7]!=0){
        vcratio=x[p]/dgraph.link_info [p][7];
        if(dgraph.link_info[p][5]!=0)
        {

    bprtt[p]=(dgraph.link_info[p][4]/dgraph.link_info[p][5])*(1+0.15*Math.pow(
vcratio,4.0));


    //if(vcratio<=1)bprtt[p]=(dgraph.link_info[p][4]/dgraph.link_info[p][5])*(1+0.15*M
ath.pow( vcratio,1.0));
                //else
if(vcratio>1)bprtt[p]=(dgraph.link_info[p][4]/dgraph.link_info[p][5])*(1+0.15*Math.pow
( vcratio,0.5));

        }
        else bprtt[p]=INF;

        if(bprtt[p]>dgraph.threshold_tt)bprtt[p]=dgraph.threshold_tt;
    }
}

// 2)  perform a new stochastic network loading procedure based on
updated link travel times.
//find the new flow pattern
    //dal.dijkstrasalgo(dgraph,bprtt);
    x=DialsAlgo(dgraph,dal.d,bprtt);

// 3) move
    for(int p=0; p<edges; p++) {
        double diff=x[p]-xp[p];
        startnode=(int)dgraph.link_info [p][1];
        endnode=(int)dgraph.link_info [p][2];

    //if(iternum<=3&&(startnode==190||endnode==190||startnode==204||endnode==204
||startnode==3131||endnode==3131||startnode==3133||endnode==3133))System.out.print(
(p+1)+"\t"+startnode+"\t"+endnode+"\t"+x[p]+"\n");
        if(Math.abs(diff)>error[iternum]){error[iternum]=Math.abs(
diff);linkno=p;}
```

```
                    int k=iternum%100;
                    if (k==0)k=100;
                    x[p]=xp[p]+(diff/(double)(k));

                }
            //4) convergence criterion: if convergence is attained, stop; if not, set
n=n+1 and go to step 1)
            System.out.print("   MSA Iteration "+iternum+":
Error="+error[iternum]+"\t"+(linkno+1)+"\n\n");

        }while(error[iternum]>errorcrit && iternum<maxiternum);

        //replace the link_info array with the resulted flow pattern (x)

        for(int p=0; p<edges; p++) {
            dgraph.link_info [p][8]=(float)x[p];
        }

        //update the BPR travel time for each link
        dgraph.updateBPRtt() ;

        ///predict the crash counts on links
        /*
        for (int p=0;p<edges;p++){
            float aadt=dgraph.link_info [p][8]*dgraph.convertionratio;
            float length=dgraph.link_info [p][4];
            int state=0,county=0,township=0;
            if(dgraph.link_info [p][17]==0)state=1;
            else if(dgraph.link_info [p][17]==1)county=1;
            else township=1;
            dgraph.link_info [p][12]=(aadt*length)*aadt*(float)Math.exp(-15.4744-
0.9595655*length-
0.0004853*aadt*length+9.933467*township+(3.387386+4.125646)/2*county+(1.711183
+2.501844+2.756652)/4*state);
        }
        */
        ///Calibration using peak hour volumes
        float real_aver=0,forecast_aver=0,RMSE=0;//volume
        for(int i=0;i<63;i++){
            forecast_aver+=dgraph.link_info [dgraph.stations [i]-1][8];
            real_aver+=dgraph.station_volumes [i];
        }
        forecast_aver/=63;
        real_aver/=63;
        for(int i=0;i<63;i++){
```

```
			RMSE+=Math.pow((dgraph.link_info [dgraph.stations [i]-1][8]-
dgraph.station_volumes [i]),2);
		}
		RMSE=(float) Math.sqrt( RMSE/62);
		System.out.print("Aver peak volume="+forecast_aver+", which is "+(100-
100*forecast_aver/real_aver)+" percent off.\n");
		System.out.print("Percent RMSE="+100*RMSE/real_aver+" percent.\n");

		System.out.print("LinkID\tLinkType\tForecast\tCounts\n");
		for(int i=0;i<63;i++){
			System.out.print(dgraph.stations [i]+"\t"+dgraph.link_info
[dgraph.stations [i]-1][3]+"\t"+dgraph.station_volumes [i]+"\t"+dgraph.link_info
[dgraph.stations [i]-1][8]+"\n");
		}

		//Calibration using aadt volumes
		/*
		float total_i94=0;
		//Calibration using I94 traffic
		for(int i=0;i<120;i++){
			total_i94+=dgraph.link_info [dgraph.I94 [i]-1][8]*dgraph.link_info
[dgraph.I94 [i]-1][4];
		}
		System.out.print("Daily vmt on I94 is "+total_i94*dgraph.convertionratio
+"\n");

		float total_35E=0;
		//Calibration using I94 traffic
		for(int i=0;i<112;i++){
			total_35E+=dgraph.link_info [dgraph.I35E [i]-1][8]*dgraph.link_info
[dgraph.I35E [i]-1][4];
		}
		System.out.print("Daily vmt on I35E is "+total_35E*dgraph.convertionratio
+"\n");

		float total_169=0;
		//Calibration using I94 traffic
		for(int i=0;i<98;i++){
			total_169+=dgraph.link_info [dgraph.H169 [i]-1][8]*dgraph.link_info
[dgraph.H169 [i]-1][4];
		}
		System.out.print("Daily vmt on 169 is "+total_169*dgraph.convertionratio
+"\n");
```

```
            float total_Mississipi=0;
            //Calibration using Mississipi bridge traffic
            for(int i=0;i<50;i++){
                  total_Mississipi+=dgraph.link_info [dgraph.Mississipi[i]-1][8];
            }
            System.out.print("Daily Traffic across bridges on Mississipi River is
"+total_Mississipi*dgraph.convertionratio +"\n");

            //for(int i=1; i<=maxiternum ; i++) {
            //      if(i<=5||i%10==0)System.out.print(i+"\t"+error[i]+"\n");
            //}
            */
      }


      double[] DialsAlgo(DirectedGraph dgraph, double d[][],double bprtt[]){
            for(int p=0; p<edges; p++) {
                  x_total[p]= 0;
            }
            System.out.print("   Dial's Algorithm running...0%");
            //Dial's algorithm
            for(int i=0;i<dgraph.Centroids() ;i++){
                  if((i+1)%48==0){
                        System.out.print(".");
                        if((i+1)%240==0){
                              System.out.print((i+1)/12+"%");
                        }
                  }
                  int origin=i+1;

                  //calculate link likelihoods

                  for(int p=0; p<edges; p++) {
                        lk[p] =w[p]=x_org [p]=0;

                        startnode=(int)dgraph.link_info [p][1];
                        endnode=(int) dgraph.link_info [p][2];
                         if(d[origin-1][startnode-1]<d[origin-1][endnode-1] && d[origin-
1][endnode-1]<INF)//dalgo.d[][] stores the O-D travel time cost
                              lk[p]=(float) Math.exp( theta*(d[origin-1][endnode-1]-
d[origin-1][startnode-1]-bprtt[p]));
                         else lk[p]=0;
                  }

                  /*
```

```
                    System.out.print("lk:\t");
                        for(int p=0; p<edges; p++) {
                              System.out.print(lk[p]+"\t");
                        }
                        System.out.print("\n");
                    */

                    //Forward pass
                        //Sort vertices ascendingly according to their distances to the origin
node (i.e.,dalgo.d[origin-1][nd-1]))

                        for(int p=0;p<vertices-1;p++){
                              for(int q=p+1;q<vertices;q++){
                                    if(d[origin-1][rank[p]-1]>d[origin-1][rank[q]-1]){
                                          int temp=rank[p];
                                          rank[p]=rank[q];
                                          rank[q]=temp;
                                    }
                              }
                        }

                        //Calculate link weights
                        //( This is the most time-consuming part, maybe because it really
calculates 8,000*20,000 times for TC network)
                        for (int p=0;p<vertices;p++){
                              sumW[p]=sumX[p]=0;
                        }
                        /*less efficient code
                        sumW[origin-1]=1;
                        for(int p=1;p<vertices;p++){//rank[0] must be the origin node, and it
doesn't need to be examined
                              ed=rank[p];//node to be examined
                              for(int q=0; q<edges; q++) {
                                    startnode=(int)dgraph.link_info [q][1];
                                    endnode=(int) dgraph.link_info [q][2];
                                    if (endnode==ed){// if the examined link enters the
examined node
                                          w[q]=lk[q]*sumW[startnode-1];
                                          sumW[endnode-1]+=w[q];
                                    }
                              }
                        }
                        */

                        sumW[origin-1]=1;
```

```
			for(int p=1;p<vertices;p++){//rank[0] must be the origin node, and it
doesn't need to be examined
				ed=rank[p];//node to be examined

					for(int q=1;q<=dgraph.endnodeTolinks[ed-1][0];q++ ){
						linkid=dgraph.endnodeTolinks[ed-1][q];
						startnode=(int)dgraph.link_info[linkid-1][1];
						w[linkid-1]=lk[linkid-1]*sumW[startnode-1];
						sumW[ed-1]+=w[linkid-1];
					}


			}
			/*
		System.out.print("w:\t");
			for(int p=0; p<edges; p++) {
				System.out.print(w[p]+"\t");
			}
			System.out.print("\n");

		//System.out.print("2\t");

		System.out.print( "\nsum of weights:\t");
		for(int p=0; p<vertices; p++) {
			System.out.print(sumW[p]+"\t");
		}
		System.out.print( "\n");
		*/



		//Backward pass
			/*
			for(int p=0; p<edges; p++) {
				x_org [p]=0;
			}
			*/
			for(int p=vertices-1;p>0;p--){
				ed=rank[p];

					if(sumW[ed-1]!=0){
						double temp=dgraph.ODMatrix(origin,ed)+sumX[ed-
1];
						if(temp!=0){
							for(int q=1;q<=dgraph.endnodeTolinks[ed-
1][0];q++ ){
```

```
								linkid=dgraph.endnodeTolinks[ed-1][q];
								if(w[linkid-1]!=0){
									startnode=(int)dgraph.link_info[linkid-
1][1];

									x_org[linkid-1]=temp*w[linkid-
1]/sumW[ed-1];
									sumX[startnode-1]+=x_org[linkid-1];
								}
							}

							/*//less efficient code
							for(int q=0; q<edges; q++) {
								startnode=(int)dgraph.link_info [q][1];
								endnode=(int) dgraph.link_info [q][2];
								if (endnode==ed && w[q]!=0){// if the
examined link enters the examined node
									x_org[q]=temp*w[q]/sumW[ed-1];
									sumX[startnode-1]+=x_org[q];
								}
							}
							*/
						}
					}


				}
			/*
			System.out.print( "\nsum of flows:\t");
			for(int p=0; p<vertices; p++) {
				System.out.print(sumX[p]+"\t");
			}
			System.out.print( "\n");
			*/
			//System.out.print("x_org:\n");

			for(int p=0; p<edges; p++) {
				x_total[p]+=x_org[p];
				//System.out.print(x_org[p]+"\t");
			}

		}
		System.out.print("\n");
		return x_total;
	}
```

```
public void MOEs(DirectedGraph dgraph,float tripproduced,double friction_factor,
double d[][], int tPeriods){

		float vht,vkt,accessibility,aver_trip_length,aver_trip_time;
		double cs;
		vht=0;
		vkt=0;
		accessibility=0;
		cs = 0;

		System.out.print("Trips produced="+tripproduced+"\n");
		for(int p=0; p<edges; p++) {
			vht+=365*dgraph.convertionratio*dgraph.link_info
[p][9]*dgraph.link_info [p][8];

	vkt+=365*dgraph.convertionratio*(dgraph.link_info[p][4]*1.609)*dgraph.link_info
[p][8];
		}
		aver_trip_length=(vkt/(365*dgraph.convertionratio))/tripproduced;
		aver_trip_time=(vht/(365*dgraph.convertionratio))/tripproduced;

		float taz_access=0;
		for (int i=0;i<dgraph.TAZ();i++){
			taz_access=0;
			for(int j=0;j<dgraph.TAZ();j++){
				if(i!=j){
					if(d[i][j]!=0)
					taz_access+=(dgraph.TAZ_info [j][7]+dgraph.TAZ_info
[j][8])*Math.exp (-friction_factor*d[i][j]);
				}
			}
			accessibility+=(dgraph.TAZ_info [i][7]+dgraph.TAZ_info
[i][8])*taz_access;
		}

		// Calculate Consummer Surplus?
		if (tPeriods == 0)
		{
			for (int i=0;i<dgraph.Centroids();i++)
			{
				for (int j=0;j<dgraph.Centroids();j++)
				{
					lastODT[i][j] = d[i][j];
					lastODQ[i][j] = dgraph.ODMatrix(i+1,j+1);
```

```
                    }
                }
            }else{
                cs = 0;
                for (int i=0;i<dgraph.Centroids();i++)
                {
                    for (int j=0;j<dgraph.Centroids();j++)
                    {
                        cs = cs +0.5*(dgraph.ODMatrix(i+1,j+1) +
lastODQ[i][j])*(lastODT[i][j] - d[i][j]);
                                //Consummer Surplus for each OD pair;
                        lastODT[i][j] = d[i][j];                    //Update matrix for
OD travel time;
                        lastODQ[i][j] = dgraph.ODMatrix(i+1,j+1); //Update matrix for
OD flow;
                    }
                }
                accumulateCS = accumulateCS + cs;
            }
            //End of Consummer Surplus;

            DecimalFormat myFormatter = new DecimalFormat("0.000");
            System.out.print("**MOE Outpus:\n");
            System.out.print("vht\t vkt \n");
            System.out.print(vht+"\t"+vkt+"\n");
            System.out.print("trip length\ttrip time\tAccessibility\n");

        System.out.print(aver_trip_length+"\t"+aver_trip_time+"\t"+accessibility+"\n");
            System.out.print("Consumer Surplus for this time period\tAccumulate
Consumer Surplus"+cs+"\t"+accumulateCS);
        }

        public void FreeFlowTravelTime (DirectedGraph dgraph, DijkstrasAlgo dal){
            System.out.println("\tCalculate Free Flow OD Travel Time:\n");
            odFFT = new double[dgraph.Centroids()][dgraph.Centroids()];
            //Chang current link flow to zero;
            int noofLink = dgraph.Edges();
            int noofCentroids = dgraph.Centroids();
            float templink_info8[],templink_info9[];
            templink_info8 = new float[noofLink];//store the link flow
            templink_info9 = new float[noofLink];//store the link travel time
            for (int i=0;i<noofLink;i++)
            {
                templink_info8[i] = dgraph.link_info[i][8]; //Store original link flow
                dgraph.link_info[i][8] = 0;
```

```
			templink_info9[i] = dgraph.link_info[i][9];// Store original link travel time
			dgraph.link_info[i][9] = 0;

		}
		dgraph.updateBPRtt();		//Calculate Free Flow Travel Time for each Link;
		//Use Dijkstra Alogrithm to find the FFT of each OD;
		dal.dijkstrasalgo(dgraph);
		//System.out.println("OD free flow travel time:");
		for (int i=0;i<noofCentroids;i++)
		{
			for (int j=0;j<noofCentroids;j++)
			{
				odFFT[i][j]=dal.d[i][j];
			//System.out.print(""+odFFT[i][j]+"\t");
			}
			//System.out.print("\n");
		}
		//Restore the data
		for (int i=0;i<noofLink;i++)
		{
			dgraph.link_info[i][8] = templink_info8[i];
			dgraph.link_info[i][9] = templink_info9[i];
		}
		//dgraph.updateBPRtt();
		//System.out.println("****************End of FFT
Algorithm************");
	}

	public void finalMOEs (DirectedGraph dgraph,float tripproduced,double
friction_factor, double d[][])
	{
		float vht,vkt,accessibility,aver_trip_length,aver_trip_time,gini;
		vht=0;
		vkt=0;
		accessibility=0;

		System.out.print("Trips produced="+tripproduced+"\n");
		for(int p=0; p<edges; p++) {
			vht+=365*dgraph.convertionratio*dgraph.link_info
[p][9]*dgraph.link_info [p][8];

	vkt+=365*dgraph.convertionratio*(dgraph.link_info[p][4]*1.609)*dgraph.link_info
[p][8];
		}
```

```
		aver_trip_length=(vkt/(365*dgraph.convertionratio))/tripproduced;
		aver_trip_time=(vht/(365*dgraph.convertionratio))/tripproduced;

		float taz_access=0;
		for (int i=0;i<dgraph.TAZ();i++){
			taz_access=0;
			for(int j=0;j<dgraph.TAZ();j++){
				if(i!=j){
					if(d[i][j]!=0)
					taz_access+=(dgraph.TAZ_info [j][7]+dgraph.TAZ_info
[j][8])*Math.exp (-friction_factor*d[i][j]);
				}
			}
			accessibility+=dgraph.TAZ_info [i][2]*taz_access;
		}

//		Euqity MOE
		System.out.println("***************Start Equity*****************");
		int noofCentroids = dgraph.Centroids();
		float odTrips[][];
		double vectorDelay[];
		float vectorODTrips[];
		vectorDelay = new double[noofCentroids*noofCentroids];
		vectorODTrips = new float[noofCentroids*noofCentroids];
		odTrips =  new float[noofCentroids][noofCentroids];
		odDelay = new double[noofCentroids][noofCentroids];
		double totalDelay;
		float totalTrips;

			//Delay for each OD pair;
		System.out.println("    Delay for OD pairs");
		int k=0;
		totalDelay = 0;
		totalTrips = 0;
		for (int i=0;i<noofCentroids;i++)
		{
			for (int j=0;j<noofCentroids;j++)
			{
				odDelay[i][j] = d[i][j] - odFFT[i][j];
//				System.out.println(""+odDelay[i][j]+"\t"+d[i][j]+"\t"+odFFT[i][j]);
				odTrips[i][j] = dgraph.ODMatrix(i+1,j+1); //ODMatrix store number
from (0,0), but OD ID from (1,1);
				//Convert Matrix to Vector for further sort;
				vectorODTrips[k]=odTrips[i][j];
				vectorDelay[k] = odDelay[i][j];
```

```
				k++;
				totalDelay = totalDelay + odDelay[i][j]*odTrips[i][j];
				totalTrips = totalTrips + odTrips[i][j];
			}
//			System.out.print("\n");
		}
		System.out.println("Total Delay:"+totalDelay);
		System.out.println("Total OD Trips:"+totalTrips);
			//Bubble Sort
		System.out.println("\t\tBubble Sort Started:");
		int noofCentroidsSquare = noofCentroids*noofCentroids;
		double tempDelay;
		float tempODTrips;
		System.out.print("Progress");
		for (int i=0;i<noofCentroidsSquare;i++)
		{
			if ((i+1)%50000 == 0)
			{
				System.out.print(".");
			}
			for (int j=0;j<noofCentroidsSquare-i-1;j++)
			{
				if (vectorDelay[j]>vectorDelay[j+1])
				{
					tempDelay = vectorDelay[j+1];
					vectorDelay[j+1] = vectorDelay[j];
					vectorDelay[j] = tempDelay;
					tempODTrips = vectorODTrips[j+1];
					vectorODTrips[j+1] = vectorODTrips[j];
					vectorODTrips[j] = tempODTrips;
				}
			}
		}
		System.out.println("\t\tBubble Sort Ended:");
			//Calculate A1 in Lorenz Curve;
		double a1,a1a2;
		double accumulateDelay;
		float accumulateODTrips;
		a1 = 0;
		accumulateODTrips = 0;
		accumulateDelay = 0;
		for (int i=0;i<noofCentroidsSquare;i++)
		{
			a1 = a1 + (accumulateODTrips/totalTrips*totalDelay-
accumulateDelay)*vectorODTrips[i];
```

```
            accumulateODTrips = accumulateODTrips + vectorODTrips[i];
            accumulateDelay = accumulateDelay + vectorDelay[i]*vectorODTrips[i];
        }
        a1a2 = totalDelay*totalTrips/2;
        gini = (float)(a1/a1a2);
        System.out.print("a1:"+a1);
        System.out.print("\ta1a2"+a1a2);
        System.out.print("\tGini"+gini);
        System.out.println("******************End of Equity**************");
        //End of Equity indicator, Gini coefficient

        DecimalFormat myFormatter = new DecimalFormat("0.000");
        System.out.print("**MOE Outpus:\n");
        System.out.print("trip length\ttrip time\tAccessibility\n");

    System.out.print(aver_trip_length+"\t"+aver_trip_time+"\t"+accessibility+"\n");
    }
}
```

Appendix B

Travel Demand Models

The model forecasts the future with the assumption that travel demand will behave according to the same factors that have affected it in the past. As with most travel demand models, we need to calibrate traffic levels predicted by the model against observed data. But we also need to compare predictions of investments made by the model with observed investments. For that reason, we begin with a base year of 1990. We are adapting the networks and data sets from the Metropolitan Council, and simplifying the planning model that is used there as described below.

The 1990 Transportation Planning Network has 20,380 links, 7,723 nodes, 1,165 Transportation Analysis Zones (TAZs) in the Seven County Metro Area, and 35 external stations, which make a total of 1200 zones for analysis. While Carver County has 32 zones, the fewest zones in the Seven County Metro Area, Hennepin County has 502 zones.

The Metropolitan Council now uses a new network structure form and model estimated with a year 2000 base. Some of the differences between these two systems are the number of TAZs and the number of intersections. The 1990 Network has 1,165 centroids, the 2000 Network has 1,201 centroids. Both Networks have 35 external stations.

The planning network had to be revised due to the incorporation of what we call "legacy links", which required new nodes (projects that are in old transportation plans from the 1960s but that have not been constructed yet). The general idea is that if a legacy link intersects an existing link, there is a creation of a new node and the old link is divided into two different links. In the revised planning network there are 20,398 links and 7,733 nodes.

The model estimated differs in some other respects from the Metropolitan Council model. It models traffic in the AM Peak Hour, calibrating against that, and then using peak hour to daily expansion factors where required to obtain AADT (which is required in some of the investment models). Base year (and subsequent) freeway capacities were increased by a 20% over the Metropolitan Council model to improve calibration results. (The afternoon peak is generally more congested than the morning overall, due to the additional non-work travel, using the afternoon may result in a different set of selected projects).

The initial base year is iterated (using Method of Successive Averages) to obtain an equilibrium between inputs to trip distribution and outputs from route assignment. From that point forward, the model is evolutionary; outputs from one five-year period (e.g. travel times, network investments) are inputs into the next five-year period, extending Levinson (1995).

Models trade off accuracy for simplicity. The model can be less accurate and simpler (and thus computationally faster and less data intensive), or it can be more accurate, capturing more detail about certain aspects of travel, at the cost of requiring more data, more computers, and more labor. Furthermore, models can try to achieve accuracy over different facets of the problem. Many agencies spend a great deal of effort to calibrate accurate mode choice models, but do not take into account realistic destination choice decision making processes. Here, we examine the evolution of transportation flows, by modeling multiple years between our base and our final forecast, which is computationally more intensive than a simple equilibrium approach. To do that in reasonable time, we sacrifice some detail in the transportation planning model, such as trip purposes and modal selection, which will affect the final forecasts in a way that is unknown without sacrificing that detail.

The model assumes the volume of each external station will increase at a compound rate of 2% every year since 1990. This rate is estimated using 1990 and 2000 observed traffic counts at external stations. The reason for not calculating the increase rate for individual external stations was that some stations produced rates that appeared unreasonable when projected forward.

This model simplifies the traditional travel demand forecasting process by dropping mode choice, and instead directly estimates vehicle trips. We also do not model freight trips directly, and instead inflate passenger car trips to account for missing trucks. The three major components

- Trip generation estimates the number of personal motor vehicle trips that originate or are destined for each zone.
- Trip distribution matches origins with destinations.
- Route assignment selects the routes that the trips will take.

These components are discussed in turn.

Trip Generation

Trip generation computes the motor vehicle trips produced by and attracted to every Transportation Analysis Zone with variables that are easy to obtain and have already being predicted for future years for the Twin Cities metropolitan area.

The volumes used to estimate the trip generation model are AM peak hour (the average from 6:00 am to 9:00 am) car trips generated by every TAZ using volumes from the 1990 Metropolitan Council Planning Model. Some of the data (population, autos, employment, and trips generated per zone) was obtained from the Twin Cities Metropolitan Council.

In order to calculate the distance variables, additional geoprocessing work in a Geographic Information System program (Arc/Info) had to be done as well. Distances were calculated from the centroid node of the zone to Downtown Minneapolis and Downtown St Paul. Then the shortest distance from that centroid to either of the downtowns was chosen.

Many regression models were tested to obtain the one with the best fit (variables with the highest significance and the highest r-squared). Variables like population, number of households, autos per household, households per population, shortest distance from the zone to either Minneapolis or St Paul downtown, income per household, were taken into consideration for regression. In order to verify that the right variables were chosen, some correlation tables were calculated. (and). By adding and/or deleting different variables, the model that provided the highest r-square and had the most significant variables is described below and includes the following variables:

- Population
- Retail Employment
- Non-retail employment
- Residential density
- Shortest distance from centroid zone to either downtown Minneapolis or St. Paul
- Shortest previous distance squared

Two different trip generation models are used in this research: trips produced by every zone and trips attracted to every zone. The regression models are shown in and respectively. This AM trip production model gave an r-squared of 0.93 with variables significant except for residential density. The AM trip attraction model gave an r-squared of 0.66 with all variables significant. Both models are based on observations for the year 1990, including each one of the seven counties

Normalization was conducted to match up the total number of trip attraction with the total number of trip generation, assumption the forecast for trip generation is more accurate. A standardized method for normalization is to add the trips generated by the 1,165 TAZ centroids as well as the trips attracted by each centroid. In order to obtain a total number of trips generated equal to the total number of trips attracted, trips attracted need to be adjusted. This happens by multiplying the number of trips attracted per each zone by the ratio of the total trips attracted to the total trips generated. Since only the total number of trips entering and exiting each external station is available, an assumption was made that the split between these trips at each station is 1:1.

Trip Distribution

After knowing the number of trips produced in each zone, trip distribution procedures matches the trips produced with the trips attracted. In this research the trip distribution is made for all trip purposes combined, since the trip generation model above does not distinguish trips by purpose.

The analysis made in this research for the trip distribution process is a doubly constrained gravity-based trip distribution model. The gravity model shows the interaction between zones, which decreases with travel cost but increases with the number of trips produced by or attracted to each zone.

$$T_{ij} = K_i K_j T_i T_j e^{-\theta C_{ij}}$$

Where

K_i, K_j are balancing coefficients
T_i is the production of zone *i*
T_j is the attraction of zone *j*
C_{ij} is the travel cost between *i* and *j*.

The gravity model assumes that the effect of distance or "separation" can be modeled by a decreasing function, in this case, the negative exponential function of the travel cost between the zones. The friction factor *theta* (θ) is a parameter in this function for calibration. A friction factor is an inverse function of travel time, which indicates whether people prefer longer or shorter trips. In this research we calibrated the value of the friction factor by minimizing the difference in link volumes derived from travel demand model results and observed AM Peak Hour traffic counts, resulting in a friction factor is set to 0.048.

The result of trip distribution is an origin destination (O-D) trip table. This table contains the number of trips from each origin node to each destination. There is a balance between the sum of the number of trips that are generated by each origin nodes and the total trips attracted to all nodes.

Because this trip distribution model is doubly constrained, the sum of the trips attracted by each zone should equal the trips attracted by the all zones. To balance origin and destination flows, trips for each cell are calculated and if the difference between the sum of square errors between one iteration and the previous one is smaller than 0.5 the algorithm is stopped, indicating the model is sufficiently close to balance in trip distribution. The error in the doubly-constrained gravity model in trip distribution is defined as follows,

$$error = \sqrt{\sum_i (T_i^k - T_i^{k-1})^2} < 0.5$$

where T_i is the attraction of TAZ *i*; *k* is iteration number.

Traffic Assignment

The Traffic Assignment model describes how trips between an origin and destination are allocated to different routes. In this research the traveler chooses the route with the lowest perceived travel time (which may differ from the actual travel time). By introducing a perceived travel time, we allow travelers to have mis-information or have preferences other than simply minimizing travel time (Zhang, 2006). There is some error perception associated with it, which is, we assume, subject to a Gumbel distribution. Based on this distribution, a logit model is used to estimate how travelers choose different routes. This is referred to as a Stochastic User Equilibrium (SUE). Coding work implementing Dial's Algorithm (Sheffi, 1985) for SUE (Davis and Sanderson, 2002) is being used for the traffic assignment phase, though the code has been translated from Fortran to Java and optimized. This codebase generates good results on smaller test networks such as Sioux Falls and Waseca. This coding can run one Method of Successive Averages (MSA) iteration on the Twin Cities Network in 9 minutes.

The coefficient used in the discrete choice model is 0.2. For example if a traveler faces two routes, and one route provides five minutes shorter travel time than the other route, then three out of four travelers would choose this route.

$$p = \frac{e^{-\theta T_1}}{e^{-\theta T_1} + e^{-\theta T_2}} = \frac{e^{-\theta (T_2 - 5)}}{e^{-\theta (T_2 - 5)} + e^{-\theta T_2}} = \frac{e^{0.2*5}}{e^{0.2*5} + 1} \approx 0.7311 \approx \frac{3}{4}$$

If it were an all-or-nothing assignment, the four travelers would choose the route that provides them with the shorter travel time, but because there is a perception error one of four travelers will perceive the longer route as the faster one. By introducing a perceived travel time, we allow travelers to have wrong information.

Convergence Issues

The equilibrium process means that the link travel time depends on the link flow. So trips are loaded into the network and the travel time is going to change depending on the volume assigned on this link. This process repeats until it reaches an equilibrium. Dial's algorithm (Sheffi 1985) is used to do the loading and Method of Successive Averages (MSA) to find a Stochastic User Equilibrium (SUE).

One of the four steps associated with the MSA is the Stochastic Network loading based on initial travel times. The initial travel time is the congested travel time from the last run. Dial's Algorithm is used to do network loading. This algorithm requires calculating the link likelihood, and performs a forward pass and backward pass. The problem of overflow occurs in calculating the link likelihood.

In some circumstances too much traffic may be assigned to a particular link (i.e. a bridge), when this happens, the link travel times become very high as well. One of the reasons this could happen is because the TAZ information forecasted is independent, exogenous to this model and the forecasted numbers are predicted using land use models without considering transportation factors.

The Bureau of Public Roads (BPR) link performance function raises the volume to capacity ratio to the fourth power. For example, when the volume on a link is very high, and when link travel time is not limited, that travel time can become very high (e.g.

600 minutes). If a 600 minute link travel time is used to calculate the link likelihood (travel time exponential function) in the next iteration of the assignment, the link travel time is too high and the link likelihood is approximately zero. In this case this link is ruled out, so all the trips get assigned to other routes. Thus link overflows cause some dysfunctions to the MSA. If there is overflow, even when MSA enforces convergence, travel demand becomes very high and it can't reach equilibrium. In order to avoid this, upper limits on link travel time have to be imposed.

In cases with very high demand convergence may not be reached even with a large number (say 50) iterations as the MSA algorithm converges ever more slowly at higher iteration numbers. In order to solve this problem, the iteration number in MSA is reinitiated every 20 iterations. In the MSA the difference of flow patterns between one year and the previous one is calculated by the following ratio, 1/iteration number. In the 21^{st} iteration, it becomes one, iteration 22^{nd} becomes iteration number two and so on.

The convergence for the SUE traffic assignment is defined by a maximal allowable link flow change. A smaller maximal allowable link flow change will result in a flow pattern that is closer to the equilibrium, but this is tradeoff between the accuracy and run time.

Davis and Sanderson used a criteria for convergence which stated that if the maximal change of link value is below a threshold equal to 5 vehicles, then the system's algorithm is in equilibrium. This threshold is somewhat arbitrary.

The convergence rule adopted here requires the maximum link flow change be less than 100 vehicles between iterations (or a maximum of 50 iterations), before starting the process for the next time period. A smaller maximal allowable link flow change will result in a flow pattern that is closer to the equilibrium, but this is a tradeoff between the accuracy and run time. The shortest path finding defines the shortest (congested travel time) path from each centroid to each other node.

Travel times

The Bureau of Public Roads (BPR) function defines the relationship between flows and congested travel times on a link. A BPR function broadly agrees with queuing theory, which says that when a flow increases, the link travel time increases accordingly and the travel time rate increases as well.

$$BPRTT = FFTT * \left(1 + \alpha * \left(\frac{V}{C} \right)^{\beta} \right)$$

where FFTT is the free flow travel time of a link, V is the volume of traffic on the link, and C is capacity of the link. Two parameters α and β are the coefficients of the function. The typical values of the coefficients are α=0.15 and β=4.0.

The maximum link travel time is set to one hour, which means if the computed travel time on a link exceeds one hour, it will drop to one hour automatically. This affects the equilibrium in an insignificant way but shortens the convergence significantly, since SUE is notoriously slow to converge under congested situations.

System Dynamics: Distribution and Assignment Convergence

Finally, trip distribution requires peak hour interzonal travel costs (C_{ij}) as inputs, which are the output of traffic assignment. This is particularly important for the base year (1990) where we do not have a congested “seed” travel time matrix a priori. In this research, the initial network conditions are estimated by running the program beginning with free flow times, and iterating between trip distribution and route assignment (using outputs of assignment as inputs to trip distribution) until the maximum difference between two successive iteration of the origin-destination matrix number of trips produced by a zone is 10.

Once this has been accomplished, the network conditions are updated with the trip generation model for every of the 1,165 zones. The Dial’s algorithm is applied and the shortest path finding is accomplished, then trips are distributed.

Calibration

Calibration is “the action or process of adjusting experimental results to take external factors into account or to allow comparison with other data” (Oxford American Dictionary). In transportation the term *calibration* implies knowing that the results produced by a model are trustworthy and are reproducing real numbers. So in order to accurately replicate travel demand in a model, a calibration is needed.

Most travel demand models try to calibrate their results with the Annual Average Daily Traffic (AADT). The advantages of this are several, AADT is readily available for most network links, AADT is sometimes used as a decision variable, and it is easier to model against a large number than a small number. However, this research tries to calibrate its model results with AM peak hour volumes. The main reason for this is to be as close to reality as possible, congestion occurs in the peak hours, and so that is what we are most interested in for the investment rules that use congestion as a critical factor. Peak hour volumes on freeways are accurately measured on a continuous basis by MnDOT’s Traffic Management Center, many AADT measures are just estimates (and thus models of a different sort).

The goal of this calibration is to minimize the difference between the AM peak hour volumes estimated by the model and actual AM peak hour volumes on specific links. Another goal is to obtain an average error of 0% between peak hour volumes on different links between the program results and actual volumes on all major highways in the Twin Cities transportation network (the goal is to reduce the average and RMSE error).

The first step is to obtain peak hour volumes. The Twin Cities metropolitan area has 999 traffic count stations on freeways and major highways. Some stations have at least two detectors and some others have four. The Minnesota Department of Transportation collects traffic data on the freeway system throughout the Twin Cities Metro area. This data is made public via XML files. Files are updated every 30 seconds. They contain measured volume (flow) and occupancy, and calculated speed data for each detector station in the Twin Cities Metro area.

Example:

```
<?xml version='1.0'?>
<!DOCTYPE traffic_sample SYSTEM 'tms.dtd'>
<traffic_sample time_stamp='Thu Feb 23 11:00:17 CST 2006' period='30'>
```

&detectors;
<sample sensor='D14' flow='840' speed='71'/>
<sample sensor='D15' flow='600' speed='58'/>
<sample sensor='D16' flow='360' speed='78'/>
<sample sensor='D17' flow='1200' speed='50'/>
<sample sensor='D18' flow='840' speed='64'/>
<sample sensor='D19' flow='840' speed='78'/>

As much as the authors of this research would like to calibrate the model with all the stations in the Metro Area, the complexity of matching every station with every links involves immense amount of time and has not yet been completed. To date, there is no correlation table for all the traffic count stations and the node and link structure of the Twin Cities planning model.

An approach is to take a specific set of stations where data is available and match them with the planning network. The calibration for this model involves 63 stations, which represent about 7% of the total number of stations. These stations have a total of 166 detectors. These stations are located all around the Metro Area as on I-35W, I-35E, I-94, I-394, I-494, I-694, TH 5, TH 36, TH 62, TH 77, TH 100, TH 169 and TH 212 ().

The real count data chosen is for the month of October of 2005. October was chosen because traffic volumes stabilize after construction over the summer and the weather does not impose significant variations for traveling. Monday, Wednesday and Friday in the first week of the month were taken into consideration to produce average peak hour volumes.

After doing some calibration, the results are as follow: The root mean square error (RMSE), defined by the formula below is about 30%. The 5-year model has a 0.78 percent average error on total traffic flows between stations and links.

$$RMSE = \sqrt{\frac{\sum_j \left(M_j - C_j\right)^2}{N - 1}}$$

where:
M_j = model estimate on link j,
C_j = observed traffic count on link j, and
N = number of counts.

There are two parameters that were adjusted to match link forecasted average volumes that go by the stations and the real counts given by the detectors. These parameters are the distribution model friction factor and the highway capacity's percentage increase. The parameter related to the capacity needs to be adjusted based on the assumption that the planning agency's link capacity on highways underestimates the real highway capacity. The final five-year model has a friction factor of 0.048 and a 20% increase of highway capacity after calibration.

More detailed peak hour volume results from the stations selected and forecasted peak hour volumes are shown in .

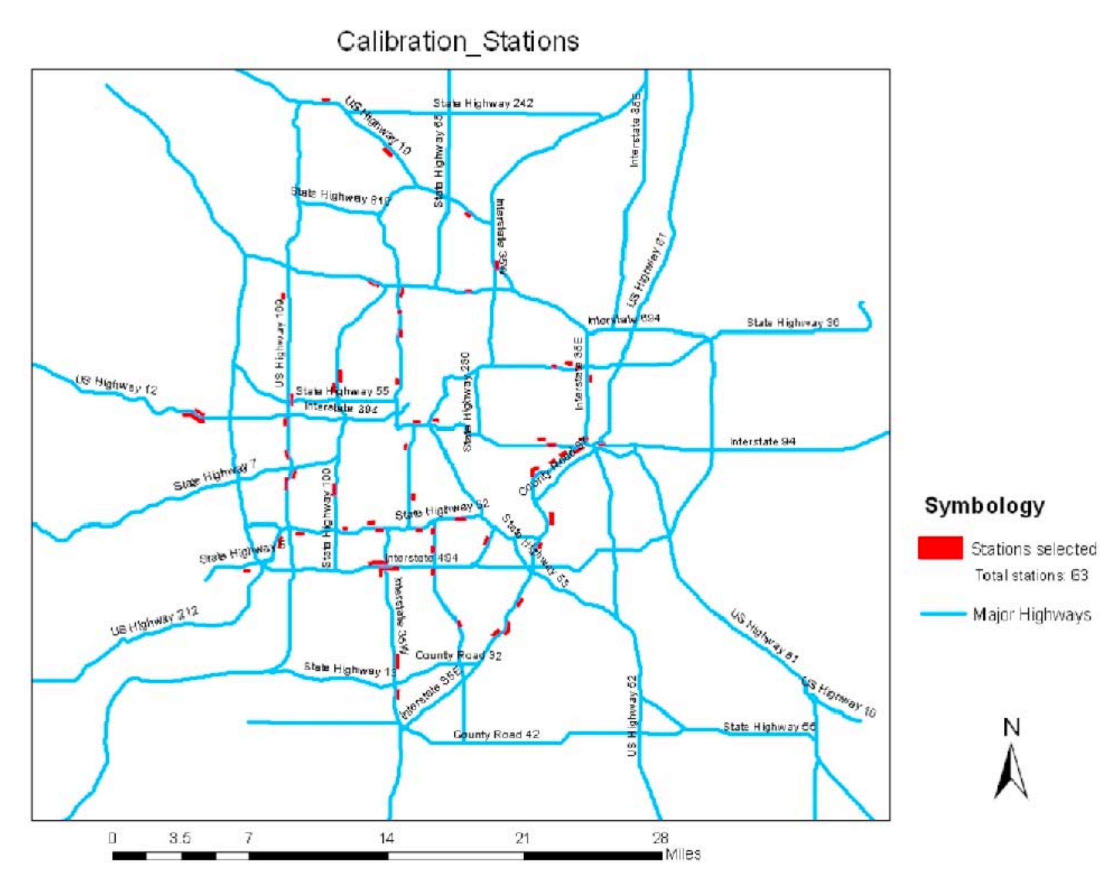


Figure B.1. Calibration – Stations locations

Table B.1. Trips generated - Correlation results

	Trips	Population	Retail Employment	Non Retail Employment	Residential Density	Distance	Distance Sq
Trips	1.00						
Population	0.95	1.00					
Retail Employment	0.11	0.01	1.00				
Non Retail Employment	-0.00	-0.11	0.37	1.00			
Residential Density	-0.03	-.04	0.03	0.17	1.00		
Distance	-0.14	-.12	-0.18	-0.25	-0.08	1.00	
Distance Sq	-0.15	-0.10	-0.16	-0.19	-0.05	0.94	1.00

Table B.2. Trips attracted - Correlation results

	Trips	Population	Retail Employment	Non Retail Employment	Residential Density	Distance	Distance Sq
Trips	1.00						
Population	0.03	1.00					
Retail Employment	0.48	0.01	1.00				
Non Retail Employment	0.77	-0.11	0.37	1.00			
Residential Density	0.06	-.04	0.03	0.17	1.00		
Distance	-0.27	-.12	-0.18	-0.25	-0.08	1.00	
Distance Sq	-0.23	-0.10	-0.16	-0.19	-0.05	0.94	1.00

Table B.3. Trip Generation Regression model - trips produced

Regression Statistics	Multiple R = 0.9654 R-square = 0.9320 Adjusted R-square = 0.9316 Standard Error = 49.5971 Observations = 1165

	Coef.	Std. Err.	t Stat	P-value
Intercept	-14.8999	4.8897	-3.0472	0.0023
Population	0.1083	0.0009	123.5499	0
Retail	0.0348	0.0044	7.8301	1.095E-14
Non Retail	0.0110	0.0010	11.3189	3.029E-28
Res Density	-0.0003	0.0060	-0.0534	0.9574
Distance	0.0052	0.0004	12.3988	3.077E-33
Distance Sq	-1.2008	9.1483	-13.1258	8.597E-37

Table B.4. Trip Generation Regression model - trips attracted

Regression Statistics	Multiple R = 0.8152 R-square = 0.6646 Adjusted R-square = 0.6629 Standard Error = 190.7532 Observations = 1165

	Coef.	Std. Err.	t Stat	P-value
Intercept	50.8388	18.8059	2.7033	0.0070
Population	0.0209	0.0033	6.2057	7.5671E-10
Retail	0.1977	0.0171	11.5633	2.4093E-29
Non Retail	0.1380	0.0037	36.8559	2.207E-197
Res Density	-0.0862	0.0231	-3.7371	0.0002
Distance	0.0027	0.0016	1.7000	0.0894
Distance Sq	-9.326E-08	3.518E-08	-2.6508	0.0081

Table B.5. Calibration-Peak Hour Volumes

Highway	Number of detectors	Station ID	Average peak hour volume	Network Link ID	Volume Forecasted
TH 5	2	502	1500	2896	1929
TH 10	2	950	4180	3219	2911
TH 10	2	989	1719	3229	2072
I-94	4	245	2339	3337	1500
TH 252	2	238	616	3338	1646
I-94	4	249	2543	3339	1773
I-94	4	137	4236	3358	3582
I-35E	2	847	2880	3472	2516
I-94	4	788	6204	3490	5139
I-94	4	490	4656	3498	3878
I-35E	3	627	3671	3601	2838
I-35W	4	5	5197	3843	4861
I-35W	3	54	5479	3885	7631
I-94	3	76	4205	3912	4152
TH 62	2	322	2394	4015	2400
I-494	3	119	5477	4063	8100
I-494	3	200	4277	4070	4551
I-35W	3	13	2390	4081	3409
I-35W	3	32	2720	4161	3363
I-94	3	561	4950	4267	5907
I-94	4	146	3202	4271	5425
TH 5	3	424	3378	4543	1968
TH 212	2	308	2117	4619	1588
TH 62	2	311	1685	4670	3493
I-494	3	185	5468	4704	7541
I-494	3	120	4013	4706	4767
TH 77	2	540	815	4821	990
I-35E	3	886	3875	4870	4618
I-35E	3	827	3517	4891	3521
I-694	3	175	4067	5250	3734
TH 169	2	457	1564	5328	2946
TH 169	2	433	2780	5332	1832
TH 169	2	442	2745	5341	1993
TH 169	2	746	3628	5375	3497
TH 169	2	453	3905	5491	3231
TH 62	2	326	1787	5605	555
TH 77	2	537	1583	5610	1723
TH 77	2	534	828	5625	1695

TH 62	2	353	3473	5639	2958
TH 62	2	69	1966	5644	2814
TH 62	2	132	3263	5649	2971
TH 77	3	800	3520	5726	5991
I-394	3	348	1458	5784	571
I-394	3	266	2975	5788	1461
I-394	3	264	2287	5805	1523
TH 100	3	414	3662	5873	2791
TH 100	2	395	1164	5978	1354
TH 100	2	398	3711	5986	2636
TH 10	3	960	3386	15980	1876
I-35E	2	845	2547	19139	2365
I-35E	2	619	1455	19143	1739
I-94	3	97	5072	19162	2993
I-94	3	780	2794	19262	2798
I-35W	3	665	2061	19273	2561
TH 36	2	596	1803	19467	1023
TH 36	2	610	3222	19479	3450
TH 36	2	599	1936	19487	1302
TH 169	2	450	2923	19620	2527
I-35E	3	883	4478	19973	3235
I-35E	3	893	1664	19980	1386
I-35E	2	830	3190	19997	3396
I-35E	2	849	2624	20037	1301
I-35W	3	77	4703	20063	6120

Table B.6. Legacy Links Description

Legacy Link	Ownership	County
State highway 65	State	Anoka
Highway 212	State	Carver
Highway 212	State	Carver
Highway 610	State	Hennepin
Parallel to Hw 694 connecting State Hw 35-State Hw212	State	Washington
County State Aid connecting CSA14 and CSA6	County	Anoka
Continuation of County road 40	County	Dakota
Continuation of County State Aid 50	County	Hennepin
Continuation of County road 57 connecting to Hw 100	County	Hennepin
Road between County14 and Hw 169	County	Hennepin
County State Aid 49	County	Hennepin
Continuation of CSA 50 connecting State Hw 55 and CSA 24	County	Hennepin
Continuation of County Road 90 between US Hw 12 and CSA 15	County	Hennepin
Road parallel to State Hw 7 connecting CSA 20 and CSA 61	County	Hennepin
County State Aid 49	County	Hennepin
Continuation of County State Aid 50	County	Hennepin
Continuation of County road 57 connecting to Hw 100	County	Hennepin
Road between County14 and Hw 169	County	Hennepin
Continuation from CSA 12 to County Road 145	County	Ramsey
Continuation of CSA 15 from State Hw 212 to State Hw 35	County	Washington
Parallel to Hw I-494 connecting CSA 22 and CR 77	County	Washington
Continuation of CR 77 parallel to US Hw 51	County	Washington

Appendix C

Crash Rate Model

One of the major criteria for investments is crash rates. Unfortunately, there is to date no reliable model that can predict crash rates on links as a function of their planning network attributes before and after an improvement. Yet, some prediction must be made of this to estimate where future investments are likely to occur. A common approach is to estimate the expected level of crashes and then compare it with the actual data (Minnesota Department Of Transportation. 1999 Traffic Safety Fundamentals Handbook).

$$Safety = ExpectedCrashRate - ActualCrashRate$$

(The concept of expected crash rate is based on historical data statistical analysis. It is recommended to use data from at least three years previous to the year in study to calculate such. While actual crash rate is the one that actually happens). It is computed at intersections as:

$$ECR_i = \frac{CR \text{ x } 10^6}{t \cdot ADT \cdot 365}$$

Where ECR_i = Expected crash rate per million entering vehicles, CR = Number of crashes, t = number of years, and ADT = Average Daily Traffic.

At Segment Rates

$$ECS_i = \frac{CR \text{ x } 10^6}{L \cdot t \cdot ADT \cdot 365}$$

Where ECS = Expected crash rate per million vehicle miles, L = segment length.

Critical Rate

$$RC = RA + k\sqrt{RA/m} - 0.5/m$$

Where RC = Critical crash rate for intersections (crashes per MEV), for segments(crashes per MVM), RA = System wide average crash rate by intersection of highway type, m = vehicle exposure during study period; for intersections = ADT (365/106), for segments=ADT (365/106)*length, and k = constant based on level of confidence.

	LEVEL OF CONFIDENCE
k=2.576	0.995
k=1.645	0.950
k=1.282	0.900

Existing safety information (prior to improvement) is stored in the “crash data” matrix in SONG 2.0, and is applied to the if-then rules process. This crash list was calculated based on the count crash average of the base year’s previous three-year periods of time. For the base year 1990, this was the years 1987, 1988 and 1989. Crashes for every year were mapped in a Geographic Information System. Buffers of 50 meters around nodes were placed and crashes were counted. (Nodes with the highest crash counts were defined as the top 200 crash locations). In SONG 2.0, each of these identified nodes is part of a link, this link based on the investment rules gets allocated a specific amount of points.

As we improve a road, we change its characteristics, improve its standard, and hopefully reduce crash rates. While we know from observed data the crash rates on existing facilities, we do not know what it will be after geometric changes. For improved facilities, we set the crash rate to the statistical estimate for that road type. According to stated decision rules, links with high crash rates are more likely to be improved, if they are improved to the regional average, the total number of crashes will decline. On the other hand, with increased traffic, we expect more crashes overall. Crash data was obtained for 19 years (1984 to 2003) for the Seven County Metro Area from the Minnesota Department of Transportation-Office of Traffic Engineering. These events were mapped onto a GIS map on a functional road based format for every year. In order to identify the severity of the crashes on every segment, four fields were added to the attribute tables and values were calculated for every type of crash. This means that a segment might have 2 crashes of severity A, 3 crashes of severity B, and so on.

Because the planning network was produced from the nodes given by the Metropolitan Council and is a simplified network compared to the actual road system network, not all the crashes that occurred on the real network were captured by the representation of the network used in the analysis. The planning network only contains 65% of the total number of crashes.

Once the network was mapped, a selection by attribute based on a spatial relationship was performed. This selection specified a total distance of 90 meters around every link of the network. So crashes that fell on the map within 45 meters on either side of each link in either direction were selected and attached to the network.

The crash model estimated takes the following form, which simplifies (eqn. 9)

Crashes = f (*road type, year, road length, AADT*)

A Poisson Regression Analysis was performed to estimate the model. Based on the characteristics of the data available it is assumed this type of analysis will produce the best fit model.

1. Years and road types are given categorical variables and tabulated
2. Set crashes per vehicle distance traveled as the dependent variable
3. Set average annual daily traffic for level of exposure
4. Set length, road type, year, vehicle distance traveled (AADT*length) as independent variables
5. Execute Poisson regression

Results are shown in . For this model there were 127,078 observations. It produced an r-squared of 0.56. Road type 1 (Interstate highways) was suppressed. This means that other road types (2-7) indicate progressively lower level roads (Road type 2 – US Highway, Road type 3 – MN Highway, Road type 4 - County State, Road type 5 – State Aid, Road type 6 – Township, Road type 7- County) and have higher crash rates (and are thus less safe). The "year" is a dummy variable for the specific year, in general, earlier years had higher crash rates than more recent years, though year 1 and year 2 raise some questions about this are warrant additional investigation about the data quality. The vehicle distance traveled is negative, indicating all else equal, longer segments with higher traffic have fewer crashes per unit length per traffic volume than shorter segments with less traffic. This tracks with higher-level facilities, but also indicates that intersections lead to more frequent crashes than pipeline sections without intersections. Overall the model comports with expectations and can be used to estimate crash rates on links after improvements and links that have not been built. Existing unimproved links will have their actual crash rate stored as a variable that may affect whether it warrants improvement. It will be assumed improvement will change the crash rate to the result of the model (in a sense the average for that type of link).

This crash rate prediction model is included to demonstrate the overall feasibility of SONG 2.0 and not necessarily would be able to withstand peer review. It is not a validated identification of how crashes change in response to network improvements.

Table C.1. Results from Poisson Regression Model of Annual Roadway Crashes

Dependent Variable = crashes per aadt per km

Independent Variables	Coef.	Std. Err.	z	P>z
Length	-.959	.097	-9.85	0.000
Roadtype2	1.711	.524	3.26	0.001
Roadtype3	2.501	.437	5.72	0.000
Roadtype4	2.756	.424	6.49	0.000
Roadtype5	3.387	.478	7.08	0.000
Roadtype6	9.933	.433	22.90	0.000
Roadtype7	4.125	.553	7.45	0.000
year2	-.906	.326	-2.78	0.005
year3	.652	.213	3.05	0.002
year4	.625	.213	2.93	0.003
year5	.342	.220	1.55	0.120
year6	.376	.218	1.72	0.085
year7	.341	.228	1.49	0.135
year8	.146	.227	0.64	0.520
year9	.176	.224	0.79	0.432
year10	.104	.227	0.46	0.647
year11	.064	.228	0.28	0.776
year12	-.008	.231	-0.04	0.971
year13	.108	.225	0.48	0.629
year14	.165	.222	0.74	0.458
year15	-.0163	.229	-0.07	0.943
Aadtxlen	-.0004	.000	-15.99	0.000
_cons	-15.474	.458	-33.75	0.000

aadt (exposure)

Poisson regression	Number of obs	=	127078
	LR chi2(22)	=	8726.72
	Prob > chi2	=	0.0000
Log likelihood = -3327.059	Pseudo R2	=	0.5674

Appendix D

Stated Decision Rules

The following information shows every county and state' point allocation ranking system. The points were weighted based on the main four rules previously listed. So if a jurisdiction does not have a rule for a specific factor, there is an allocation of zero points. Every jurisdiction has a total of 100 points to allocate to each project. It was decided to make it consistent with the use of a generalized scoring system, but still have individual scoring for each category.

Table D.1. Anoka County – Normalized Scoring System

Anoka County	Points
Safety	
No specific information then allocate	0
Pavement Conditions	
IF PQI<60 THEN allocate	50
Or IF PQI<55 THEN allocate	25
Or IF PQI<50 THEN allocate	12
If else allocate	0
Level of Service	
No specific information then allocate	0
Capacity	
IF ADT>30,000 THEN allocate	50
Or IF 20,000<ADT<30,000 THEN allocate	38
Or IF 10,000<ADT<20,000 THEN allocate	25
Or IF ADT<10,000 THEN allocate	0
TOTAL	100

Table D.2. Scott County – Normalized Scoring System.

Scott County	Points
Safety	
If location is part of top 200 high crash list THEN	
approve one project every year and allocate	50
or IF location is NOT part of top 200 high	
Crash list THEN allocate	0
Pavement Conditions	
No specific information then allocate	0
Level of Service	
No specific information then allocate	0
Capacity	
IF ADT>15,000 THEN allocate	50
Or IF ADT<15,000 THEN allocate	0
TOTAL	100

Table D.3. Dakota County – Normalized Scoring System

Dakota County	Points
Safety	
No specific information then allocate	0
Pavement Conditions	
IF 2.8<un-normalized PQI<3.1 THEN	
allocate	34
or IF PQI<2.8 THEN allocate	16
if else allocate	0
Level of Service	
IF Level Of Service worse than "D"	
Meaning (Volume/Capacity per daily	
Average Ratio)>=0.75 THEN allocate	33
If else allocate	0
Capacity	
IF intersection volume >= 75,000 ADT	
THEN allocate	8.25 per
or if gravel highway ADT>300 vehicles	link
per day THEN allocate	
if else allocate	16
TOTAL	0
	100

Table D.4. Ramsey County – Normalized Scoring System.

Ramsey County	Points
Safety	
No specific information then allocate	0
Pavement Conditions	
No specific information then allocate	0
Level of Service	
No specific information then allocate	0
Capacity	
IF ADT>8,000 on 2 lane road THEN allocate	100
if else allocate	
Or IF ADT>15,000 on 3 or 4 lane road THEN	100
Allocate	0
If else allocate	100
TOTAL	

Table D.5. Hennepin County – Normalized Scoring System.

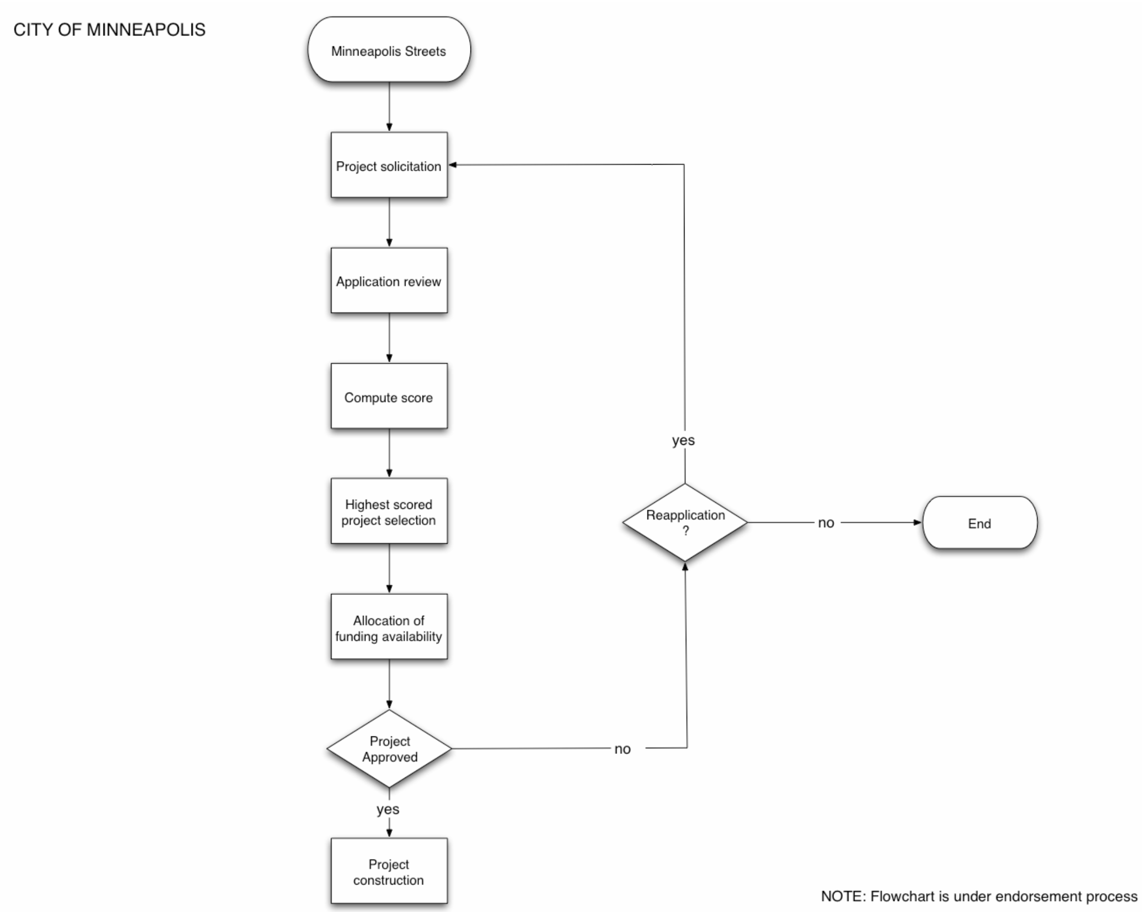
Hennepin County	Points
Safety	
IF crash rate/County crash rate average>5 THEN allocate	33
Or IF crash rate/County crash rate average>3 THEN allocate	30
Or IF crash rate/County crash rate average>2 THEN allocate	27
Or IF crash rate/County crash rate average>1.5 THEN allocate	24
Or IF crash rate/County crash rate average>1.25 THEN allocate	21
Or IF crash rate/County crash rate average>1.00 THEN allocate	18
Or IF crash rate/County crash rate average>0.87 THEN allocate	15
Or IF crash rate/County crash rate average>0.75 THEN allocate	12
Or IF crash rate/County crash rate average>0.62 THEN allocate	9
Or IF crash rate/County crash rate average>0.50 THEN allocate	6
Or IF crash rate/County crash rate average<0.50 THEN allocate	0
County crash rates average for road type	
Urban 4 lane undivided=2.67	
Urban 4 lane divided=1.10	
Urban 2 lane undivided=2.01	
Rural 2 lane=1.31	
Pavement Conditions	
Normalize Highest of (100-PQI), *where PQI = (PCI*.5) + (normalized PSR*.5)* If	
normalized score=100 then allocate	34
or Based on normalization then allocate	0-33
NOTES: PQI is the pavement quality index weighted	
(PCI and PSR are each weighted 50%)	
PCI (pavement condition index) is scored as a perfect	
roadway (100 points) minus point deductions	
for "distresses" that are observed.	
PSR (present service-ability Rating rideability) is	
measured as a vertical movement as one drives	
along the road (smoothness),it is made on scale 0-5,	
but converted to a 0 to 100 scale for compatibility	
with the PCI.	
Level of Service	
No specific information then allocate	0
Capacity	
If (Current highest AADT for project/	
Current capacity per hour)*.10 = total highest score	
THEN normalized and allocate	33
or Based on normalization then allocate	0-32
TOTAL	100

Table D.6. State Level – Normalized Scoring System.

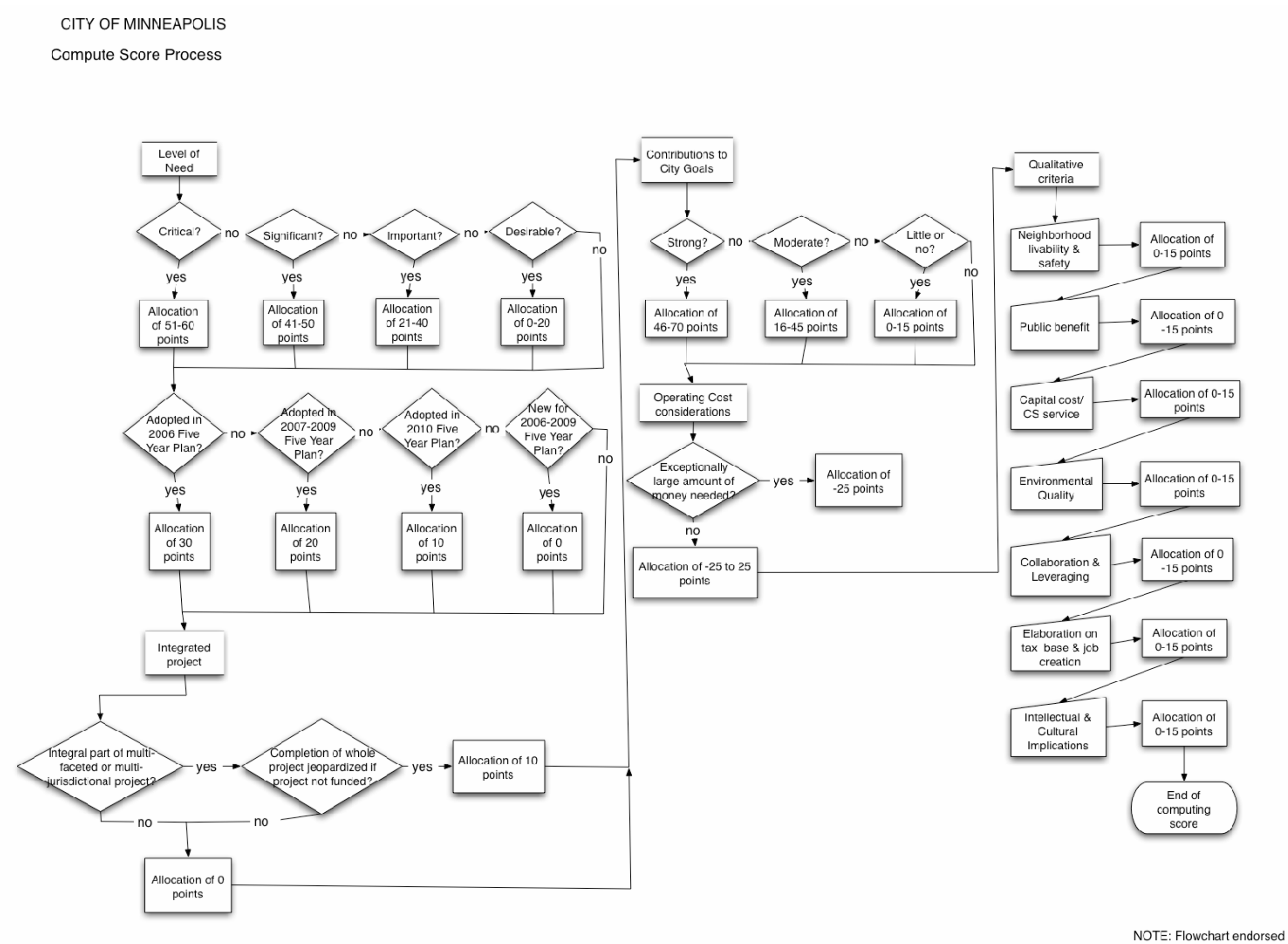
State Level	Points
Safety	
IF accident rate is two standard deviations above average by road type THEN allocate	25
If else then allocate	0
Pavement Conditions	
If PQI =3.1 on interstate freeway THEN allocate	20
Or IF PQI=2.9 on principal arterial THEN allocate	20
Or IF PQI=2.6 on minor arterial THEN allocate	20
IF else then allocate	0
Level of Service	
IF freeway speed<45 mph THEN allocate	25
or IF arterial speed<40 mph THEN allocate	25
If else then allocate	0
Capacity	
IF 150,000<ADT<200,000 THEN allocate	25
Or IF 100,000<ADT<150,000 THEN allocate	20
Or IF 50,000<ADT<100,000 THEN allocate	10
Or IF 25,000<ADT<50,000 THEN allocate	5
Or IF 0<ADT<25,000 THEN allocate	0
Other	
IF segment falls within 5 miles of Minneapolis or St Paul CBD THEN allocate	5
If else then allocate	0
TOTAL	100

Appendix E

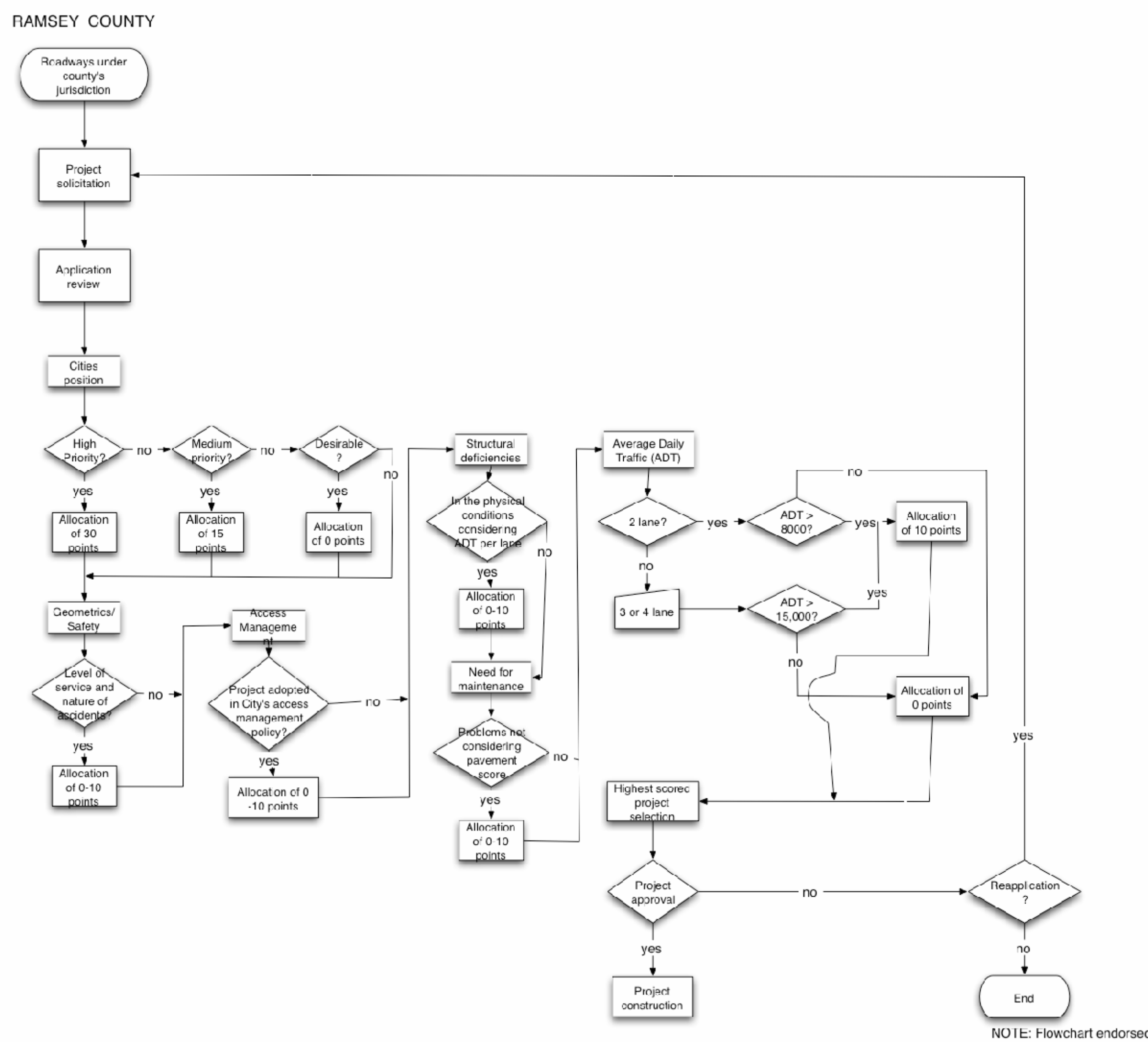
Flowcharts



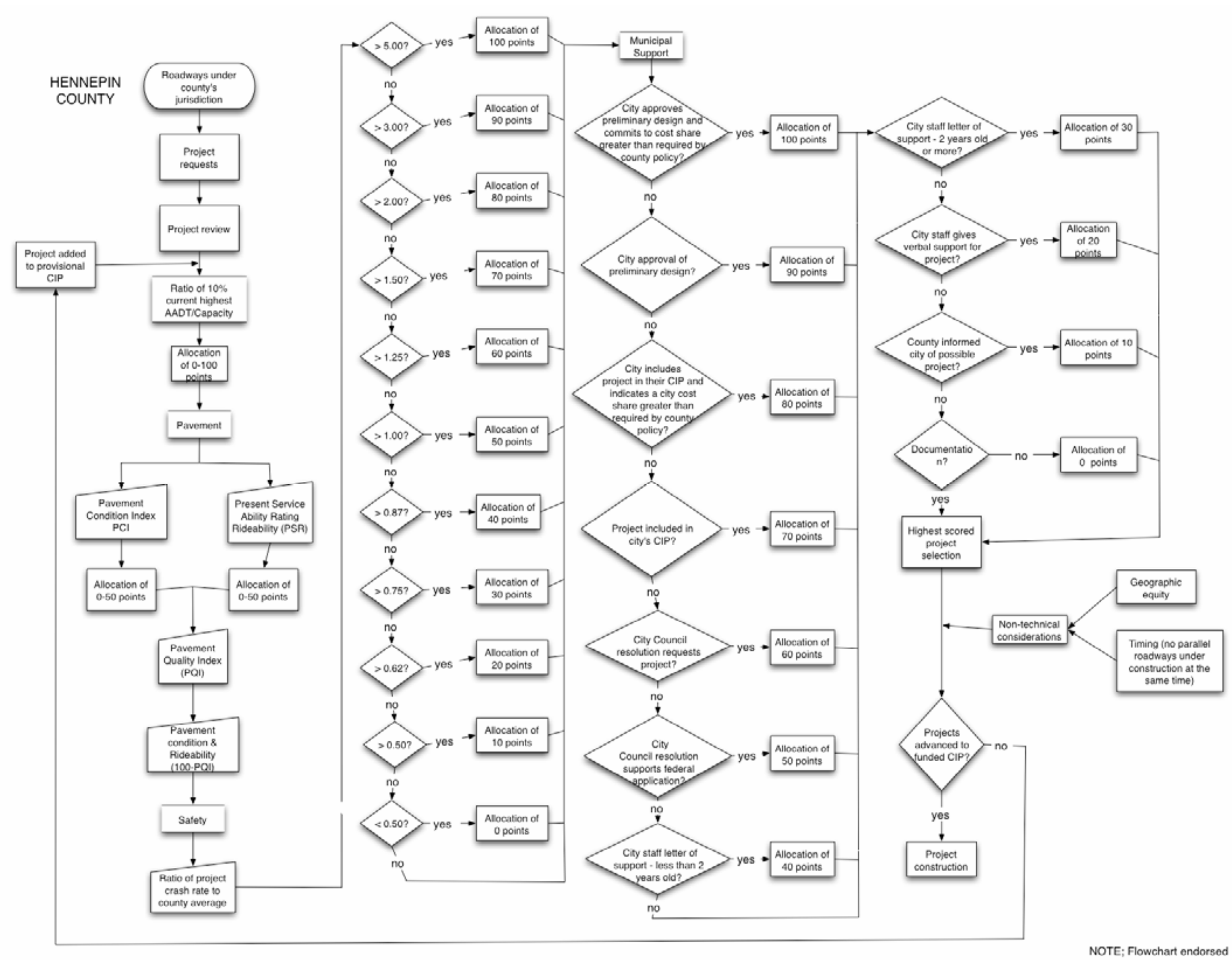
Flowchart E.1.City of Minneapolis Selection Process



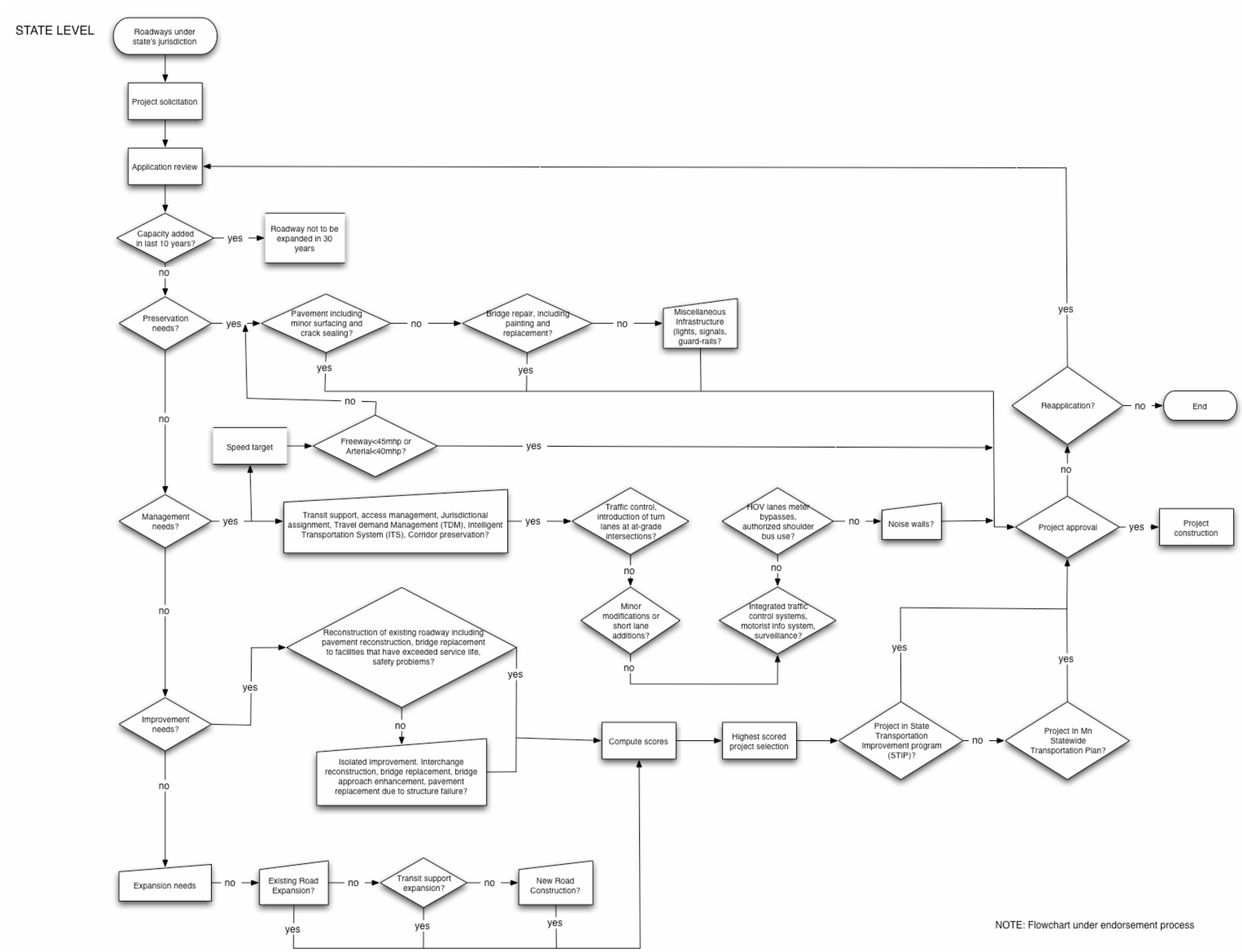
Flowchart E.1.1. City of Minneapolis Selection Process (continuation)



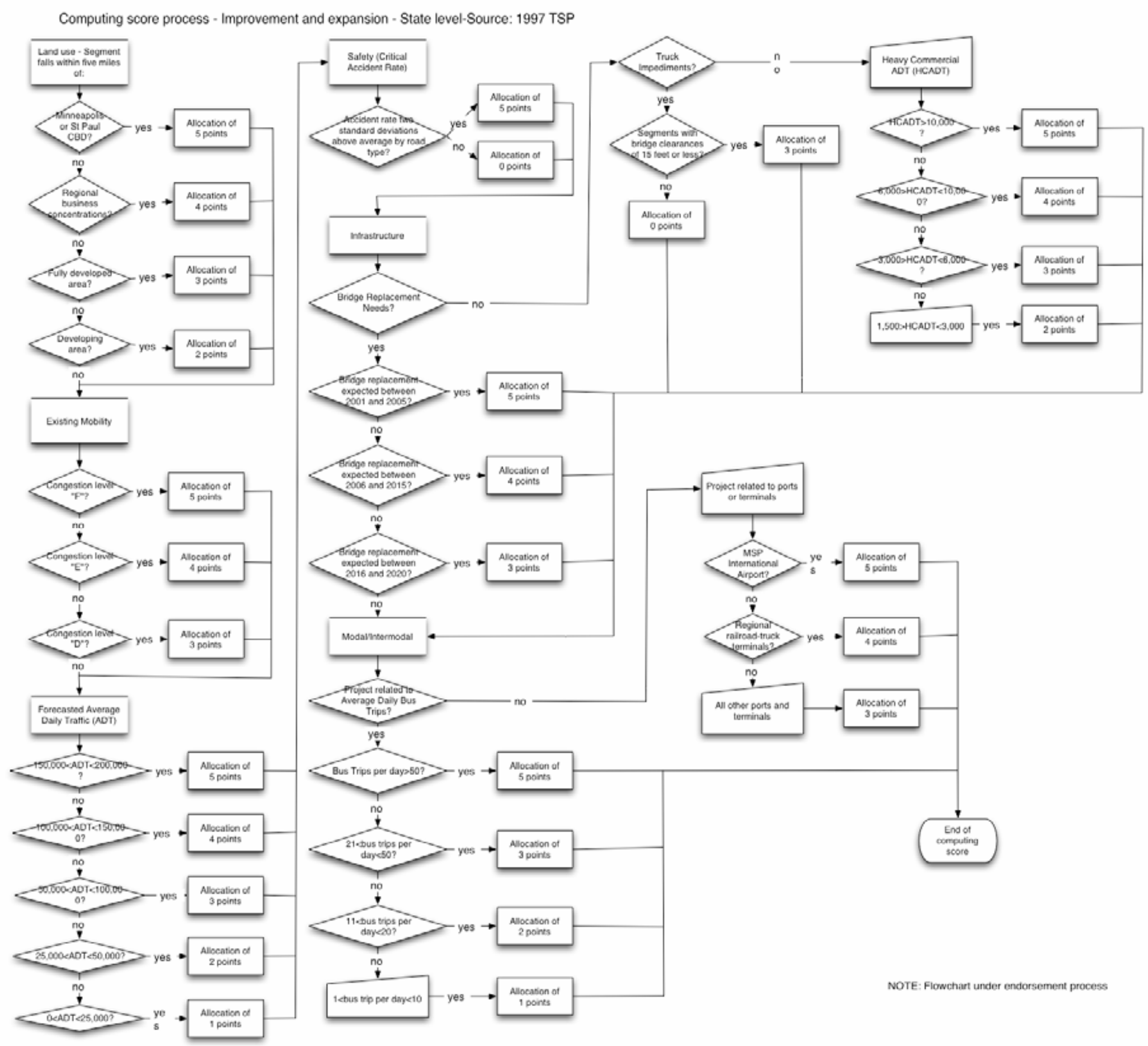
Flowchart E.2. Ramsey County Selection Process



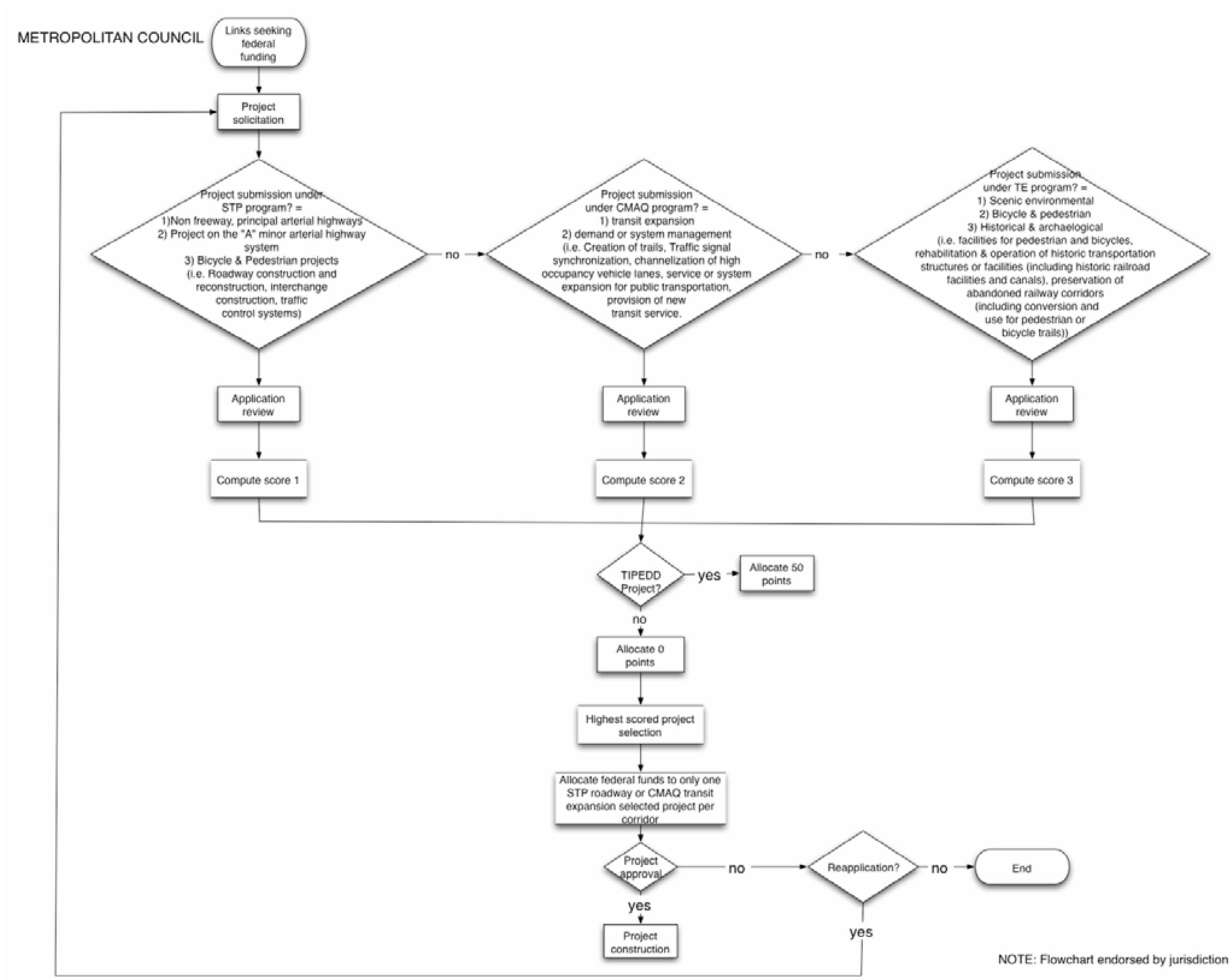
Flowchart E.3.Hennepin County Selection Process



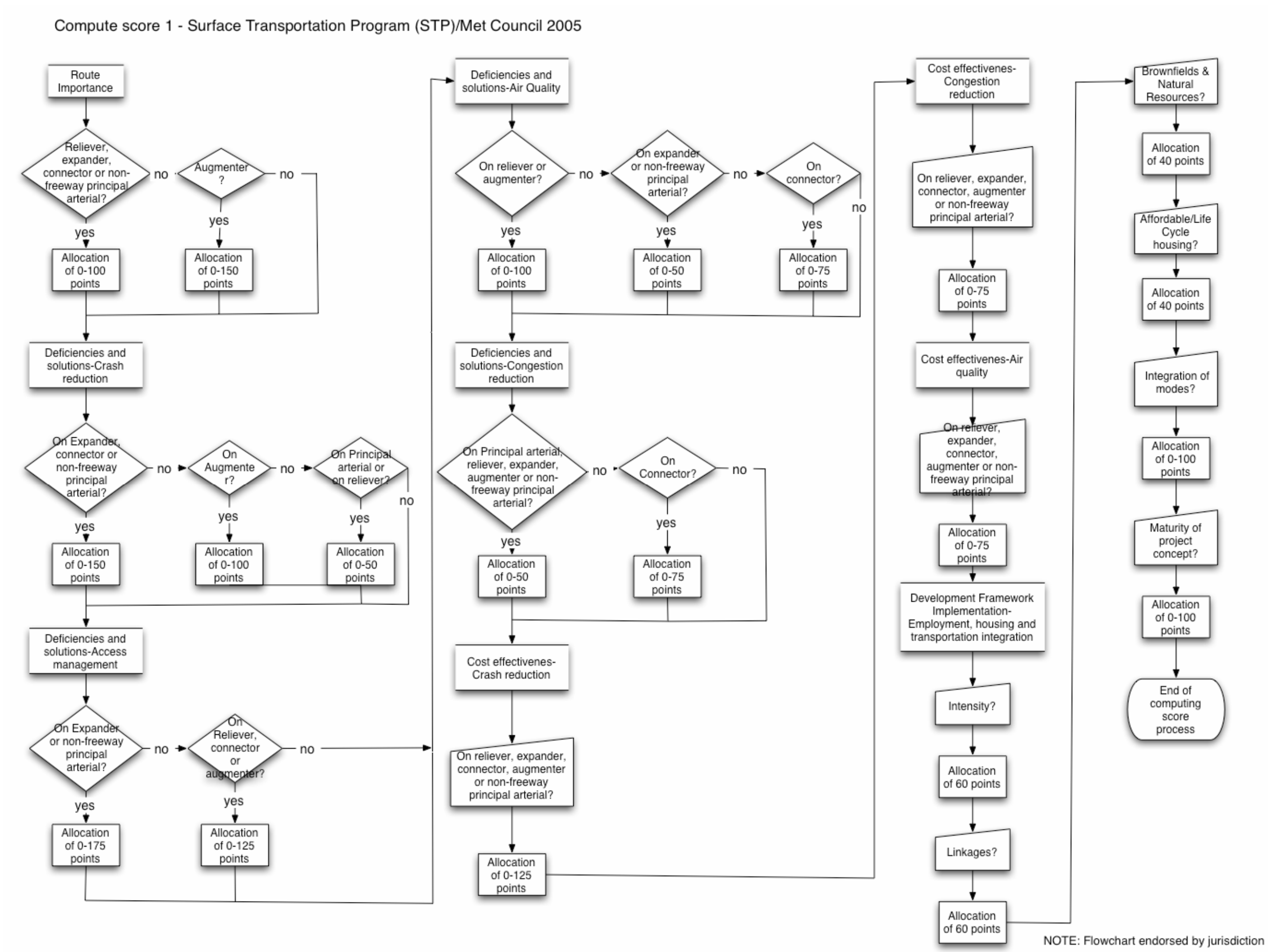
Flowchart E.4.State-Metro District Selection Process



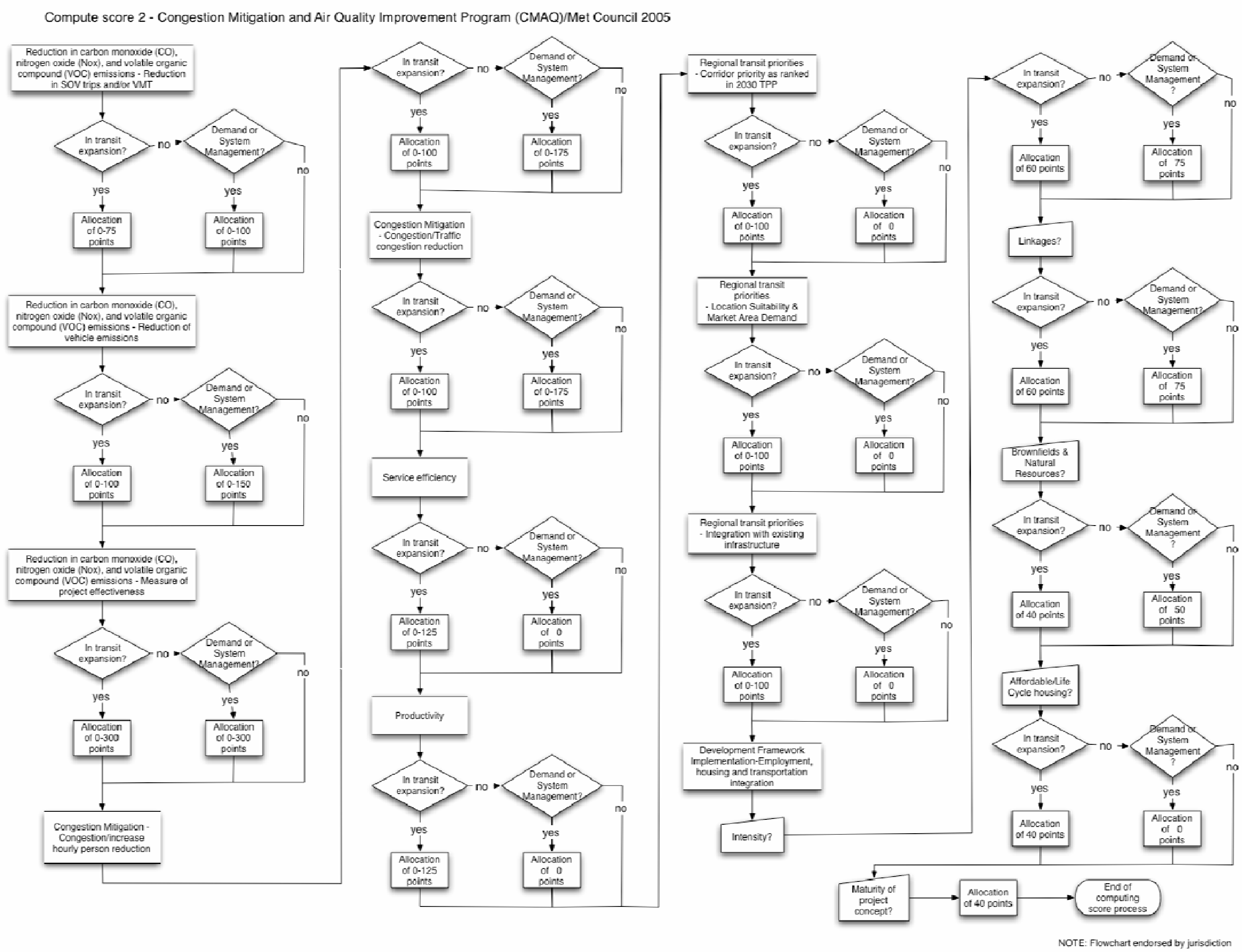
Flowchart E.4.1.State-Metro District Selection Process



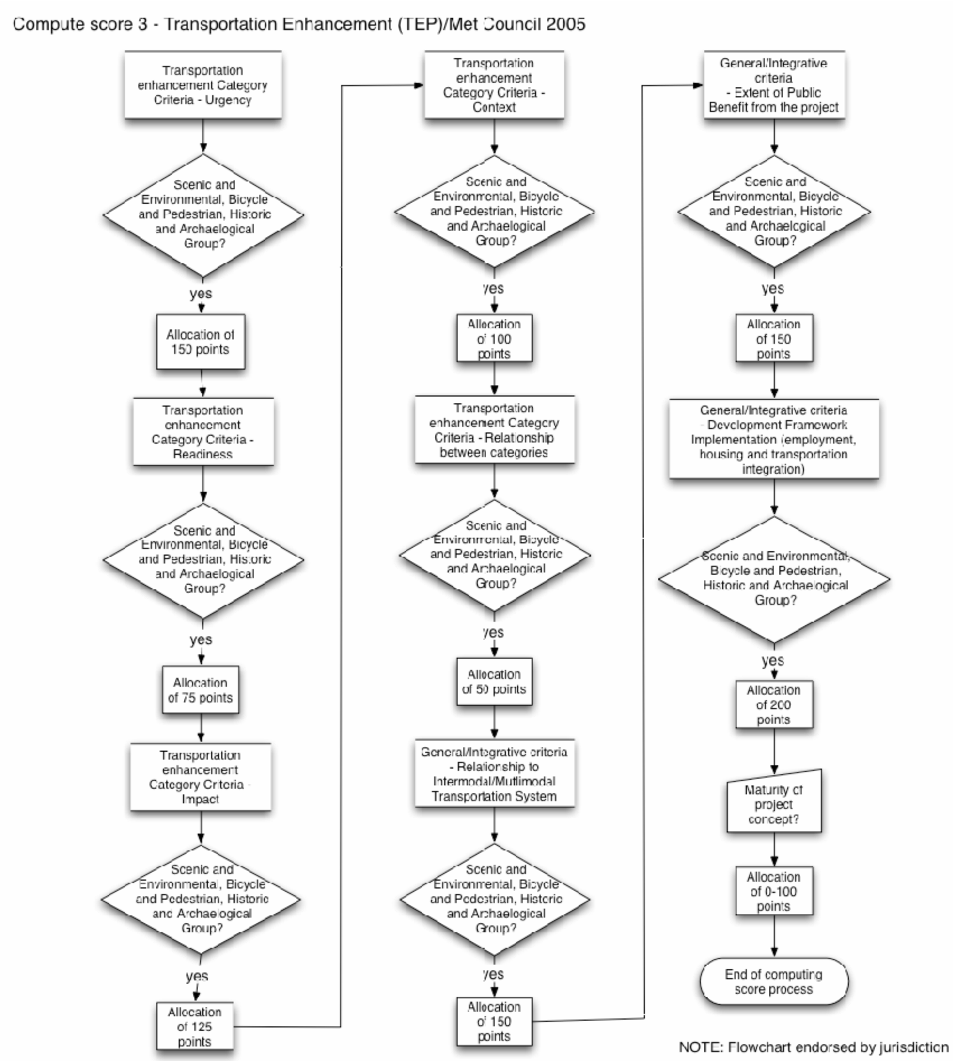
Flowchart E.5.Metropolitan Council Selection Process



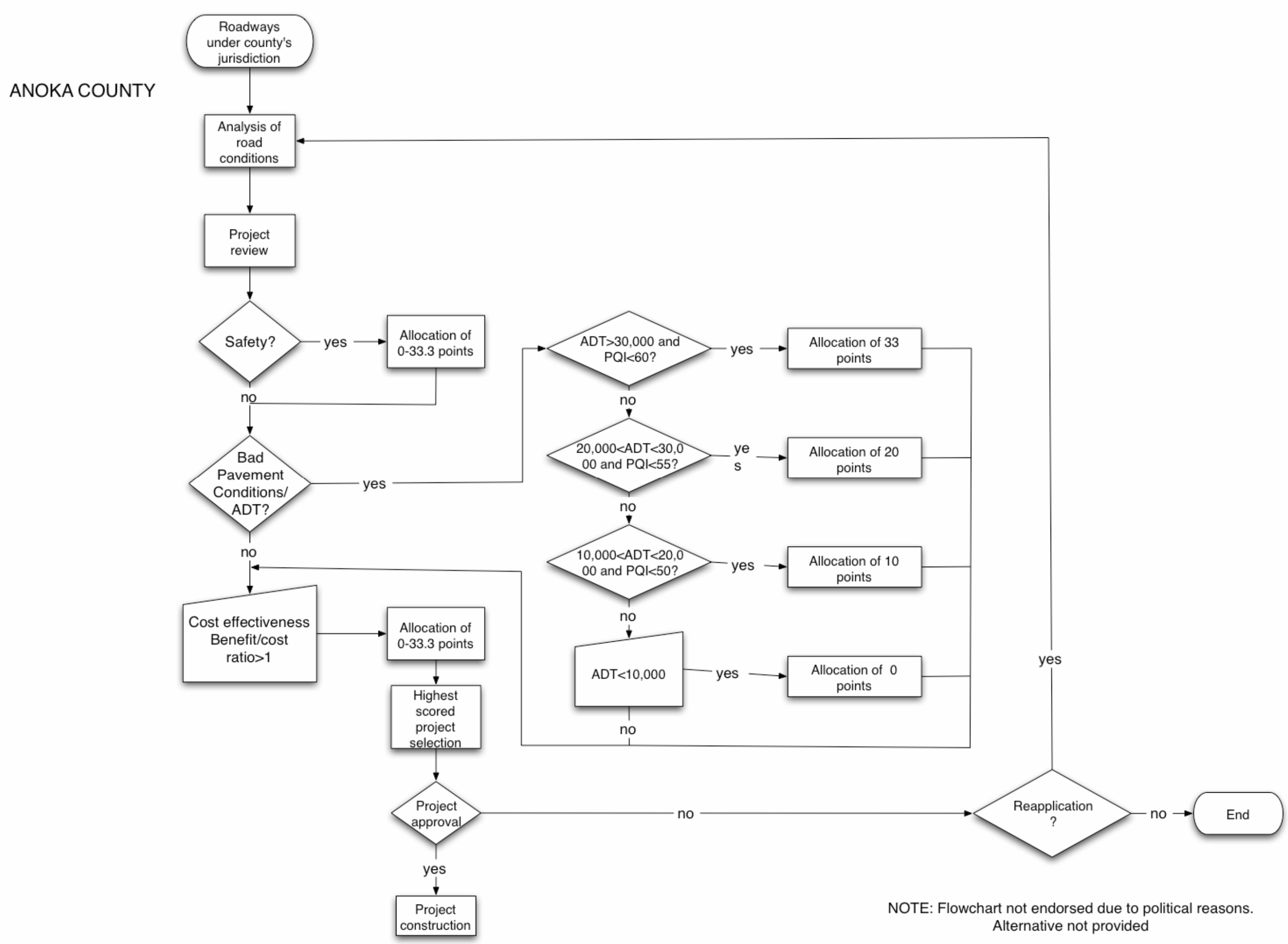
Flowchart E.5.1.Metropolitan Council Selection Process-Surface Transportation Program (STP)



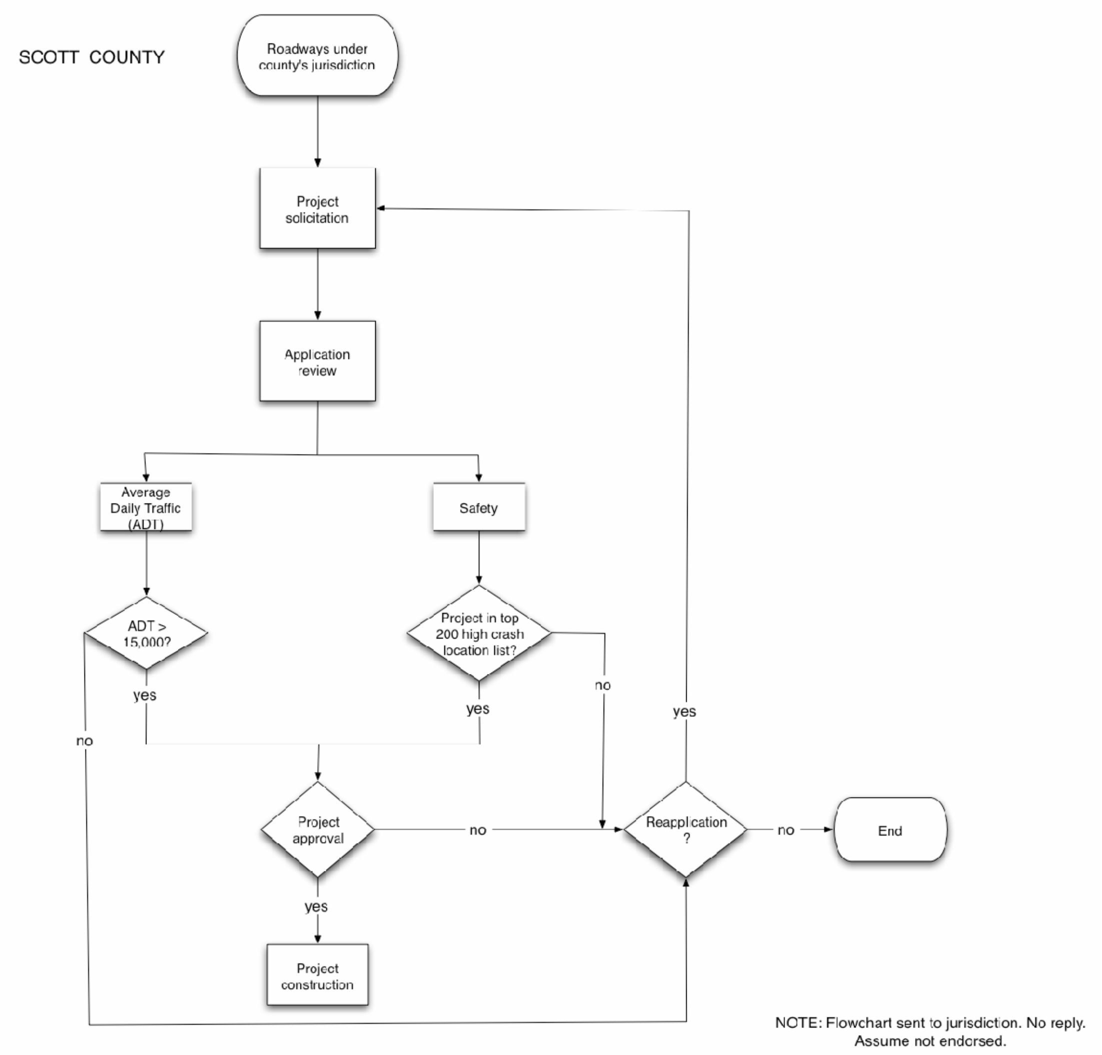
Flowchart E.5.2.Metropolitan Council Selection Process-Congestion Mitigation Air Quality Improvement Program (CMAQ)



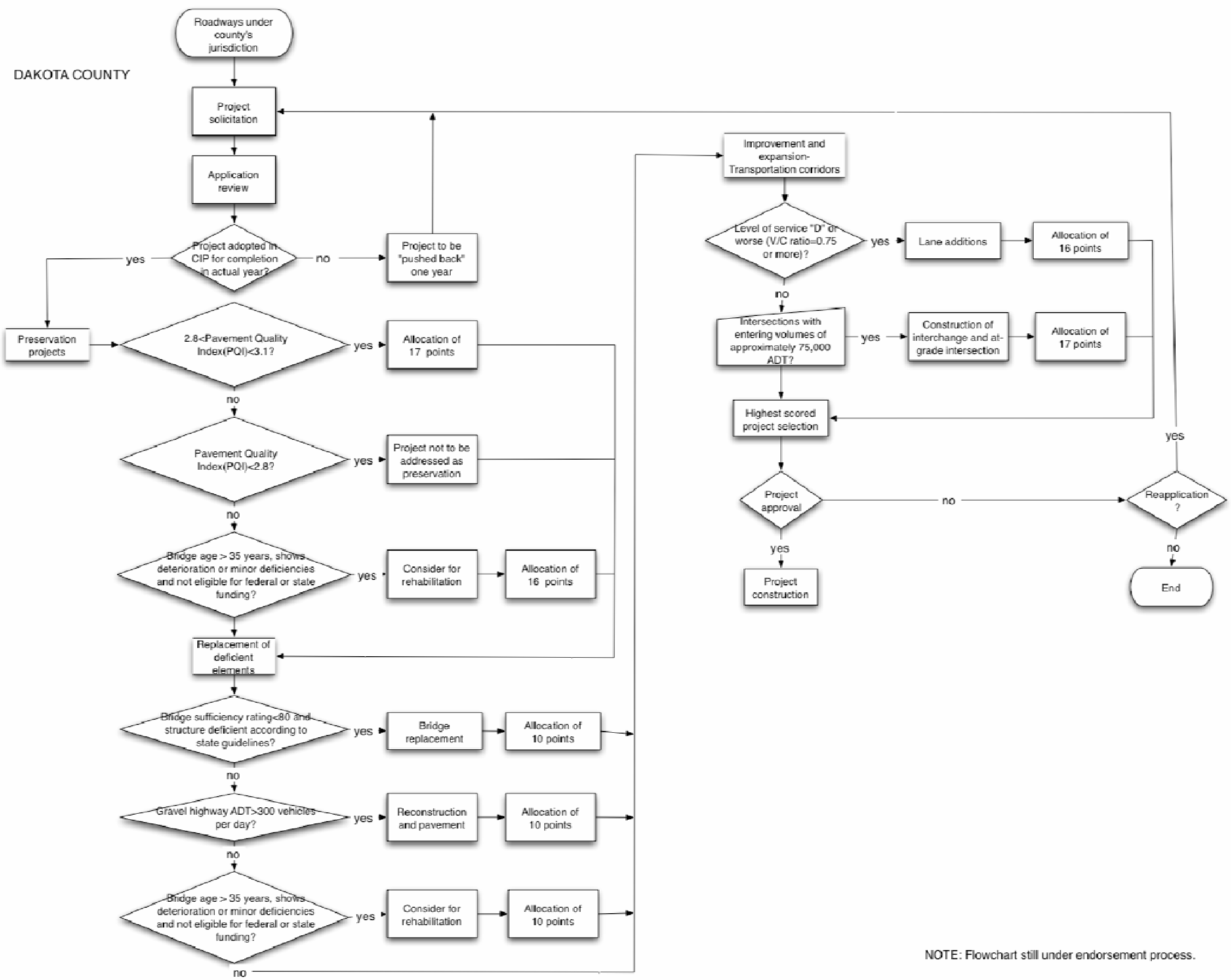
Flowchart E.5.3.Metropolitan Council Selection Process-Transportation Enhancement Program (TEP)



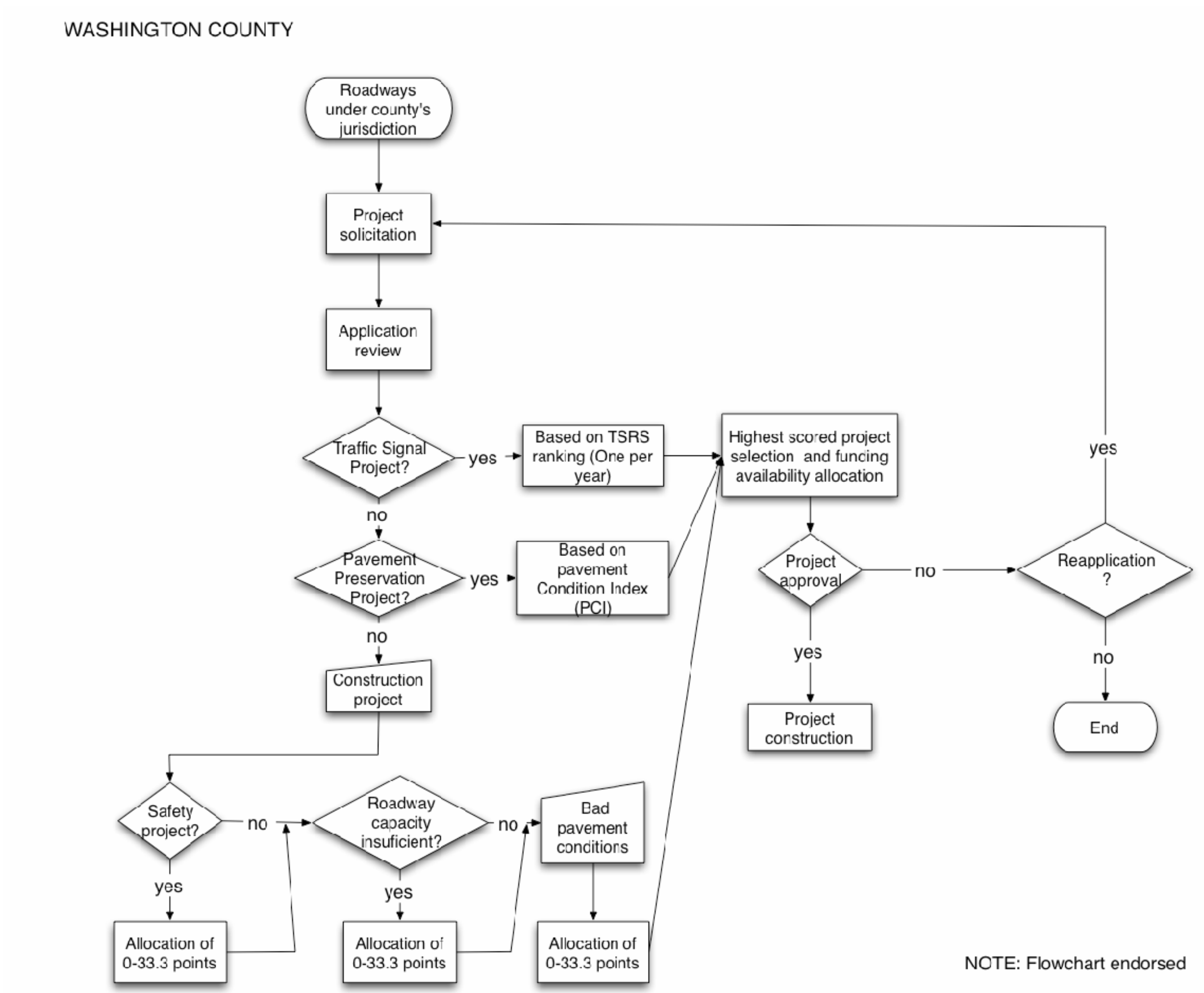
Flowchart E.6.Anoka County Selection Process



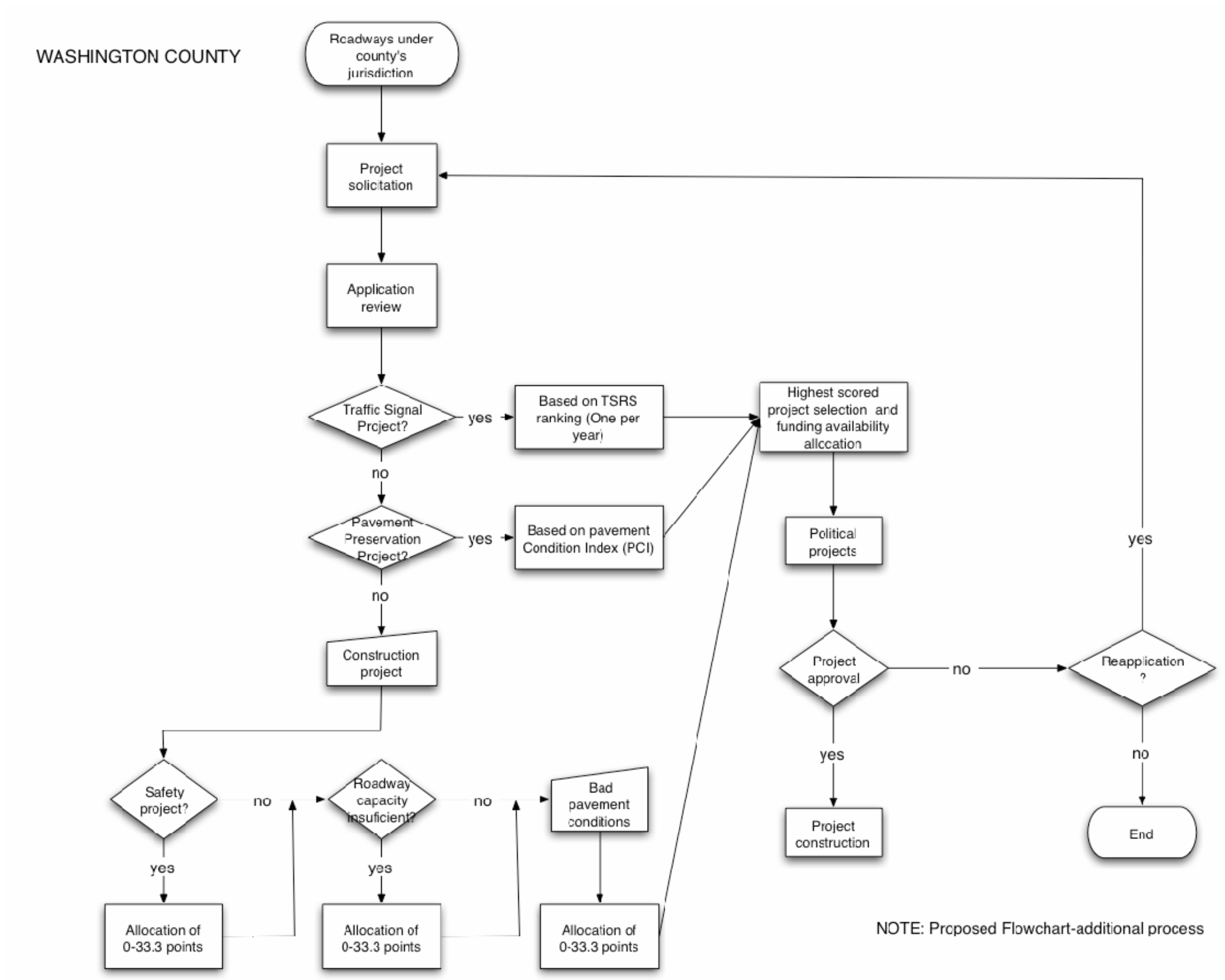
Flowchart E.7.Scott County Selection Process



Flowchart E.8.Dakota County Selection Process



Flowchart E.9.Washington County Selection Process



Flowchart A5.10.Washington County Selection Process-Proposed