2004-03

Final Report

Transportation-Related Impacts of Different Regional Land-Use Scenarios

MINNESOTA DEPARTMENT OF TRANSPORTATION

Research

Transportation-Related Impacts of Different Regional Land-Use Scenarios

Final Report

Gary Barnes
Humphrey Institute of Public Affairs
University of Minnesota

December 2003

Published by
Minnesota Department of Transportation
Office of Research Services
Mail Stop 330
395 John Ireland Boulevard
St. Paul, Minnesota 55155-1899

Technical Report Documentation Page

1. Report No. MN/RC 2004-03	2.	3. Recipients Accession No.
4. Title and Subtitle TRANSPORTATION-RELATED IMPACTS OF DIFFERENT REGIONAL LAND-USE SCENARIOS		5. Report Date December 2003
		6.
7. Author(s) Gary Barnes		8. Performing Organization Report No.
9. Performing Organization Name and Address University of Minnesota Humphrey Institute of Public Affairs 301 19th Ave. S. Minneapolis, MN 55455		10. Project/Task/Work Unit No.
		11. Contract (C) or Grant (G) No. (C) 74708 (wo) 188
12. Sponsoring Organization Name and Address Minnesota Department of Transportation 395 John Ireland Boulevard Mail Stop 330 St. Paul, Minnesota 55155		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes http://www.lrrb.gen.mn.us/PDF/200403.pdf		

16. Abstract (Limit: 200 words)

This research addresses the question of how different regional land-use patterns would impact travel behavior and resulting transportation costs and benefits. This report defines six hypothetical future regional land-use scenarios for the Twin Cities region, representing combinations of different styles of residential and commercial development. The traffic patterns resulting from each of these scenarios are then used to describe the resulting congestion, air pollution, and accessibility to jobs.

The results of the research indicate that the current conventional wisdom that compact development is better is at best an oversimplification. Certain types of compact development do appear to be better for certain goals, or for certain locations; however, at the same time they are often worse for other goals or other locations.

Despite some difficult methodological problems, this seems like a question worth exploring further. While it appears that land use alone cannot solve transportation-related problems, it does seem that the rate at which these problems grow can be impacted at least moderately at a regional level, and sometimes very substantially at local levels.

17. Document Analysis/Descriptors Land Use Travel Behavior Traffic Forecasting Transportation Costs	Congestion Air Pollution Accessibility	18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 65	22. Price

Acknowledgements

This research was funded by the Minnesota Department of Transportation (Mn/DOT). The author would like to thank project technical liaison Mark Filipi (Metropolitan Council) for his considerable help on this project. I would also like to thank technical advisory panel members Steve Wilson (SRF Consulting), David Levinson (University of Minnesota), Karen Linner (Builders Association of Minnesota), and Dan Warzala, Linda Zemotel, and Jim Dustrude (Mn/DOT).

I would also like to acknowledge a contribution from David Anderson. In an earlier research project, he had developed a program to match highway links to the closest traffic analysis zone. Without this matching, much of the detailed geographical analysis in this report would not have been possible.

Any errors in the report or the research that it describes are the sole responsibility of the author.

Table of Contents

CHAPTER 1 INTRODUCTION 1

LITERATURE ON LAND USE AND TRANSPORTATION 2
CONTRIBUTIONS OF THIS RESEARCH 3

CHAPTER 2 METHODOLOGY, SCENARIOS, AND GENERAL RESULTS 5

THE LAND-USE SCENARIOS 5
FORECASTING METHODOLOGY 7
SUMMARY OF SCENARIO CHARACTERISTICS AND FORECAST RESULTS 10

CHAPTER 3 CONGESTION IMPACTS 13

OVERALL CONGESTION STATISTICS 13
CONGESTION BY LOCATION 14
CONGESTION BY DRIVER HOME LOCATION 22
THE "WORST 100 MILES" 26

CHAPTER 4 AIR POLLUTION IMPACTS 27

CHAPTER 5 ACCESSIBILITY 33

CHAPTER 6 CONCLUSION 39

REFERENCES 43

ADDITIONAL REFERENCES 44

APPENDIX A MAPS AND RESULTS BY ZONES A-1

List of Tables

TABLE 2.1 Assumed Trip Attractions....8
TABLE 2.2 Assumed Transit Shares....9
TABLE 2.3 Population by Ring....10
TABLE 2.4 Jobs by Ring....10
TABLE 2.5 Jobs per Worker by Ring....11
TABLE 2.6 Summary Statistics, With Transit....11
TABLE 2.7 Summary Statistics, No Transit....11

TABLE 3.1 Aggregate Congestion, With Transit....13
TABLE 3.2 Aggregate Congestion, No Transit....14
TABLE 3.3 Congestion by Ring, With Transit....15
TABLE 3.4 Congestion by Ring, No Transit....15
TABLE 3.5 Average Commute in Minutes, With Transit....22
TABLE 3.6 Average Commute in Minutes, No Transit....23
TABLE 3.7 Average Commute in Minutes With Free Flow....23
TABLE 3.8 Worst 100 Miles, Percent of Total Scenario Congestion....26
TABLE 3.9 Percent of Total "Worst 100 Miles" Congestion, by Ring....26

TABLE 4.1 Hydrocarbons by Ring, With Transit....27
TABLE 4.2 Hydrocarbons by Ring, No Transit....27
TABLE 4.3 Carbon Monoxide by Ring, With Transit....27
TABLE 4.4 Carbon Monoxide by Ring, No Transit....28
TABLE 4.5 NOX by Ring, With Transit....28
TABLE 4.6 NOX by Ring, No Transit....28
TABLE 4.7 Aggregate Normalized Total Pollution....29
TABLE 4.8 Aggregate Normalized Pollution Exposure....29

TABLE 5.1 Accessibility by Ring, With Transit....33
TABLE 5.2 Accessibility by Ring, No Transit....33
TABLE 5.3 Accessibility by Ring, Free Flow and Current....34
TABLE 5.4 Regional Average Accessibility, Year 2000 Baseline....34

TABLE A.1 Population and job percent change from 2000....A-3
TABLE A.2 Job to worker ratio....A-4
TABLE A.3 Overall congestion (percent delay from free flow)....A-5
TABLE A.4 Freeway congestion (percent delay from free flow)....A-6
TABLE A.5 Non-freeway congestion (percent delay from free flow)....A-7
TABLE A.6 Commute times....A-8
TABLE A.7 Pollution level as ratio of LL zone 1 baseline....A-9
TABLE A.8 Job accessibility....A-10

List of Maps

Map 3.1 Total congestion, worst scenario by zone....16
Map 3.2 Total congestion, best scenario by zone....17
Map 3.3 Freeway congestion, worst scenario by zone....18
Map 3.4 Freeway congestion, best scenario by zone....19
Map 3.5 Non-freeway congestion, worst scenario by zone....20
Map 3.6 Non-freeway congestion, best scenario by zone....21
Map 3.7 Commute to work travel time, worst scenario by zone....24
Map 3.8 Commute to work time, best scenario by zone....25

Map 4.1 Air pollution level, worst scenario by zone....31
Map 4.2 Air pollution level, best scenario by zone....32

Map 5.1 Access to jobs, worst scenario by zone....35
Map 5.2 Access to jobs, best scenario by zone....36

Map A-1 The 66 Zones in the Twin Cities Metropolitan Area....A-1
Map A-2 The Zones in the Central Part of the Twin Cities Metropolitan Area....A-2

Executive Summary

This research addresses the question of how different regional land-use patterns would impact travel behavior and resulting transportation costs and benefits, such as congestion, air pollution, and accessibility to jobs. There has been considerable discussion in recent years about regional development patterns, and an intuition seems to have developed that more compact development is better from a transportation perspective because it reduces trip lengths, increases use of non-auto modes, and when planned appropriately, can better utilize excess capacity on dense urban street networks.

However, this intuition can be questioned on three grounds. The first question is how much regional land-use patterns really impact the amount of driving. If small changes to land use lead to big reductions in driving, then this is an important point. If, on the other hand, big changes to land use lead to small reductions in driving, then perhaps transportation problems would be best addressed through other means.

The second question is how a given amount of driving translates into actual costs. The natural instinct on which most discussion seems to be based, is that less total driving will mean less congestion and pollution. However, both of these costs are fundamentally driven not just by the number of cars on the road, but by how those cars interact with each other and with the surrounding areas; changes to these interactions could lead to worse outcomes even if total driving declines. For example, a policy that reduced total driving but concentrated the remainder on a smaller set of roads might actually increase congestion levels. Similarly, if there were less driving but it was more concentrated in densely populated areas, total exposure to pollution could increase.

The third question is how different impacts might interact with each other. Some discussion focuses on a single issue or a single location; however, the best solution to one specific problem could actually be a bad solution to other problems. For example, attempting to increase transit use by concentrating development could increase congestion because traffic might also become more concentrated.

This report defines six hypothetical future regional land-use scenarios, representing combinations of different styles of residential and commercial development. The traffic patterns resulting from each of these scenarios are then used to describe the resulting congestion, air pollution, and accessibility to jobs. The objectives correspond to the three questions noted above: to determine the size of the overall impacts on driving; to establish how overall driving levels translate into impacts of interest; and to understand the relationships between the various impacts. The major features of the research described in this report, that collectively distinguish it from past work, are the following:

- Use of a regional analysis, rather than focus on a specific neighborhood. The concern here is with how land-use changes impact transportation costs over the region as a whole. Changes invariably benefit some localities at the expense of others; these geographic distributions of costs and benefits are examined as well, but within the context of regional impacts.

- Studying the specific issues of concern, such as congestion and pollution, rather than measuring indirect indicators such as vehicle miles traveled (VMT). As noted before, fewer VMT need not imply less congestion; even if it does, the nature of how congestion is geographically reallocated is of interest. The relationship between the indicators and the costs themselves is a subject of some interest here.

- Using very stylized and extreme land-use scenarios and a very simplified traffic forecasting model, to isolate the effects of land use from other possible confounding factors, and to clarify the specific assumptions driving the results.

The point of all this is not to recommend a land-use policy that is best in some objective sense, but to help clarify some of the possible pros and cons of the various possibilities. Understanding, even in a stylized way, some of the likely impacts of different regional development scenarios, can be of help to planners and decision makers in formulating general strategies for regional development.

The results of the research indicate that the current conventional wisdom that compact development is better is at best an oversimplification. Certain types of compact development appear to be better for certain goals, or for certain places, while being worse for other goals or other places.

The following are the major general findings.

- The primary beneficiaries of compact housing development are residents of outlying areas that remain sparsely populated as a result. Conversely, central city residents are better off when population is allowed to spread out, because the associated problems are moved to outlying areas.
- More compact housing did lead to reduced congestion overall compared to lower density scenarios, apparently due to the resulting shorter trips and use of excess central city road capacity.
- In all the scenarios much of the congestion was concentrated on a relatively small amount of roadway.
- The level of air pollution rises dramatically toward the center of the region. As a result, the high population density scenarios, because they housed more people in the area of highest pollution, had the lowest overall amount of pollution, but the highest degree of exposure of people to pollution.
- In terms of accessibility to jobs, there was no way of placing jobs that would be best for a large fraction of the population. There are only as many jobs as workers; moving some jobs to be closer to some people inevitably makes them farther away from others. Better overall balancing of jobs and housing at a regional scale did have some aggregate benefit, but again at the expense of certain locations.
- The actual location of jobs seemed to matter less to accessibility than did the level of congestion that the placement implied. Given free-flow conditions, all the scenarios had similar accessibility levels.

- In all the scenarios, accessibility to jobs, and by implication congestion and air pollution, were worse in 2020 than in the present. That is, even the most extreme changes to current land use did not reverse present trends, but merely allowed them to progress at a somewhat reduced rate.
- Transit tended to have a fairly limited role in alleviating problems. It did have a somewhat bigger impact in the areas with the biggest problems, primarily in the central cities.

Despite some difficult methodological problems, this seems like a question worth exploring further. While it appears that land use alone cannot turn back the clock in terms of transportation-related problems, it does seem that the rate at which those problems grow can be impacted at least moderately at a regional level, and sometimes very substantially at local levels. A more careful analysis, and one that could accommodate changes to the highway network as well as to land use, could very well identify certain regional development paths for the future that would be generally better than the path we are on now.

Chapter 1
Introduction

This research addresses the question of how different regional land-use patterns would impact travel behavior and resulting transportation costs and benefits, such as congestion, air pollution, and accessibility to jobs. There has been considerable discussion in recent years about regional development patterns, and an intuition seems to have developed that more compact development is better from a transportation perspective because it reduces trip lengths, increases use of non-auto modes, and when planned appropriately, can better utilize excess capacity on dense urban street networks.

However, this intuition can be questioned on three grounds. The first question is how much regional land-use patterns really impact the amount of driving. If small changes to land use lead to big reductions in driving, then this is an important point. If, on the other hand, big changes to land use lead to small reductions in driving, then perhaps transportation problems would be best addressed through other means.

The second question is how a given amount of driving translates into actual costs. The natural instinct on which most discussion seems to be based, is that less total driving will mean less congestion and pollution. However, both of these costs are fundamentally driven not just by the number of cars on the road, but by how those cars interact with each other and with the surrounding areas; changes to these interactions could lead to worse outcomes even if total driving declines. For example, a policy that reduced total driving but concentrated the remainder on a smaller set of roads might actually increase congestion levels. Similarly, if there were less driving but it was more concentrated in densely populated areas, total exposure to pollution could increase.

The third question is how different impacts might interact with each other. Some discussion focuses on a single issue or a single location; however, the best solution to one specific problem could actually be a bad solution to other problems. For example, attempting to increase transit use by concentrating development could increase congestion because traffic might also become more concentrated.

This report defines six hypothetical future regional land-use scenarios, representing combinations of different styles of residential and commercial development. The traffic patterns resulting from each of these scenarios are then used to describe the resulting congestion, air pollution, and accessibility to jobs. The objectives correspond to the three questions noted above:

- To determine the size of the overall impacts on driving,
- To establish how overall driving levels translate into impacts of interest,
- To understand the relationships between the various impacts.

Literature on Land Use and Transportation

There has been a substantial amount of research in recent years on the subject of how urban land-use patterns impact travel behavior and transportation costs. This body of research is discussed in considerable depth in Boarnet and Crane (*1*). Without going into the same depth here, there are a few general characteristics of prior research that the work described in this report attempts to improve upon.

Most significant is that much of this work examines specific neighborhoods rather than entire urban regions. Examples of this include Boarnet and Sarmiento (*2*), Cervero and Gorham (*3*), Frank and Pivo (*4*), and Friedman, et al. (*5*). There are two implicit assumptions that underlie this type of analysis. First, that impacts observed in a given neighborhood can be repeated elsewhere in the region. Second, that land-use decisions that benefit a given neighborhood will have no offsetting negative impacts on non-residents. The second of these especially is open to question. For example, Ewing et al. (*6*) find that residents of an outlying neighborhood have much longer commutes; they propose to reduce this problem by locating more jobs in this neighborhood. But while this would probably reduce commute times for some local residents, it would almost certainly increase commute times for workers at the affected companies who live in more central locations. There are only as many jobs as workers; they can't just be moved around without creating regional impacts.

Another issue with much of the past research, including all the works cited in the previous paragraph, is that it focuses on indirect indicators of costs, such as transit share or vehicle miles traveled (VMT), rather than examining costs directly. All other things equal, it is certainly true that more transit and fewer VMT will reduce transportation costs. But when land uses are being modified, all other things are not equal. As noted earlier, higher density land uses could actually make problems worse even though they increase transit and reduce VMT, because they concentrate the remaining traffic on a smaller amount of road space.

There are some regional analyses of alternative land uses and their impacts on traffic patterns. The best known is probably the LUTRAQ (Land Use Transportation Air Quality) study from Portland, OR (*7*). Most of these studies are done as part of regional planning exercises. As such, they generally try to accurately represent regional economic and demographic idiosyncrasies, and to examine a variety of policy options. These two features taken together mean that it is often hard to separate the effects of land use from impacts due to demographic changes or other policy tools. For example, the LUTRAQ study poses a higher density development scenario, but in this scenario they also increase parking charges and make other significant policy changes.

The study that is the most closely related to the work described in the present report, is "Two Roads Diverge," done by Center for Energy and Environment and others in the Twin Cities in 1998 (*8*). This work defined two alternative land uses for the Twin Cities in 2020; what they call a "sprawl" scenario based on current development trends, and a "smart growth" scenario based on some urban infill, higher density edge development, and preservation of ecologically significant areas. The study examined a range of considerations including a somewhat cursory overview of transportation impacts.

Contributions of this Research

This research defines six different hypothetical future Twin Cities land-use scenarios, and examines the likely impacts on three major transportation-related outcomes: congestion, air pollution, and job accessibility. While land-use changes will probably also impact other important factors such as housing prices and the need for auto ownership, these considerations are beyond the scope of this analysis. The major features of the research described in this report, that collectively distinguish it from past work, are the following:

- Use of a regional analysis, rather than focus on a specific neighborhood. The concern here is with how land-use changes impact transportation costs over the region as a whole. Changes invariably benefit some localities at the expense of others; these geographic distributions of costs and benefits are examined as well, but within the context of regional impacts.
- Studying the specific issues of concern, such as congestion and pollution, rather than measuring indirect indicators such as VMT. As noted before, less VMT need not imply less congestion; even if it does, the nature of how congestion is geographically reallocated is of interest. The relationship between the indicators and the costs themselves is a subject of some interest here.
- Using very stylized and extreme land-use scenarios and a very simplified traffic forecasting model, to isolate the effects of land use from other possible confounding factors, and to clarify the specific assumptions driving the results.

The point of all this is not to recommend a land-use policy that is best in an objective sense, but to help clarify some of the possible pros and cons of the various possibilities. Understanding, even in a stylized way, some of the likely impacts of different regional development scenarios, can be of help to planners and decision makers in formulating general strategies for regional development.

Chapter 2
Methodology, Scenarios, and General Results

The objective of this research was to understand the general impacts on transportation costs resulting from different ways of allocating future jobs and housing across the region. In order to isolate these impacts, and because there was no need to produce forecasts that would have the kind of local accuracy needed for detailed planning purposes, a very simplified version of the standard four-step traffic forecasting model was used to predict the general traffic patterns resulting from each of the scenarios that were analyzed.

For the same reasons, the land uses themselves, with two exceptions, were quite stylized; jobs and housing were placed according to simple rules, such as "higher density close to downtown," rather than based on actual land availability or excess highway capacity. While this led to land uses that are not realistic in any political or even economic sense, again the intent was to isolate and exaggerate the types of impacts that would be likely to result from different land-use philosophies.

The three main steps of the process are described in the three sections of this chapter:

1. Define land-use scenarios reflecting a range of assumptions about the placement of new jobs and housing between 2000 and 2020, assuming that jobs and housing in place in 2000 will remain where they are.

2. Estimate a simplified version of the standard four-step traffic-forecasting model for each of the scenarios, using the same assumptions for all scenarios to increase comparability.

3. Use the model results to calculate descriptors of the impacts on congestion, air pollution, and accessibility under the different scenarios.

One simplifying assumption in particular is worth singling out. This is that the same road system was used for all the scenarios. This created certain problems; most notably that some of the scenarios that involved significant local density increases tended to overload the highway network leading to extreme levels of congestion. Obviously this is not realistic; the region would not pursue a policy, for example, of developing downtown-style suburban subcenters without doing anything to improve the local road network. In general this is the biggest flaw in this methodology; all the scenarios suffer from extreme localized costs to some degree. These are often costs that could be significantly reduced at relatively little expense. This issue is discussed further in the chapter on congestion.

The Land-use Scenarios

Six scenarios were studied, representing combinations of three ways of placing new population, and four ways of placing jobs. Housing and jobs in place in 2000 were assumed to remain where they are; new housing and jobs arising between 2000 and 2020 were manipulated. Placement was on the basis of Traffic Analysis Zones (TAZs), which are defined by the Metropolitan Council for purposes of forecasting land uses and traffic flows. The 7-county region is divided into 1165 TAZs (in the 1990 model used for this analysis); the physical area is inversely related to the job and population density in an area. Thus the TAZs are generally smaller in area in the center of the region and larger at the edges.

The six land-use combinations used in this study are:

1. Low-density population, low-density jobs (LL). This is the baseline scenario, representing the current expectations regarding the evolution of land use in the region in the absence of significant efforts to induce some other outcome. This scenario was taken from an earlier study of alternative land-use patterns, where it is called the "sprawl" scenario. All other scenarios are assumed to have the same number of people and jobs as this one.

2. Medium-density population, medium-density jobs (MM). It was also taken from an earlier study of alternative land-use patterns, where it is called the "smart growth" scenario. This represents a relatively modest variation from the LL scenario, with more new development in the center of the region, and with new edge development at somewhat higher densities. There were a few small adjustments made to the original data to make the total population and jobs counts the same as LL.

3. High-density population, low-density jobs (HL). This scenario uses the job placement from LL, but places new population all within a ring of ten miles around the two downtowns, with density gradually decreasing from the center to the edge of this ring.

4. Low-density population, high-density jobs (LH). This uses the population placement from LL, but places all new jobs within four high-density centers. Two of these are the two existing downtowns, which increase to about twice their current size. The other two are new suburban subcenters in the northwest and northeast, which become about the size of the current downtown St. Paul. The primary interest here is in the impacts of the higher overall transit shares that result from the job concentration.

5. Low-density population, "balanced" jobs (LB). This scenario was developed in response to early results indicating that the center of employment was shifting to the southwest part of the region. In this scenario, all new jobs were placed in TAZs in the north and east part of the region, in an effort to maintain the balance of employment over the existing downtown axis. Population was placed as in LL.

6. High-density population, high-density jobs (HH). This combines the population placement from HL and the job placement from LH.

The basic construction of the high population density scenario is as follows. All population growth from 2000 to 2020 is assumed to be housed within a ten-mile radius of the two downtowns. Outside this radius, population is assumed to remain at 2000 levels. Within the ten-mile radius, the new people were placed using an exponential function, ae^{bD}, where a and b are constants and D is the distance from the nearer of the two downtowns, so density declines based on the distance from downtown (using TAZ 816 as the center of St. Paul, and 407 as the center of Minneapolis). The one exception to the formula was that any TAZ that was denser in 2000 than the formula value was kept at its 2000 density.

The average density of the ring centered on ten miles from downtown is about 2,000 per square mile. Thus the density function was constrained to generate a density of 2,000 in TAZs ten miles from downtown, with a and b calculated to generate the correct total population. This implied a density of about 23,000 at the central points. Thus there is considerably higher density in and immediately around the downtowns, and the decline from this level is more gradual than it is now.

The high job density scenario was constructed by placing all new jobs created between 2000 and 2020 into four large subcenters. Non-subcenter TAZs were set to 2000 levels. The locations of the suburban subcenters were chosen to add jobs to the north and east part of the region, where they are somewhat less plentiful. The southwest suburbs are already congested from the existing jobs. The four subcenter locations are:

- Downtown Minneapolis. It is currently about 135,000 jobs; it grows to 170,000.
- Downtown St. Paul. It goes from 65,000 to 130,000.
- Maple Grove, at 694/94. About 65,000 jobs.
- Maplewood, at 694/35E. About 90,000 jobs.

The primary point of interest in this scenario is in the impacts of the higher transit use that is assumed to result from the high concentration of employment. While the original concept was that the suburban TAZs would be of the size and density of a current downtown, this could not be literally applied for forecasting purposes as it overloaded the local road networks to the point where the model could not converge. Thus a compromise was made for forecasting purposes, in which the suburban job centers were spread out over 6 or 7 TAZs, with the transit share assumed to still be as high as if they were as dense as a downtown.

The "balanced" jobs scenario was created in response to early results indicating that the regional center of jobs was drifting significantly to the southwest. Thus this scenario was intended to represent a possible better balance between regional jobs and population. The new jobs created between 2000 and 2020 were all placed in about 450 mostly suburban TAZs around the north and east sides of the region.

Forecasting Methodology

The objective of this research was to understand, in a general way, the impacts on transportation costs resulting from different ways of allocating jobs and housing across the region. In order to isolate these impacts, a very simplified application of the standard four-step forecasting model was estimated. The idea was to eliminate situations where the reason for a particular result might be unclear because of multiple factors changing at the same time. For example, income levels were assumed to be equal across the region; although this is not realistic, it makes it possible to be sure that lower driving rates in the central cities are due to land use and not to concentrations of low income residents. In general there was no reason to be accurate in the sense of predicting flows on specific highways; what matters is how the flows differ across scenarios, not what the absolute levels are. Thus it was more important that the assumptions were consistent across scenarios, than that they were realistic.

The major simplifying assumptions are the following:

- Residents of all TAZs were assumed to have the same economic and demographic characteristics.
- All TAZs were assumed to generate the same number and types of *person* trips per resident; 4 trips per person was used. However, the modes by which these trips were made varied across TAZs according to land-use characteristics of the trip origin and destination. Thus, the number of *vehicle* trips per person was not necessarily the same across all TAZs.
- Trips are attracted to TAZs based on the number of retail and non-retail jobs, which attract at different rates, and the population, as personal visits generate some trips. The rates used are summarized in Table 2.1. These were based on standard figures, modified to make the number of attractions equal to the number of trip productions.
- Only the single hour between 7-8 AM was studied. The assumption was that the *general* differences between scenarios that occurred in this hour would continue in some form throughout the day. This probably has the effect of exaggerating the level of congestion as well as the differences between scenarios, since trips are not allowed to shift modes or time of day due to high congestion levels.
- Only two trip types were used, home-based work, and home-based other. Non-home based trips were not used because only a single hour was studied, a time at which most people would still be starting from home. The gravity model was consolidated to correspond to these two trip types; parameters from the Metropolitan Council (1990) model were used, as this was the most recent calibrated model.
- Mode choice was based on land-use characteristics of origin and destination TAZs rather than on an explicit mode choice model. The objective was to gain greater control over the predicted level of alternate mode use, as well as simplifying the model in general. All forecasts were run assuming the presence of transit, and also assuming that all trips would be made by automobile to isolate the impact of transit.
- No special generators or K factors were used; again, the point was understanding broad patterns, not producing realistic forecasts of volumes on specific roads.

TABLE 2.1 Assumed Trip Attractions

	Retail jobs	Non-retail jobs	Population
Home-based work	2	2	0
Home-based other	7	0.9	0.35

The assumptions about transit use were based on research results in Barnes and Davis (*9*) about 1990 patterns in the Twin Cities, in which transit share depends on both the origin and destination. A very simplified version of these results was applied here, as shown in Table 2.2.

TABLE 2.2 Assumed Transit Shares

	Destination	
Origin	Downtown	Other
Central City	25%	3%
Other	15%	1%

Downtown includes TAZs in and near the two downtowns and the Minneapolis campus of the University of Minnesota. In the high job density scenarios "downtown" also includes additional TAZs of the two (expanded) downtowns as well as TAZs of the defined suburban job centers.

These assumptions imply a certain number of trips on the region's roads during the 7-8 AM hour. At some point in the future, there will likely be this number of trips during this hour. This may not happen in 2020, and it may not happen because any of these assumptions are true. But the point is that even if all these assumptions are individually inaccurate or overly simplified, they are cumulatively generating a situation that will in fact at least approximately happen at some point in the future, even if it does not happen at the time or in the way assumed in this report.

Given these assumptions, the procedure used to generate traffic forecasts was the following. Productions and attractions by TAZ were generated using the simple assumptions above. The simplified Met Council gravity model (home-based work, and home-based "other" trips only) was used to distribute trips from origins to destinations, assuming (to start with) year 2000 TAZ-to-TAZ travel times. Then a certain number of trips from each origin-destination pair was taken out of the forecast based on the assumed transit share as described above. The remaining trips were assigned to travel-time minimizing routes using the Transcad® software program, applied to the expected 2020 highway network.

The TAZ-to-TAZ travel times implied by the traffic forecast at the end of this process were not the same as the year 2000 travel times that were used to distribute trips from origins to destinations at the beginning of the process. This inconsistency between starting assumptions and end results can be a significant problem with traffic forecasts if the process is only run once. Here I ran the process multiple times, using the travel times from the forecasts of one stage as the input to trip distribution to start the next stage. I repeated this until the total travel time from the forecast was within 2% of the total travel time of the previous stage forecast. Travel time for individual routes may not always have converged to this level, but at least at an aggregate level the travel times implied by the forecasts were consistent with the assumed travel times on which the forecasts were based.

Summary of Scenario Characteristics and Forecast Results

Jobs and population were allocated into the 1165 traffic analysis zones (TAZs). These TAZs were then grouped into 66 larger "zones" for purposes of simplifying the maps. The zones are loosely based on municipalities, with an effort to create zones of roughly similar populations; small towns and rural areas are generally grouped together, while larger cities are broken into multiple zones. The zones were also grouped into four area types or rings for further simplification; these are based on Metropolitan Council definitions, and include rural, developing suburbs, developed suburbs, and central city. Maps of the zones are shown in the appendix.

Tables 2.3 and 2.4 summarize population and jobs by the area types where they occur: rural, developing suburbs, developed suburbs, and central city. Year 2000 is shown for comparison.

TABLE 2.3 Population by Ring

	Rural	Developing	Developed	Central City
LL	572467	1112721	755580	649487
MM	405053	1146552	818398	720252
HL	345253	980865	901476	862661
LH	572467	1112721	755580	649487
LB	572467	1112721	755580	649487
HH	345253	980865	901476	862661
Year 2000	345253	930205	696351	636489

TABLE 2.4 Jobs by Ring

	Rural	Developing	Developed	Central City
LL	141271	440894	746030	468805
MM	126646	430672	741488	498194
HL	141271	440894	746030	468805
LH	87299	457839	671120	580742
LB	105893	426285	786204	478618
HH	87299	457839	671120	580742
Year 2000	87299	338280	641230	478618

A couple of points of interest are that all the rings have equal or greater population in all the scenarios compared to the present (2000). Even the LL "sprawl" scenario includes an increase in central city and developed suburb population. Similarly, jobs increase or remain essentially stable in all rings and all scenarios compared to the present.

Table 2.5 shows the ratio of jobs to workers by ring for the six scenarios and for the present. The two inner rings generally have a surplus of jobs compared to workers, except for HL, where central city population increases dramatically; while the opposite is true of the two outer rings. The ratio of jobs to workers shows fairly sizable variation across scenarios.

TABLE 2.5 Jobs per Worker by Ring

	Rural	Developing	Developed	Central City
LL	0.42	0.68	1.70	1.24
MM	0.54	0.65	1.56	1.19
HL	0.70	0.77	1.42	0.93
LH	0.26	0.71	1.53	1.54
LB	0.32	0.66	1.79	1.27
HH	0.43	0.80	1.28	1.16
Year 2000	0.43	0.63	1.58	1.29

Tables 2.6 and 2.7 show summary travel statistics by ring and by transit presence. Note that the "no transit" scenarios include a defined transit share of zero. Total time and total miles are shown as a fraction of the LL with transit scenario, which is normalized to equal 1 in each case. Thus for example, the MM without transit scenario has the same number of total driving minutes as LL with transit, and 95% as many total driving miles.

TABLE 2.6 Summary Statistics, With Transit

	Total Minutes	Total Miles	Average Speed	Transit Share
LL	1.00	1.00	26.21	3.66
MM	0.90	0.93	27.18	3.92
HL	0.89	0.91	26.71	3.91
LH	1.19	1.05	23.14	5.92
LB	1.11	1.04	24.54	3.34
HH	0.93	0.92	25.92	6.28

Time and miles calculated using LL scenario as baseline=1

TABLE 2.7 Summary Statistics, No Transit

	Total Time	Total Miles	Average Speed	Transit Share
LL	1.10	1.03	24.52	0.00
MM	1.00	0.95	24.98	0.00
HL	0.97	0.94	25.37	0.00
LH	1.40	1.09	20.51	0.00
LB	1.18	1.06	23.49	0.00
HH	1.09	0.96	23.01	0.00

Time and miles calculated using LL with transit scenario as baseline=1

The LH and HH scenarios have much higher transit shares than the others, as these are defined so that all new jobs are placed in high-transit destinations. The HL share is the same as the MM share, which may seem surprising since HL involved placing all new residents in central locations. However, HL also assumes that jobs are low density, while MM somewhat centralizes both people and jobs. The greater centralization of jobs in MM apparently exactly offsets the greater concentration of residents in HL.

In most cases these transit shares are slightly lower than are currently observed, at least given the assumed 7-8 AM hour. However, the difference is not so great as to impact the general results. Given increasing incomes and the declining transit share that typically results, these shares may be roughly accurate for 2020.

In general, the differences in travel time across scenarios are considerably larger than differences in miles traveled, due to the impacts of extreme congestion levels in some scenarios. The differences in miles driven are on the order of 10-15%, which is either very small or very large depending on one's perspective. On the one hand it seems small since even impossibly large land-use changes are reducing travel by only 10% compared to just letting things go their own way. On the other hand it could be seen as big, since the total number of people and jobs being placed are only about 15% of the total, as everything in place in the year 2000 is assumed to remain where it is.

Chapter 3
Congestion Impacts

There are a number of different ways of describing the traffic congestion that occurs under different land-use scenarios. This chapter begins by providing some simple overall statistics on total regional congestion, expressed as the percent amount by which total travel time exceeds the hypothetical free flow time for the same trips. The second section of the chapter provides the same statistics, but with more detail on where the congestion occurs. This is described by the development ring, and in more detail in terms of zones. The third section addresses the question of who experiences congestion (as opposed to where it occurs), by describing how average commute times for residents of the different development rings are impacted by the congestion that is experienced. The final section examines the implications of the fact that much of the forecasted congestion occurs on a relatively small amount of roadway.

Overall Congestion Statistics

The first congestion descriptor is just an aggregate summary of the percentage by which the forecasted travel time exceeds the free flow time for the trips that are made in each scenario. Each scenario generates different trips, depending on where homes and jobs are located, as well as on travel times as impacted by congestion. For each scenario, the method is to multiply the total traffic volume for each link by the forecasted travel time for that link to get total travel time; then to multiply the same total volume by the free flow time for that link to get total free flow time. The ratio of the two is the congestion measure. In Tables 3.1 and 3.2 below, the LL free flow time is normalized to equal 1; all other times are expressed as a ratio of this.

TABLE 3.1 Aggregate Congestion, With Transit

	Total Time	Free Flow	% Excess
LL	1.49	1.00	48.98
MM	1.34	0.94	42.27
HL	1.33	0.93	43.41
LH	1.77	1.05	68.79
LB	1.65	1.04	59.17
HH	1.38	0.93	48.22

Total and free flow time calculated using LL freeflow as baseline=1

TABLE 3.2 Aggregate Congestion, No Transit

	Total Time	Free Flow	% Excess
LL	1.58	1.00	58.27
MM	1.45	0.94	53.68
HL	1.40	0.93	50.80
LH	2.02	1.07	89.14
LB	1.71	1.03	65.45
HH	1.57	0.95	65.88

Total and free flow time calculated using LL freeflow as baseline=1

Both with and without transit, the MM and HL scenarios generate the lowest total travel time, in part because trips are shorter (as reflected in the lower free flow times) and because congestion is lower. However, there is a large amount of excess travel time in all the scenarios, and neither the presence of transit nor the higher densities have a huge impact on this, compared to the baseline LL scenario.

The three scenarios in which job placement plays a major role (LH, LB, HH) all have much worse congestion than the three housing-based scenarios. For the LH and HH scenarios, where jobs are concentrated into downtowns and suburban centers, this higher congestion is reflecting a huge influx of traffic on roads that are not built to handle it; this is a byproduct of the assumption of keeping the road network the same across scenarios. For all these scenarios, part of the problem is also that all the new jobs are placed north of the downtowns; this negatively impacts the large fraction of the population that lives south of the downtowns. The intent in creating these scenarios was to compensate for the apparent south-north job imbalance, but seemingly went too far in the other direction.

The problem is that this major distortion in terms of congestion ends up negatively impacting everything else about these scenarios, so that to a large extent the purpose of including them is very seriously compromised. There is still a question of whether appropriate job placement can mitigate transportation-related problems, but it appears that addressing this question will require two changes to the analysis here. First, there should be more effort to place the jobs based on an explicit analysis of where congestion is occurring and how job placement can be used to divert trips from those areas (while not creating new congestion elsewhere). Second, the “no new roads” requirement would need to be relaxed, at least in the case of major subcenter construction or expansion.

Congestion by Location

The second congestion analysis uses the same calculation described above, but divides the links into the area types where they occur: rural, developing suburbs, developed suburbs, and central city. The numbers in the Tables 3.3 and 3.4 below correspond to the last column of the tables above; that is, they are the percent by which the forecasted travel time exceeds the free flow time for the links in each ring. Note that these numbers describe where congestion occurs, not where the drivers live who are generating that congestion.

TABLE 3.3 Congestion by Ring, With Transit

	Rural	Developing	Developed	Central City
LL	25.1	55.3	51.9	50.6
MM	12.5	40.3	46.7	52.2
HL	7.9	22.4	53.2	64.4
LH	38.7	97.1	61.2	59.9
LB	35.8	75.1	62.2	45.9
HH	10.5	45.4	51.2	61.5

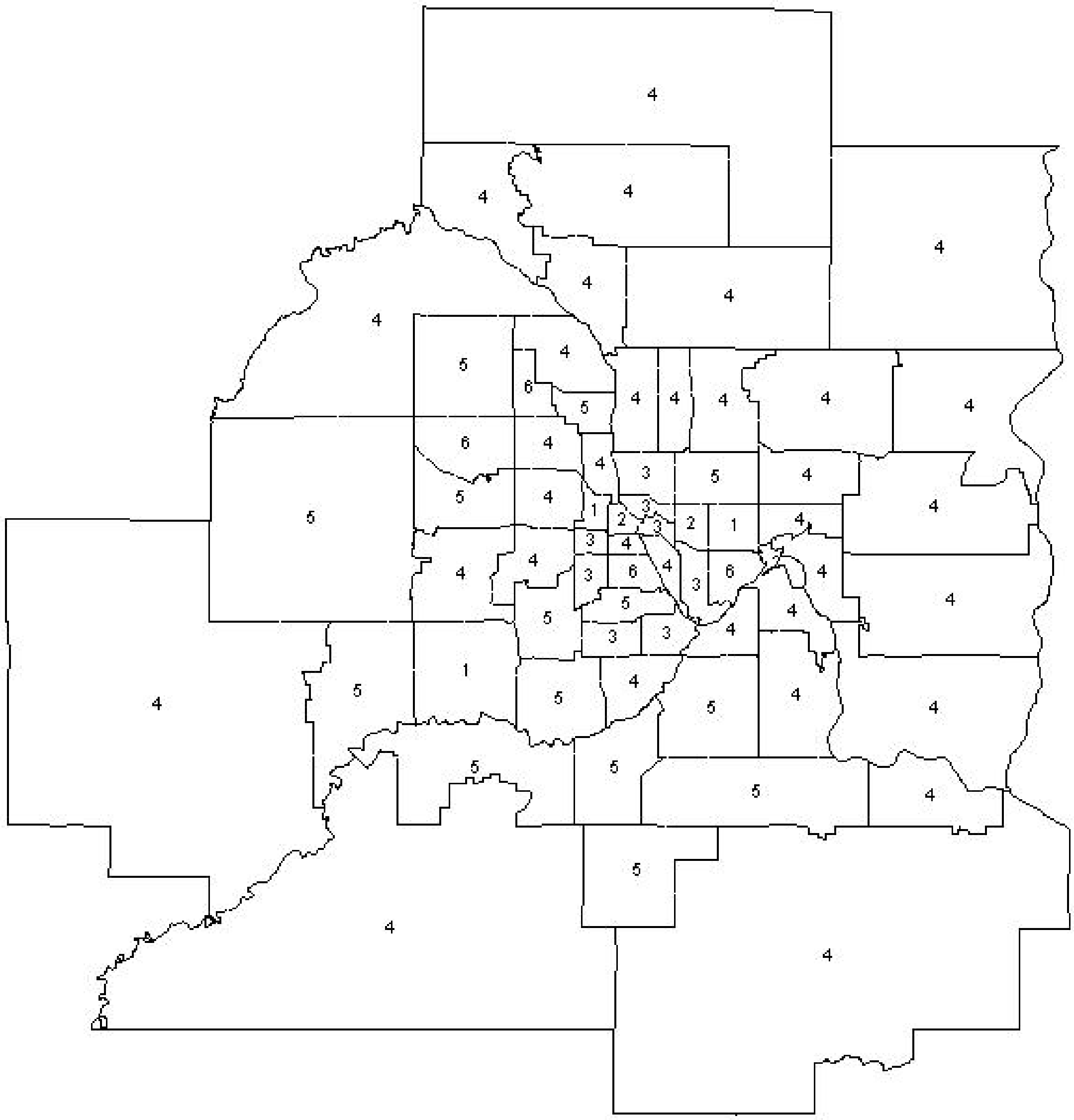
TABLE 3.4 Congestion by Ring, No Transit

	Rural	Developing	Developed	Central City
LL	26.6	58.5	55.7	81.5
MM	13.6	43.2	50.6	89.5
HL	10.7	27.5	53.4	88.0
LH	45.9	125.0	72.1	92.7
LB	38.6	80.5	66.4	59.6
HH	12.2	67.0	60.5	92.7

Four points stand out here. First, central city congestion is far higher without transit; transit has the effect of bringing central city congestion down to the same levels observed elsewhere. Second, congestion is about the same in all the rings except rural; it is no worse in the central areas. Third, congestion in the central areas is not that much higher in the higher density scenarios, compared to LL, lending credence to the idea that developed areas are capable of absorbing more than is already there. Fourth, the primary beneficiaries of the higher density scenarios are people who live in outlying areas, who enjoy much lower congestion under HL than under LL.

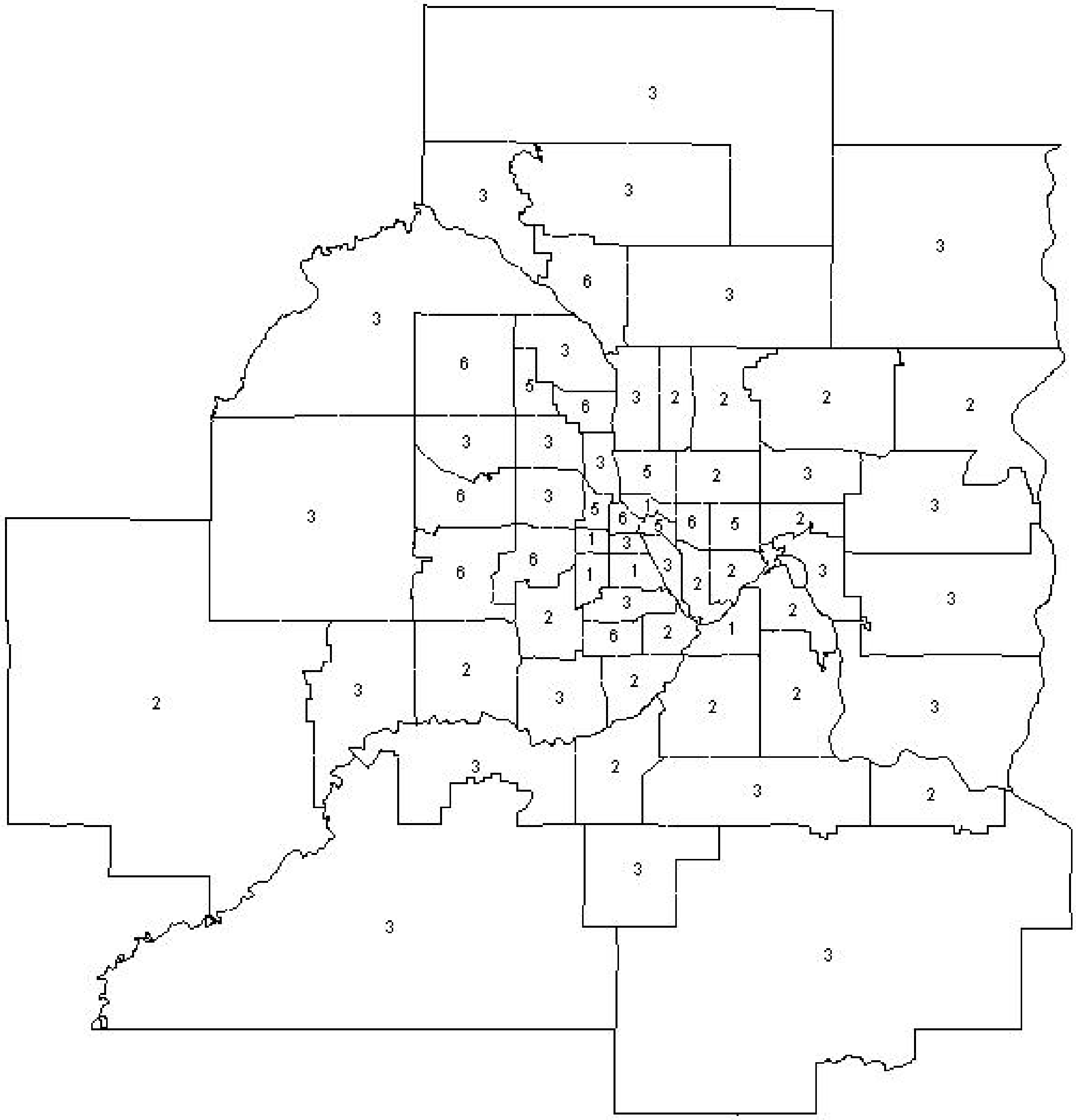
The analysis of where congestion occurs can be taken further by dividing the region into the 66 zones described in the methodology chapter. The following pages contain six maps describing congestion levels. All of these are based on the idea of showing, for each zone, which of the six scenarios gives the best and the worst outcomes for congestion. The six maps are:

- Which scenario gives the worst overall congestion for each zone, calculated as percent delay compared to free flow
- Which scenario gives the best overall congestion for each zone
- Which scenario gives the worst freeway congestion for each zone
- Which scenario gives the best freeway congestion for each zone
- Which scenario gives the worst non-freeway congestion for each zone
- Which scenario gives the best non-freeway congestion for each zone



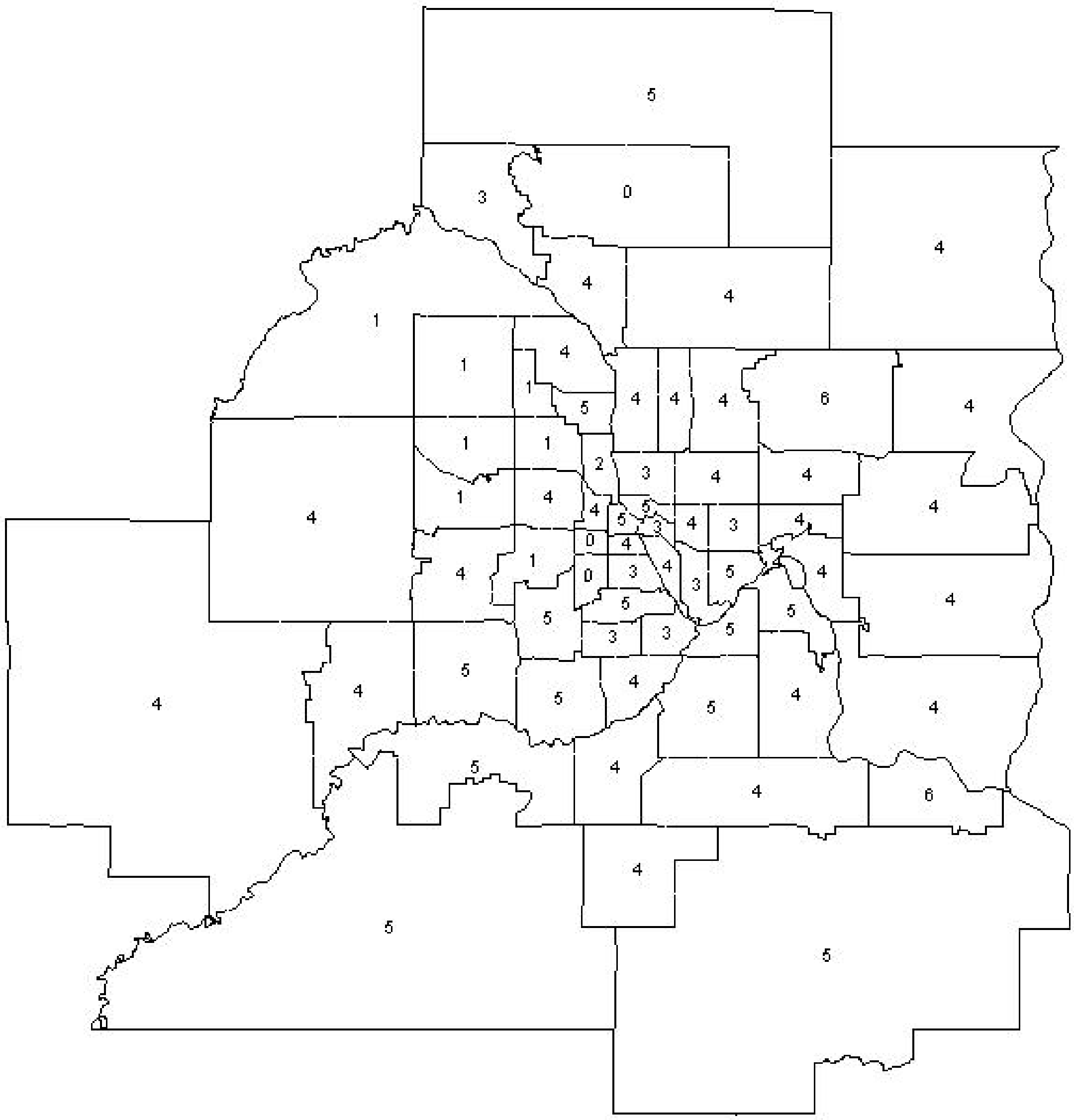
Map 3.1 Total congestion, worst scenario by zone

Key:
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density



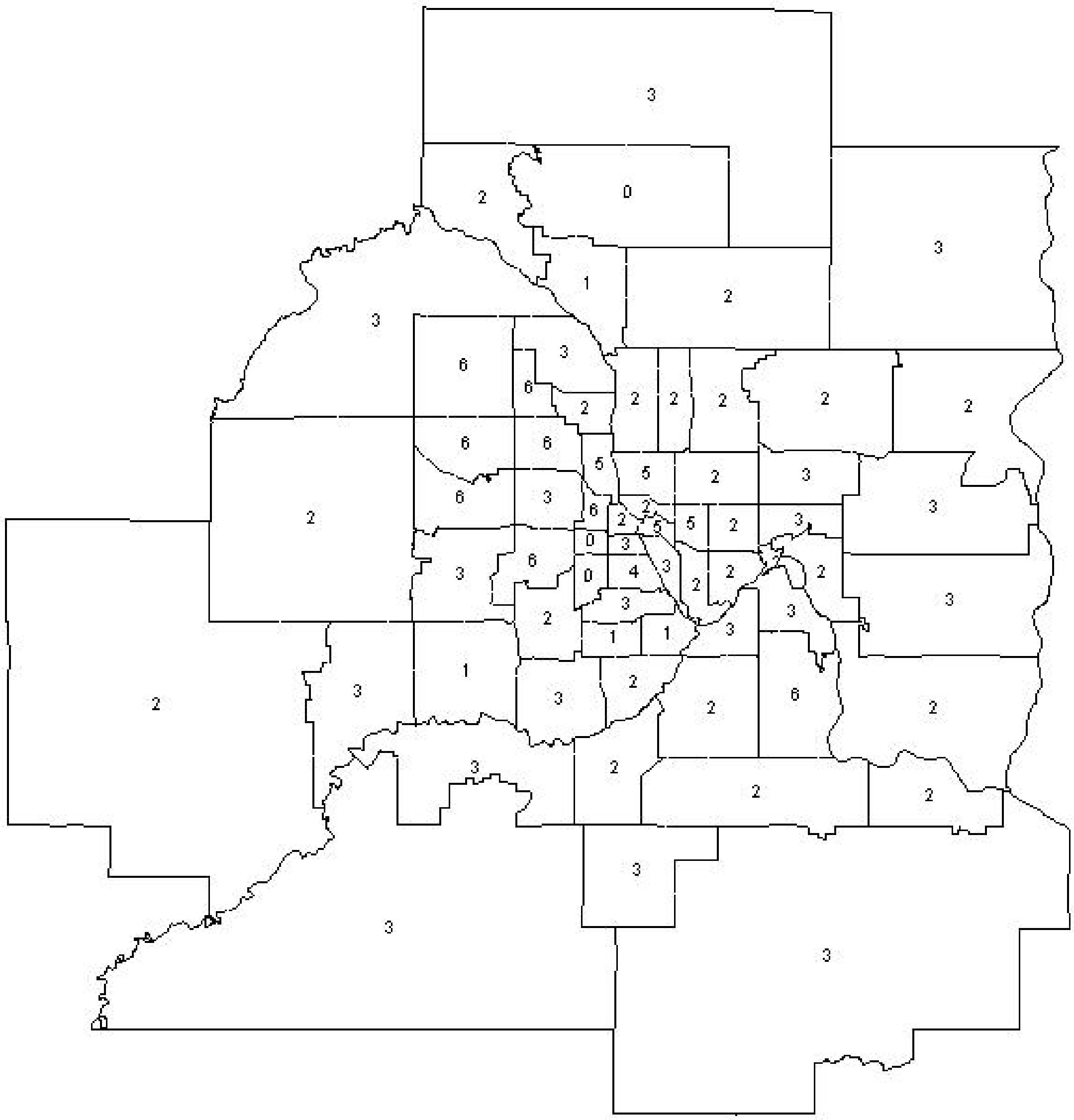
Map 3.2 Total congestion, best scenario by zone

Key:
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density



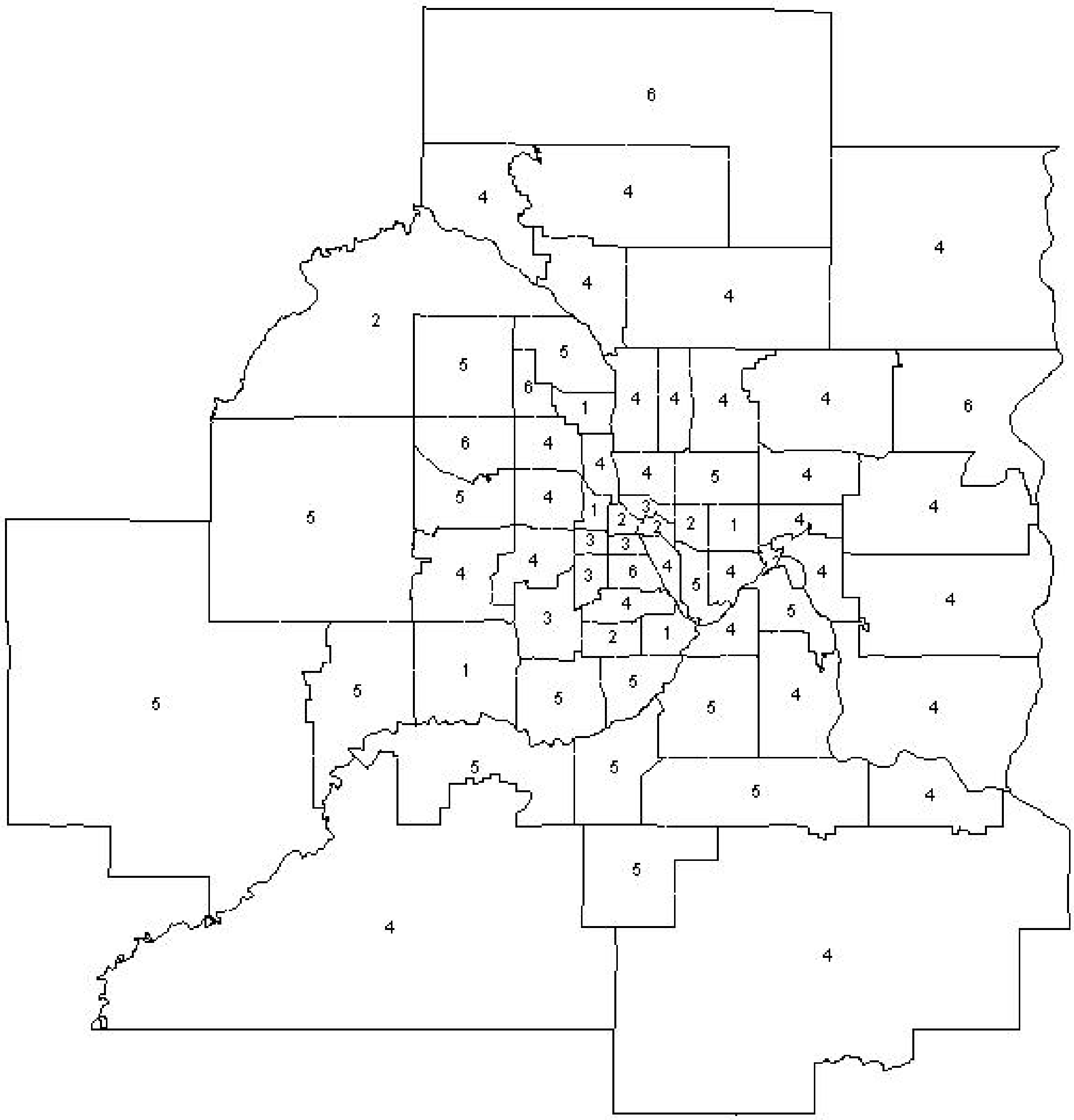
Map 3.3 Freeway congestion, worst scenario by zone

Key:
0: No freeways in the zone
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density



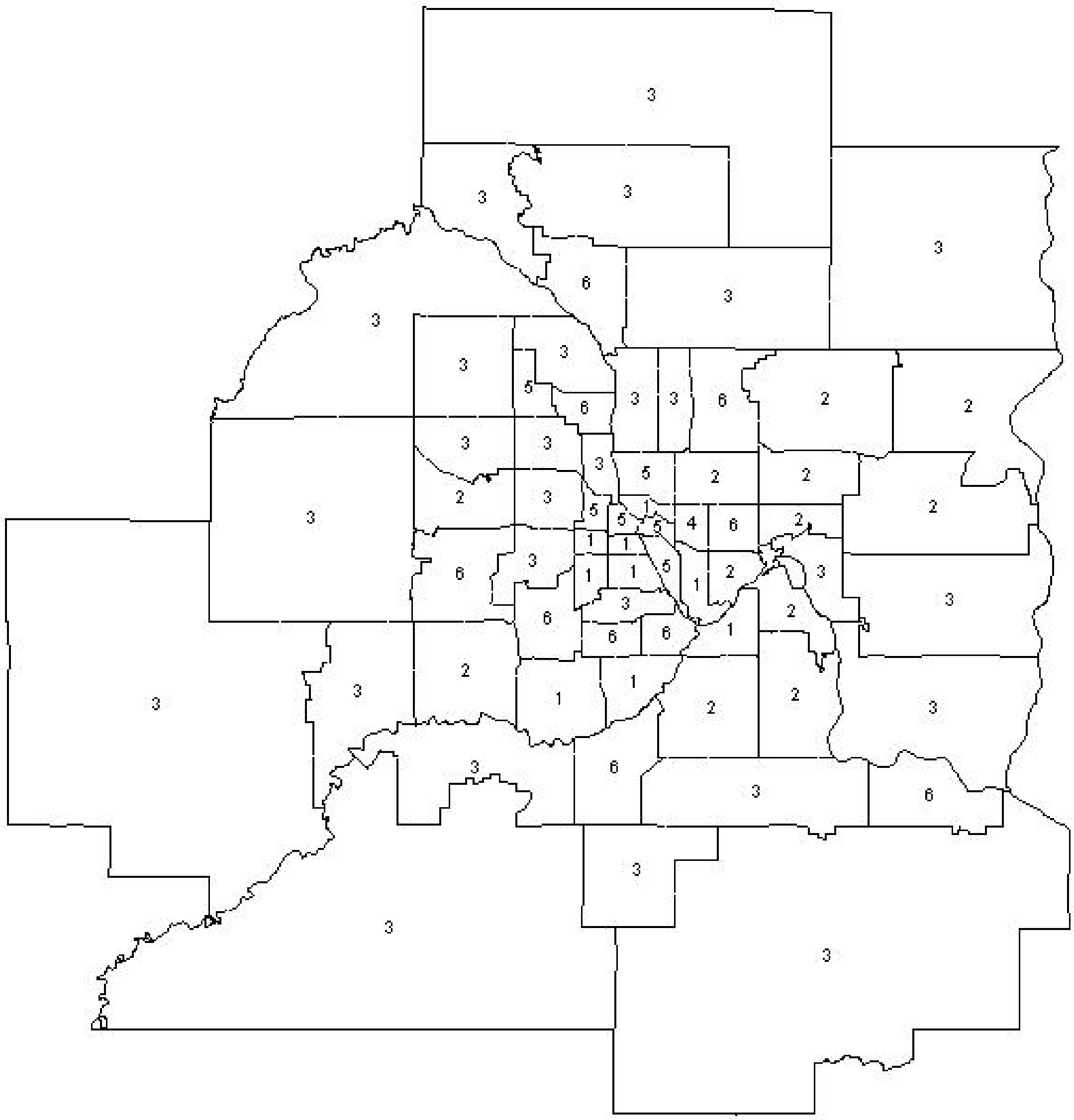
Map 3.4 Freeway congestion, best scenario by zone

Key:
0: No freeways in the zone
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density



Map 3.5 Non-freeway congestion, worst scenario by zone

Key:
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density



Map 3.6 Non-freeway congestion, best scenario by zone

Key:
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density

Perhaps the most striking feature of these maps is the absence of noticeable patterns. With two exceptions, the region seems almost entirely random in terms of which scenario generates the best or worst congestion for a given zone. For example, there are six contiguous zones between the two downtowns in which all six of the scenarios give the worst overall congestion in one zone each. The HL scenario, which gives the worst congestion overall in the central cities, gives the best congestion for some individual central city zones. In general, the scenario that generates the best or worst freeway congestion for a given zone does not generate the best or worst non-freeway congestion for the same zone.

The two broad patterns that emerge both impact the outlying zones. The LH scenario tends to give the worst congestion in outlying zones, because the assumed large population increases are not balanced by increased job opportunities, leading to long commutes. Conversely, the HL scenario gives the best congestion in these zones, because job opportunities increase while population does not.

There is an interesting point to the randomness of congestion impacts. It seems to be implied that congestion is influenced to an unexpected degree by land-use decisions that may take place nowhere near the location where the congestion is being experienced. There are several cases where a scenario that gives the best congestion in one zone gives the worst congestion in an adjacent zone, even though the main impact of the scenario occurs somewhere else entirely. Alternately, there are cases where major local land-use impacts have little effect on congestion levels (the zones around downtown St. Paul in the HL scenario).

There is a general recognition that local land-use patterns can impact local congestion levels. However, the implication here that far away land-use decisions can impact local congestion levels seems less well understood. This could be an interesting point for further study.

Congestion by Driver Home Location

This analysis examines the impact of congestion based on where drivers live. The method is to look at where residents of a given zone are driving to, calculate the zone-to-zone travel time for these trips, and compare this to the free flow time for the same trips. The first two tables below show the six scenarios without and with transit, and the third shows free flow times.

TABLE 3.5 Average Commute in Minutes, With Transit

	Rural	Developing	Developed	Central City	Average
LL	32.6	25.2	20.4	19.6	24.2
MM	28.6	23.5	19.8	19.5	22.3
HL	25.1	21.2	20.2	21.3	21.4
LH	43.4	30.5	22.5	19.0	28.5
LB	38.3	27.7	20.9	19.1	26.2
HH	31.1	23.8	20.9	19.3	22.5

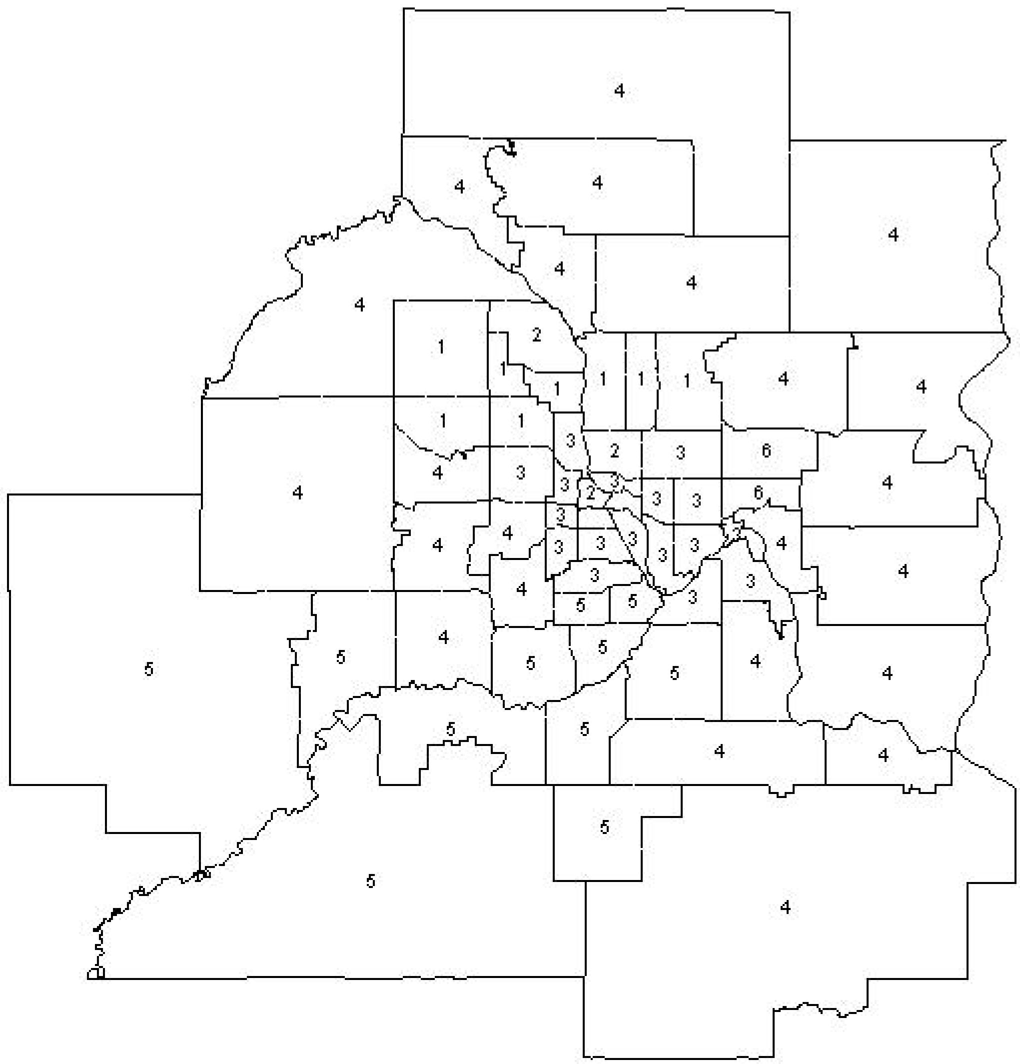
TABLE 3.6 Average Commute in Minutes, No Transit

	Rural	Developing	Developed	Central City	Average
LL	33.9	26.5	21.7	22.1	25.7
MM	29.5	24.9	21.3	22.3	24.0
HL	27.2	22.7	20.9	21.8	22.4
LH	48.6	34.3	25.2	21.6	32.1
LB	39.8	28.7	21.5	20.0	27.2
HH	33.9	26.2	23.1	21.6	24.9

TABLE 3.7 Average Commute in Minutes With Free Flow

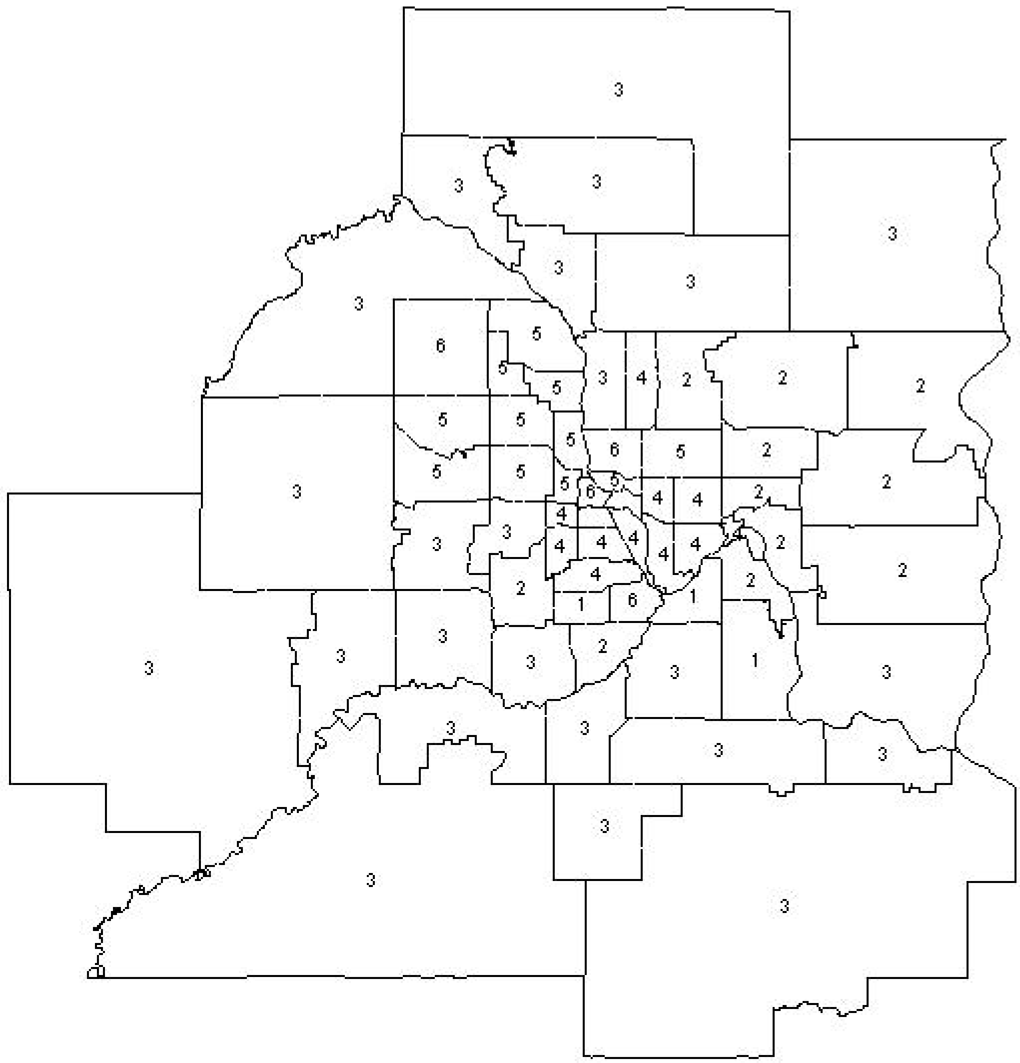
	Rural	Developing	Developed	Central City	Average
LL	22.9	17.6	15.8	15.5	17.7
MM	22.7	17.5	15.6	15.2	17.1
HL	22.3	17.1	15.4	15.0	16.6
LH	25.5	18.1	15.8	14.5	18.1
LB	24.2	17.7	15.4	15.1	17.8
HH	24.4	17.2	15.3	14.1	16.6

As is the case now, commute times are about the same in the two inner rings and increase farther out. As with the previous tables, the main beneficiaries of the higher density scenarios are the residents of the outlying areas. This is confirmed by the maps on the following two pages, showing which scenarios give the shortest and longest commute times at the zone level. The shortest commute times for outlying areas generally occur under the HL scenario, which conversely gives the longest commutes for central city residents. By contrast, the LH scenario, in which jobs are concentrated but housing is not, gives the shortest commutes in the central city but the longest in outlying areas.



Map 3.7 Commute to work travel time, worst scenario by zone

Key:
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density



Map 3.8 Commute to work time, best scenario by zone

Key:
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density

The "Worst 100 Miles"

The final analysis here is based on the observation that in all the scenarios, a substantial portion of the total regional congestion delay occurs on a relatively small amount of the total highway network. There are 9,500 total miles of highway links in the regional forecasting network; the worst 100 miles of highway create 30% or more of the total congestion, as seen in Table 3.8.

TABLE 3.8 Worst 100 Miles, Percent of Total Scenario Congestion

	Total	Freeway	Non−freeway
LL	33.5	11.3	22.2
MM	37.2	13.6	23.6
HL	44.6	19.1	25.5
LH	33.4	13.7	19.7
LB	32.1	14.4	17.7
HH	44.2	16.3	27.9

This table suggests that overall congestion levels could be substantially reduced through improvements to a relatively limited amount of roadway. It is also notable that a majority of the congestion on these roads is not on freeways; capacity improvements could be even less expensive in these cases. However, some caution should be applied to this interpretation. Eliminating the congestion from these especially bad sections would almost certainly improve conditions; however, by improving flow through currently congested areas, it may just overload other sections downstream from these links.

Table 3.9 shows the ring in which the congestion occurs in the worst 100 miles for each of the scenarios.

TABLE 3.9 Percent of Total "Worst 100 Miles" Congestion, by Ring

	Rural	Developing	Developed	Central City
LL	5.0	36.2	39.6	19.3
MM	0.6	25.6	45.0	28.7
HL	0.3	5.7	54.0	40.0
LH	6.2	55.9	28.0	9.9
LB	7.3	49.6	35.6	7.6
HH	0.6	26.6	41.8	31.0

The scenarios show considerable variation in where the most congested sections of roadway are located. In HL virtually none of the most congested roads are in the outer two rings, while in LH virtually none are in the central cities. There could be implications for congestion management in that low population density land uses tend to generate bottlenecks in outlying areas where they are presumably less costly to mitigate. Thus these scenarios could actually look considerably better from an overall congestion standpoint if limited road improvement expenditures were allowed.

Chapter 4
Air Pollution Impacts

Pollution levels were estimated by using standard tables that relate driving speeds to emissions of various pollutants. The three examined here were hydrocarbons, carbon monoxide, and Nitrogen Oxides (NOX). For each scenario, a total emission level for each link was calculated based on the speed and traffic volume. These calculations come from standard emissions models; these are time-specific, so that future year forecasts will assume a lower emissions rate, as would be indicated by trends and regulatory requirements. Links were then grouped by a land area unit (ring or zone) and total pollutants for that land area summed. This total was then divided by the total square mileage of the land unit to get a concentration level of "pollution per square mile." The following Tables 4.1 through 4.6 show the three pollutants, with and without transit. In each case the emissions for the rural ring of the LL scenario with transit is set as the baseline with a value of 1, and emissions in the other rings and scenarios are expressed as a ratio of this baseline.

TABLE 4.1 Hydrocarbons by Ring, With Transit

	Rural	Developing	Developed	Central City
LL	1.0	8.6	21.3	27.6
MM	0.7	7.2	20.4	28.1
HL	0.6	5.9	21.4	32.0
LH	1.1	10.6	23.0	31.5
LB	1.1	9.7	23.6	28.4
HH	0.6	6.7	21.1	32.9

TABLE 4.2 Hydrocarbons by Ring, No Transit

	Rural	Developing	Developed	Central City
LL	1.0	8.8	22.2	31.9
MM	0.7	7.5	21.1	32.4
HL	0.7	6.4	21.9	34.2
LH	1.2	11.8	24.9	37.4
LB	1.1	10.1	24.5	31.4
HH	0.7	7.3	22.5	38.4

TABLE 4.3 Carbon Monoxide by Ring, With Transit

	Rural	Developing	Developed	Central City
LL	1.0	9.2	22.4	30.4
MM	0.7	7.7	21.3	30.9
HL	0.6	6.1	22.4	35.4
LH	1.1	11.6	24.4	34.9
LB	1.1	10.5	25.1	31.4
HH	0.6	7.1	22.1	36.5

TABLE 4.4 Carbon Monoxide by Ring, No Transit

	Rural	Developing	Developed	Central City
LL	1.0	9.5	23.4	35.4
MM	0.7	7.9	22.1	35.9
HL	0.7	6.6	23.0	37.9
LH	1.2	13.0	26.6	41.7
LB	1.1	10.9	26.1	34.8
HH	0.6	7.8	23.7	42.8

TABLE 4.5 NOX by Ring, With Transit

	Rural	Developing	Developed	Central City
LL	1.0	6.9	17.8	18.3
MM	0.8	6.2	17.5	18.5
HL	0.7	5.6	17.8	20.1
LH	1.0	7.5	18.4	19.7
LB	1.0	7.2	18.7	18.8
HH	0.7	5.9	17.7	20.5

TABLE 4.6 NOX by Ring, No Transit

	Rural	Developing	Developed	Central City
LL	1.0	7.0	18.2	19.7
MM	0.8	6.3	17.7	19.8
HL	0.8	5.9	18.1	20.7
LH	1.0	7.8	19.0	21.3
LB	1.0	7.4	19.0	19.7
HH	0.7	6.1	18.2	22.0

The same broad patterns emerge for all three pollutants. First, the presence of transit reduces levels in the central city by perhaps 10-15%, and considerably less than that elsewhere. Second, levels in the inner two rings are substantially higher than in the outer rings, in general 20 to as much as 50 times higher in the central cities compared to the rural ring. Third, while the scenarios differ from each other, the differences are never so great as to come close to changing the rankings of the rings.

With the exception of greenhouse gases, the primary reason that we care about most pollutants is the presumption that they negatively impact people's health. But these findings indicate that by far the biggest factor affecting exposure to pollution is living in the central city; different land uses or more transit have a very minor impact compared to this. The following two tables show two different measures of regional pollution, each shown for the six scenarios both with and without transit, and with hypothetical free flow conditions.

Table 4.7 shows total regional emissions. Table 4.8 shows a weighted average pollution exposure, calculated by multiplying the level in each ring by the fraction of the total population living in that ring. In each case, the level of pollution in the LL/No transit scenario is taken as a baseline and set equal to 1; then levels under the other scenarios, including all transit scenarios, are taken as a fraction of this. All three pollutants are weighted equally in this aggregate measure.

TABLE 4.7 Aggregate Normalized Total Pollution

	With Transit	No Transit	Free Flow
LL	1.000	1.048	0.860
MM	0.912	0.957	0.804
HL	0.894	0.939	0.787
LH	1.117	1.223	0.902
LB	1.079	1.124	0.893
HH	0.920	0.995	0.796

TABLE 4.8 Aggregate Normalized Pollution Exposure

	With Transit	No Transit	Free Flow
LL	1.000	1.071	0.853
MM	1.035	1.109	0.895
HL	1.186	1.242	1.001
LH	1.116	1.240	0.901
LB	1.069	1.126	0.886
HH	1.214	1.337	1.015

The interesting result here is that the high population density scenarios (HL, HH) have the lowest total pollution being generated, but the highest average pollution exposure, because so many more people live in the central part of the region where pollution levels are much higher. This calls into question the whole argument that high density development is environmentally superior because it reduces driving. While it does indeed reduce driving, and even reduces the total amount of pollution being generated, it does not reduce total pollution costs, because it brings people and pollution closer together than they are in lower density environments. This seems like a fairly serious point that should be studied more deeply.

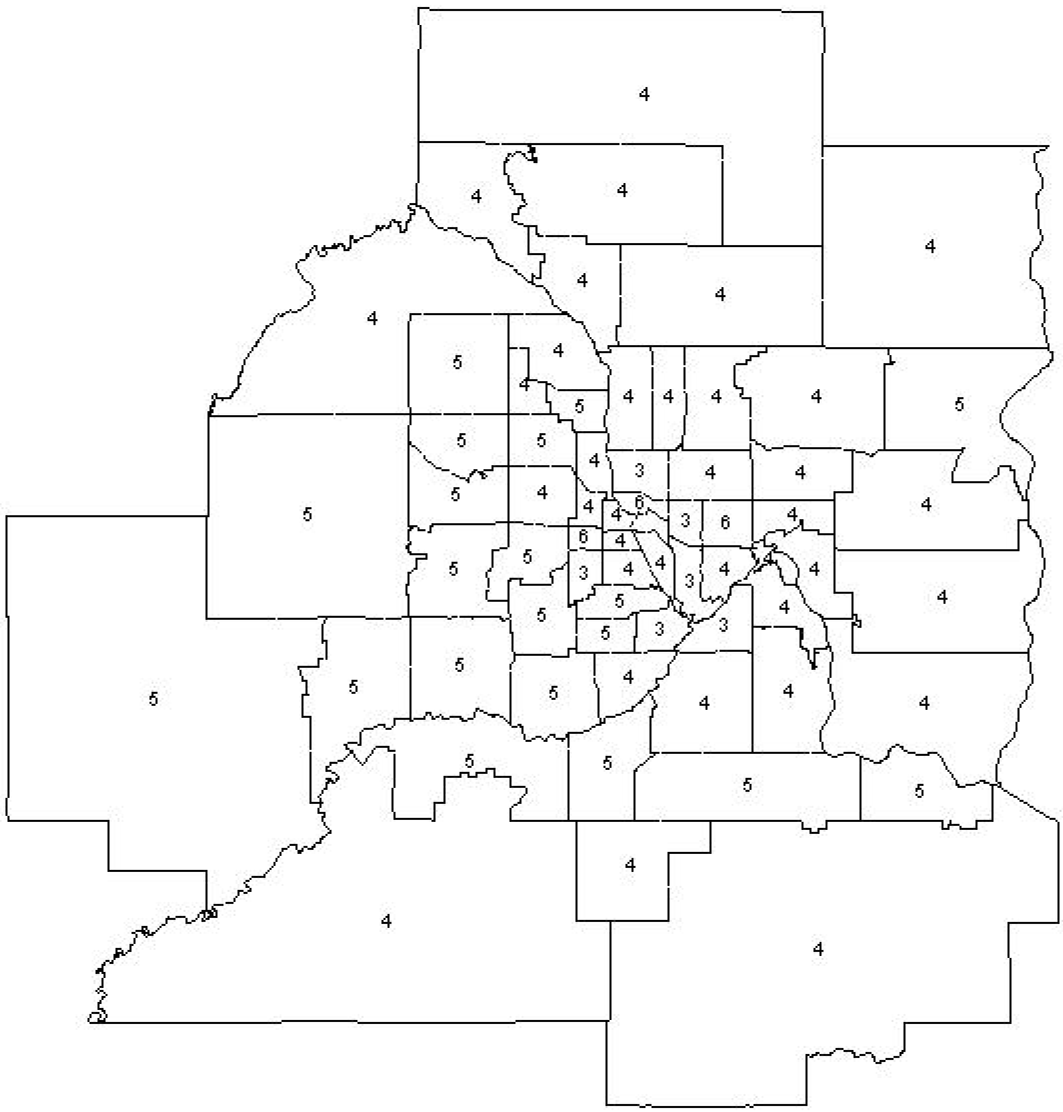
There are a couple of complications worth mentioning. First, this analysis is based on home locations. To the extent that people are not at home all day, their exposure could be greater or less than the average for their location. In this sense HL is probably a little bit better than HH because it has fewer jobs in the central city; a larger number of people are spending at least some of their day in the less polluted suburbs. Another point is that exposure to pollution is by far at its highest when people are driving; they are right there on the road where the pollution is being generated. From this perspective, the fact that the higher density scenarios involve less total driving might compensate somewhat for the higher exposure during non-driving times.

It is also worth noting that this simple analysis does not address subtleties such as cold starts and other factors that impact emissions. However, the overall patterns seem so firm that it is hard to imagine that a more sophisticated analysis would change the results much.

A final interpretive point is that the differences between best and worst pollution outcomes are relatively small in percentage terms. That is, the total regional costs due to automobile pollution might be quite large, but there is relatively little that can be done to reduce these costs in terms of land-use changes. Even the fairly substantial land uses analyzed here reduce total emissions by only 10% or so, and when person-exposure is considered, the LL “sprawl” scenario is actually the best of the outcomes. It appears from these results that the best way to achieve significant reductions in exposure to pollution is to focus policy and resources on reducing the amount of pollution that comes out of the car, rather than on reducing driving through land-use changes.

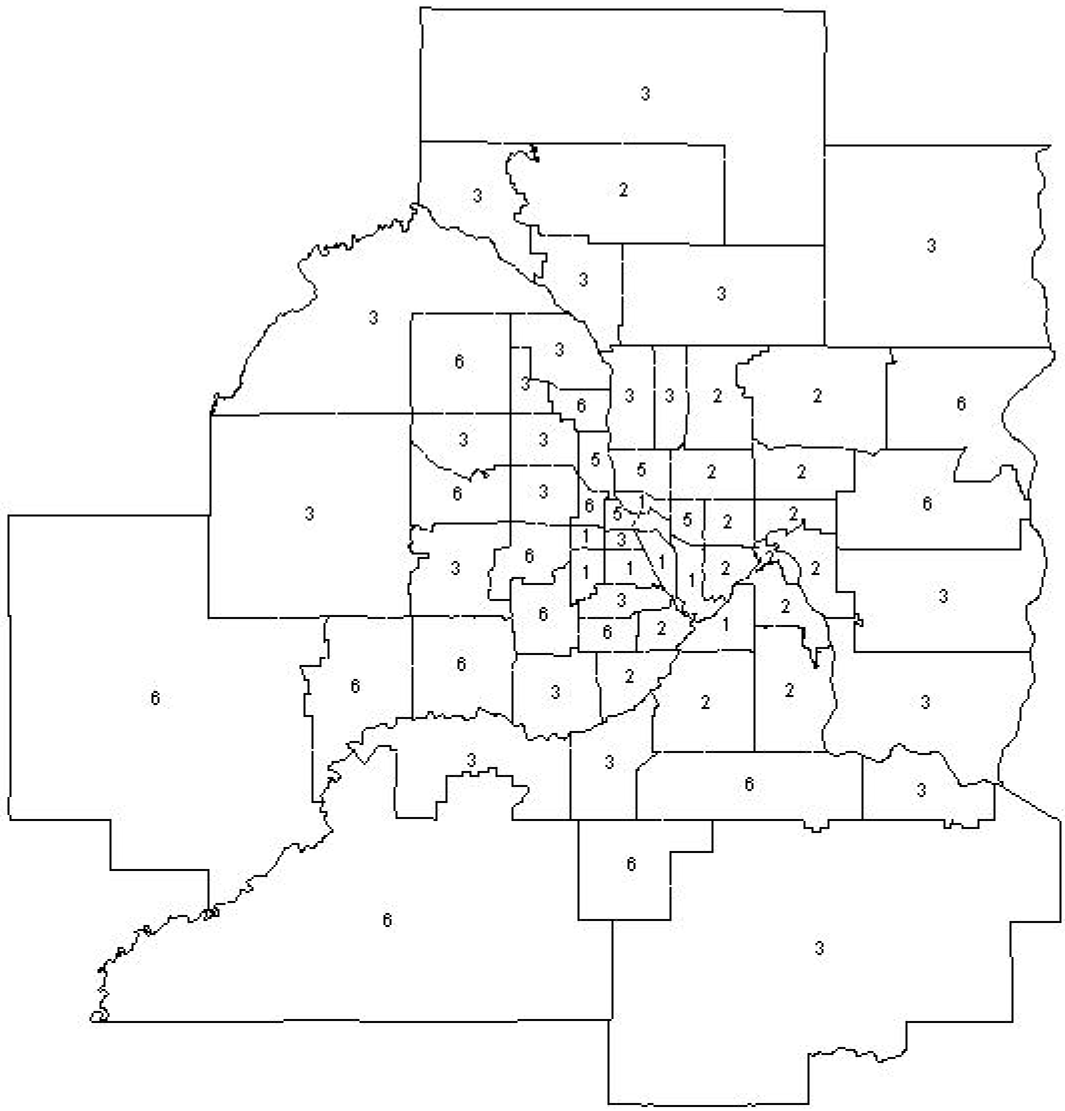
Mapping pollution at the more detailed zone level rather than by ring shows considerably greater uniformity than was observed in the congestion maps, as can be seen in the maps on the following two pages. The LH scenario generates the worst pollution over a majority of the region; interestingly, the LL “sprawl” scenario does not generate the worst pollution anywhere (and neither does the MM “smart growth” scenario). However, the HL scenario gives the worst pollution over a significant swath of the central cities.

Roughly the opposite is true in terms of which scenarios generate the best (lowest) pollution for a given zone. The LL and MM scenarios are best over much of the central part of the region, while HL and HH are best over most of the outer part. The LH scenario, as might be expected, is best nowhere.



Map 4.1 Air pollution level, worst scenario by zone

Key:
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density



Map 4.2 Air pollution level, best scenario by zone

Key:
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density

Chapter 5
Accessibility

The final impact studied here is accessibility. The idea is to measure how many jobs can be reached from a home in a given location; jobs that can be reached in a short time are weighted more heavily than jobs that take longer to reach.

I calculated accessibility by counting the total number of jobs within a one-hour drive, but weighting closer jobs more than far away ones. The weighting is 60-M, where M is the number of minutes to reach a given zone. Thus jobs 10 minutes away are multiplied by 50, jobs 30 minutes away are multiplied by 30, and so on. The objective is to capture the idea that a close job is better than a distant one. Another purpose is to avoid an arbitrary cutoff, as would happen if the definition were something simpler like "jobs within 20 minutes".

Given that the measure is a weighted average, the numbers themselves have no inherent meaning, but the ratio between numbers does correspond to ratios of access levels. For example, a level of 30 represents being able to access twice as many jobs for a given commute time, on average, compared to a level of 15.

Tables 5.1 through 5.3 show average accessibility levels for each ring, with transit, without transit, and with free flow travel conditions. The final line of the free-flow table shows current accessibility levels given jobs and travel times existing as of 2000; levels are lower in 2000 because there are fewer total jobs available.

TABLE 5.1 Accessibility by Ring, With Transit

	Rural	Developing	Developed	Central City
LL	13.1	30.4	43.7	53.0
MM	15.9	32.5	45.1	53.8
HL	20.3	36.8	43.0	46.2
LH	7.6	24.2	40.6	53.3
LB	9.8	27.4	43.0	52.9
HH	15.7	33.9	42.7	49.3

TABLE 5.2 Accessibility by Ring, No Transit

	Rural	Developing	Developed	Central City
LL	12.0	28.2	41.2	50.0
MM	14.8	30.1	42.4	50.5
HL	18.5	34.4	41.4	45.1
LH	6.1	20.4	36.5	48.9
LB	9.1	25.9	41.5	51.1
HH	13.3	29.8	38.7	44.9

TABLE 5.3 Accessibility by Ring, Free Flow and Current

	Rural	Developing	Developed	Central City
LL	28.9	45.0	51.3	58.5
MM	28.0	45.6	52.2	59.3
HL	27.5	45.9	52.4	58.2
LH	29.3	45.9	52.7	60.8
LB	28.9	45.5	52.1	59.3
HH	27.8	47.0	54.0	60.6
Year 2000	21.2	37.7	43.8	51.1

The same general themes emerge from these tables as have been seen before. As is the case currently, accessibility is better in more central locations, reflecting the greater centralization of jobs compared to housing. But as with other costs, the HL scenario appears to benefit residents of outlying areas (who suffer less congestion and hence have better job access) at the (slight) expense of central city residents.

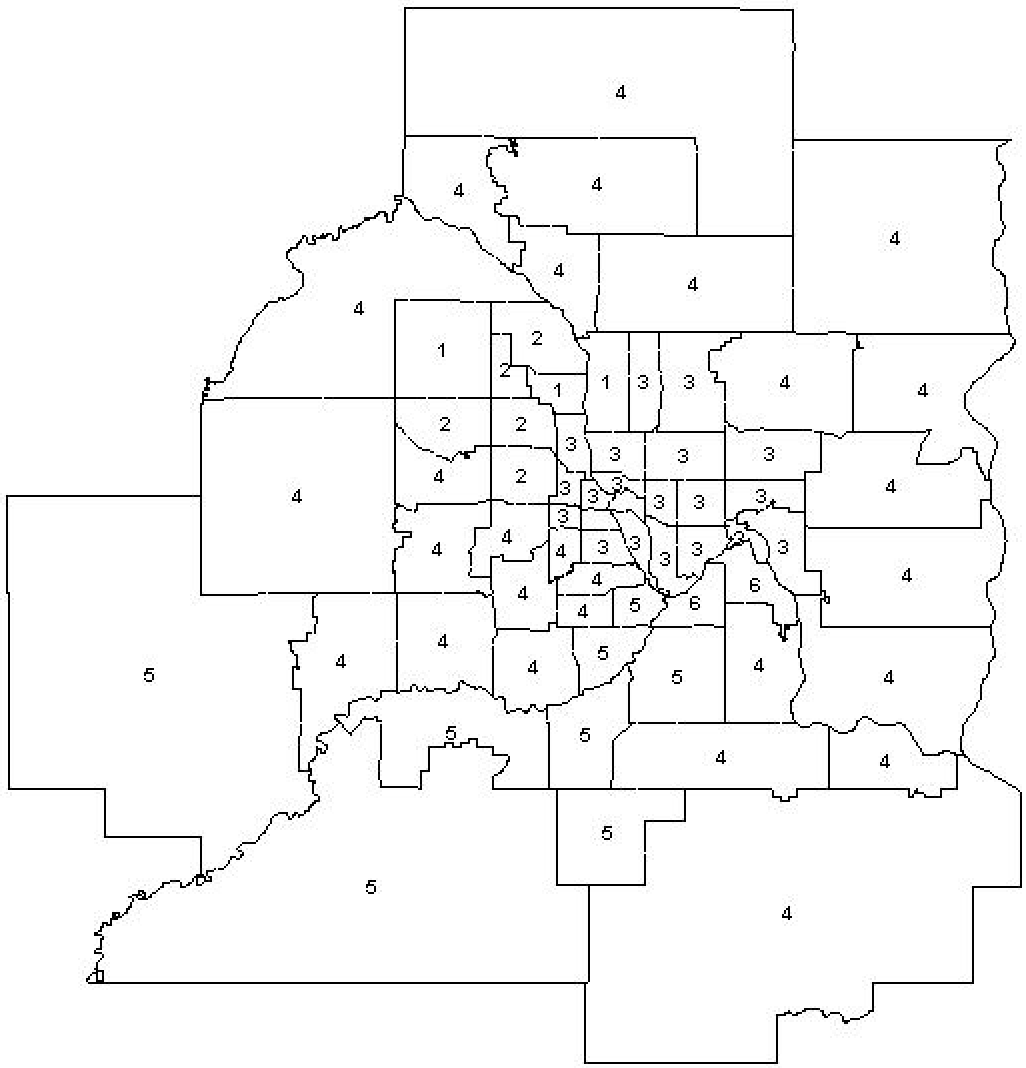
Maps on the following two pages showing accessibility by zone support the broad patterns observed in the tables. The worst accessibility for central city residents is in the HL scenario, which is correspondingly the best accessibility for most outlying areas. The worst accessibility for outlying areas occurs in the LH and LB scenarios, which are generally the best for much of the central part of the region.

All these results support the general point that there are unavoidable tradeoffs involved in changing where jobs are located – moving jobs closer to some peoples' homes will invariably make them farther away from others. This is not to say that there might not be ways to achieve overall net improvements in accessibility through careful job location, but it does not seem to be possible to improve accessibility for everyone, or even a substantial majority, simply through changing the way jobs are placed. (However, see the discussion of Table 5.4 below.)

Finally, Table 5.4 shows regional average accessibility levels. These are all calculated as a fraction of a baseline of 1, where the baseline is the regional average accessibility in the year 2000. Free flow accessibility is always higher than 1 because there are more total jobs available in 2020 compared to 2000. However, actual accessibility is always lower because of the higher congestion levels.

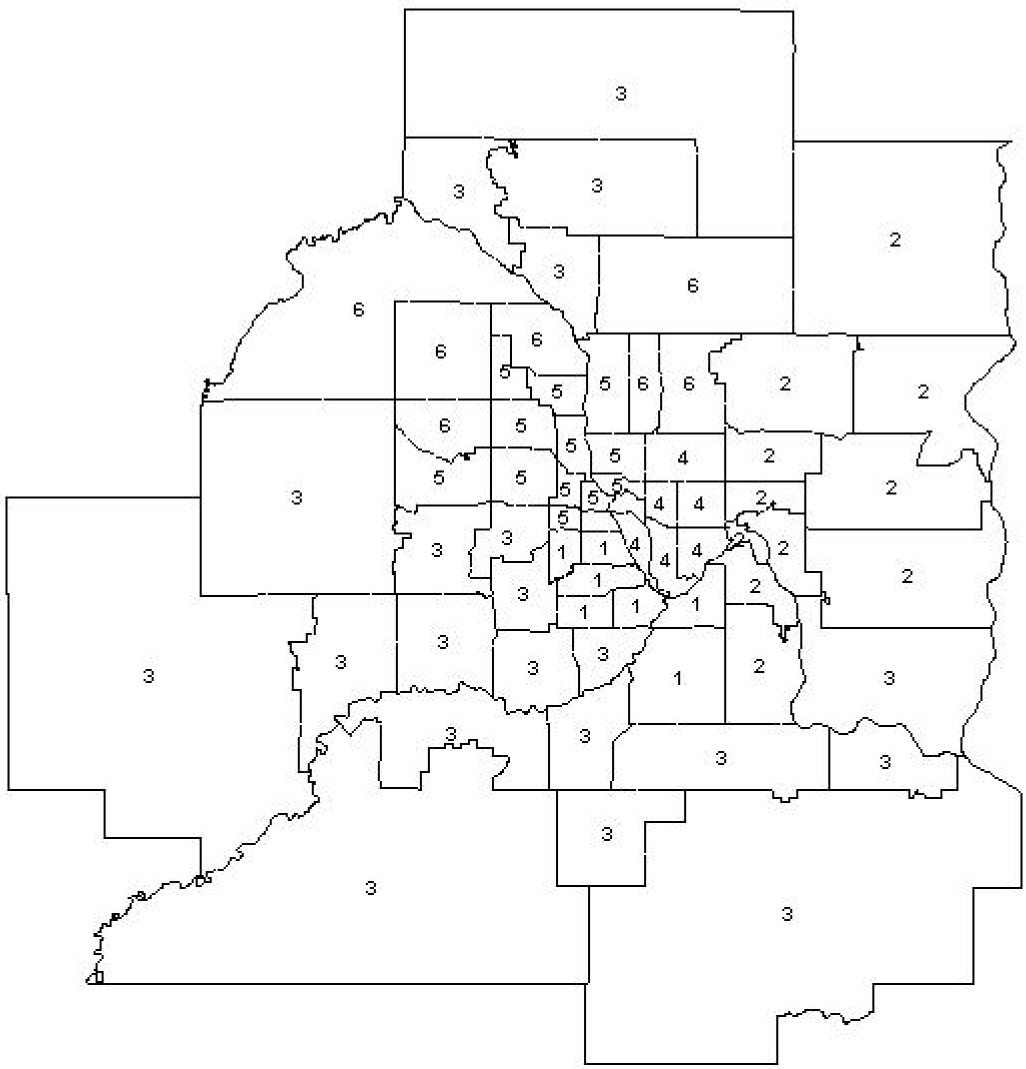
TABLE 5.4 Regional Average Accessibility, Year 2000 Baseline

	With Transit	No Transit	Free Flow
LL	0.872	0.817	1.148
MM	0.956	0.894	1.194
HL	0.975	0.932	1.218
LH	0.774	0.685	1.179
LB	0.824	0.790	1.162
HH	0.959	0.861	1.254



Map 5.1 Access to jobs, worst scenario by zone

Key:
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density



Map 5.2 Access to jobs, best scenario by zone

Key:
1: Low population density, low job density
2: Medium population density, medium job density
3: High population density, low job density
4: Low population density, high job density
5: Low population density, balanced job density
6: High population density, high job density

There are two major points of interest here. The first is that there is an overall improvement in average accessibility in the scenarios (MM, HL, HH) that place more housing in the job-rich central part of the region. In the case of the best overall scenario, HL, this arises from a combination of two things. First, accessibility is much better in the outlying areas because there is much less new housing and hence less congestion there, and there are a few additional jobs, so at least some existing residents don't have to commute as far. Second, although this is the worst scenario for many central city residents, it is not that much worse than the others. The large gains to the outlying areas outweigh the small losses to the central areas. It is also worth noting that the central areas have the best accessibility anyway, so this scenario not only leads to the highest overall average, but also reduces somewhat the differences in accessibility between the center and edge of the region.

The first is that there is only a very small difference in accessibility across scenarios, given free flow conditions. That is, even the large differences in land use that are examined here have only a very small impact on people's ability to access the regional job base; most people can still access most jobs under all of the scenarios. The presence of congestion makes a much bigger difference to accessibility than the land-use conditions per se. Congestion reduces accessibility under all the scenarios by 20-40% compared to free flow conditions, while there is a difference of only 10% between scenarios given free flow. The importance of land use seems to be not how it places jobs as a baseline, but how it impacts congestion levels and travel speeds. As with pollution, the role of land use in impacting accessibility seems to be relatively small; focusing on congestion reduction appears to have more promise.

Chapter 6
Conclusion

The general question that this research has attempted to answer is the following: are there ways of accommodating growth in an urban region that are significantly better than other methods in terms of achieving transportation goals? The results indicate that the current conventional wisdom that compact development is better is at best an oversimplification. Certain types of compact development appear to be better for certain goals, or for certain places, while being worse for other goals or other places.

The basic finding that there are tradeoffs inherent in different styles of land development, reasonable as it may seem on the surface, represents a degree of subtlety that seems to be missing from much of the debate on this issue, where the various schools of thought tend to be represented as either "good" or "bad." Part of the problem arises out of the tendency in the literature to examine only a single issue at a time: how can transit use, or walking, be increased? How can fuel consumption, or congestion be decreased? The notion of tradeoffs is hard to accommodate in this kind of single-issue analysis.

This research has attempted to shed light on these issues through three methodological innovations:

- Using a regional, rather than neighborhood scale analysis
- Examining a variety of impact areas simultaneously
- Using a stylized forecasting model to isolate the direct impacts of land use.

The work was accomplished by defining six hypothetical future Twin Cities land-use scenarios, generating traffic forecasts for each, and comparing the results in terms of congestion, air pollution, and accessibility. Specific findings relating to these three impact areas are in the relevant chapters earlier in the report. The following are the major general findings.

- The primary beneficiaries of compact housing development are residents of outlying areas that remain sparsely populated as a result. Conversely, central city residents are better off when population is allowed to spread out, because the associated problems are moved to outlying areas.
- More compact housing did lead to reduced congestion overall compared to lower density scenarios, apparently due to the resulting shorter trips and use of excess central city road capacity.
- In all the scenarios much of the congestion was concentrated on a relatively small amount of roadway.
- The level of air pollution rises dramatically toward the center of the region. As a result, the high population density scenarios, because they housed more people in the area of highest pollution, had the lowest overall amount of pollution, but the highest degree of exposure of people to pollution.

- In terms of accessibility to jobs, there was no way of placing jobs that would be best for a large fraction of the population. There are only as many jobs as workers; moving some jobs to be closer to some people inevitably makes them farther away from others. Better overall balancing of jobs and housing at a regional scale did have some aggregate benefit, but again at the expense of certain locations.
- The actual location of jobs seemed to matter less to accessibility than did the level of congestion that the placement implied. Given free-flow conditions, all the scenarios had similar accessibility levels.
- In all the scenarios, accessibility to jobs, and by implication congestion and air pollution, were worse in 2020 than in the present. That is, even the most extreme changes to current land use did not reverse present trends, but merely allowed them to progress at a somewhat reduced rate.
- Transit tended to have a fairly limited role in alleviating problems. It did have a somewhat bigger impact in the areas with the biggest problems, primarily in the central cities.

While these results in general seem fairly robust, there were a couple of methodological problems that might limit the degree to which they can be generalized. These both arise out of situations where the assumptions used to create the forecasts might have impacted some scenarios differently from others.

The most significant of these was the decision made early in the research to use the same road network for all scenarios. While at one level this does create a standard baseline for comparison, at a more subtle level it favors those scenarios that happen, by accident or design, to best exploit this assumed network. For example, the scenarios with low population density and/or high commercial density tend to have worse congestion; but it is not clear to what extent this congestion might be alleviated by a limited set of road improvements in the most severely affected areas. To say that downtown size suburban employment centers will be built, but that no improvements will be made to the surrounding road network is obviously unrealistic, and analyzing the scenario under this assumption very likely makes it appear worse than it really would be.

The other issue with the methodology is the more abstract problem that the forecasts inevitably reflect the assumptions about human behavior that are built into the model. Specifically, the gravity model that is used to match people with jobs is merely an empirical reflection of current patterns; it is not formally derived from a more basic model of how choices are made. In general, the parameters of these types of models are different from one city to the next. As a result, there is no particular reason to believe that model parameters derived from 1990 data will accurately describe behavior in 2020. This is an issue with all long-term forecasts, but it is especially an issue for those scenarios that involve significantly different land uses than the present; again, the higher density land uses might appear worse (or better) than they really would be, because they are being analyzed with behavioral assumptions derived from completely different circumstances.

Despite these difficult methodological problems, this still seems like a question worth exploring further. While it appears that land use alone cannot turn back the clock in terms of transportation-related problems, it does seem that the rate at which those problems grow can be impacted at least moderately at a regional level, and sometimes very substantially at local levels. A more careful analysis, and one that could accommodate changes to the highway network as well as to land use, could very well identify certain regional development paths for the future that would be generally better than the path we are on now.

References

1. Boarnet, Marlon G., and Randall Crane. *Travel by Design: The Influence of Urban Form on Travel*. New York, Oxford University Press, 2001.

2. Boarnet, Marlon G., and Sharon Sarmiento. Can Land Use Policy Really Affect Travel Behavior?: A Study of the Link Between Non-Work Travel and Land Use Characteristics. *Urban Studies*, Vol. 35, No. 7, 1998, pp. 1155-69.

3. Cervero, Robert, and Roger Gorham. Commuting in Transit Versus Automobile Neighborhoods. *Journal of the American Planning Association*, Vol. 61, No. 2, Spring 1995, pp. 210-225.

4. Frank, Lawrence D., and Gary Pivo. Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single-Occupant Vehicle, Transit, and Walking. In *Transportation Research Record 1466*, TRB, National Research Council, Washington, D.C., 1994, pp. 44-52.

5. Friedman, Bruce, Stephen P. Gordon, and John B. Peers. Effect of Neotraditional Neighborhood Design on Travel Characteristics. In *Transportation Research Record 1466*, TRB, National Research Council, Washington, D.C., 1994, pp. 63-70.

6. Ewing, Reid, Padma Haliyur, and G. William Page. Getting Around a Traditional City, a Suburban Planned Unit Development, and Everything in Between. In *Transportation Research Record 1466*, TRB, National Research Council, Washington, D.C., 1994, pp. 53-62.

7. Cambridge Systematics, Inc., and others, *Making the Land Use Transportation Air Quality Connection (LUTRAQ)*, 1000 Friends of Oregon, eight volumes, 1991-1997

8. Center for Energy and Environment, and others. *Two Roads Diverge: Analyzing Growth Scenarios for the Twin Cities Region*, 1999.

9. Barnes, Gary, and Gary Davis, *Land Use and Travel Choices in the Twin Cities, 1958-1990*, Center for Transportation Studies, University of Minnesota, 2001.

Additional References

Crane, Randall. Travel by Design? *Access*, No. 12, Spring 1998, pp. 2-7.

Hanson, Susan, ed., *The Geography of Urban Transportation*, New York, The Guilford Press, second edition 1995

Harvey, Greig and Elizabeth Deakin, et al., *A Manual of Regional Transportation Modeling Practice for Air Quality Analysis*, National Association of Regional Councils, July 1993, http://www.bts.gov/tmip/papers/airqual/mrtm/toc.html

Newman, Peter, and Jeffrey Kensworthy. *Sustainability and Cities: Overcoming Automobile Dependence*. Island Press, Washington, D.C., 1999.

Parsons Brinckerhoff Quade & Douglas, Inc., *The Full Social Costs of Alternative Land Use Patterns: Theory, Data, Methods and Recommendations*, for U.S. Department of Transportation, June 1998

Pas, Eric I., "The Urban Transportation Planning Process," chapter 3 of Hanson, ed., 1995

Pickrell, Don. Transportation and Land Use. Chapter 12 of Gomez-Ibanez, et al., 1999.

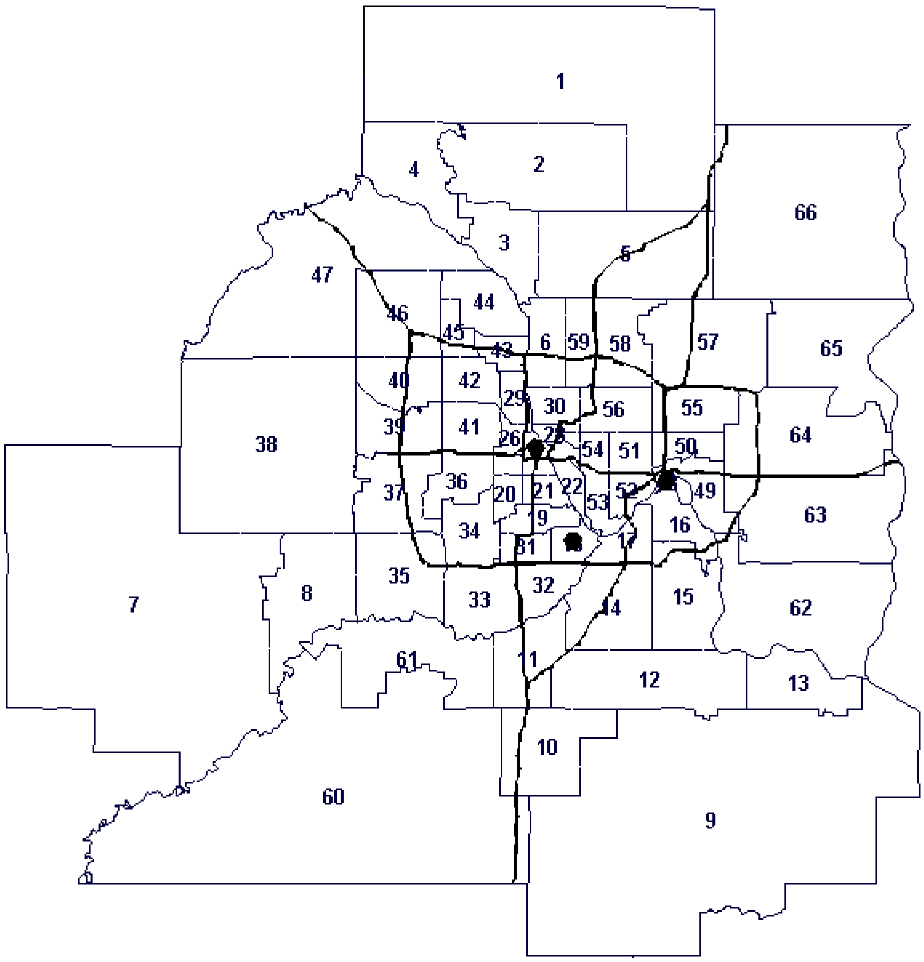
Steiner, Ruth L. Residential Density and Travel Patterns: Review of the Literature. In *Transportation Research Record 1466*, TRB, National Research Council, Washington, D.C., 1994, pp. 37-43.

Appendix A

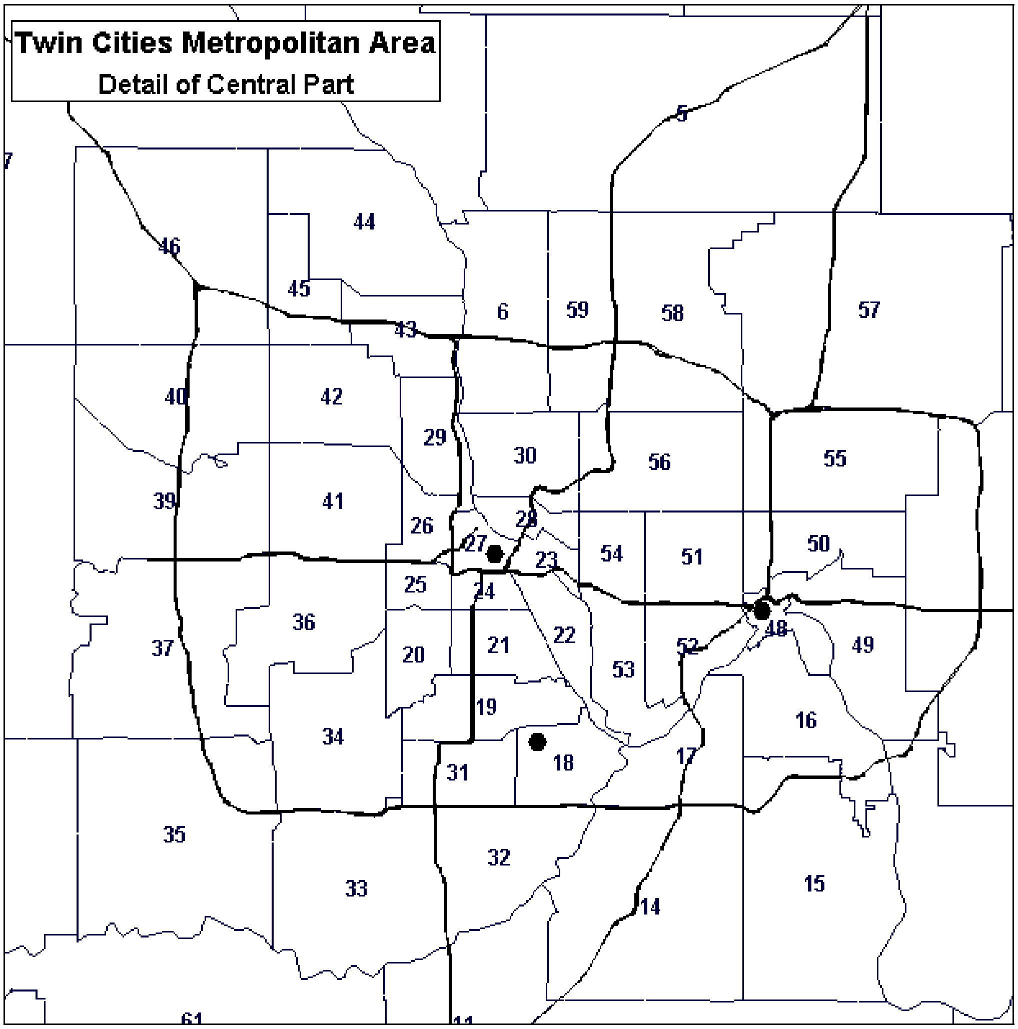
Maps and Results by Zones

Results by Zone

The 66 zones within the TCMA are defined in terms of traffic analysis zones (TAZs). The TAZs have been defined by the Metropolitan Council. Map A.1 below shows the zones for the entire seven county region. Map A.2 is the same map, but with the central part of the region expanded for greater readability.



Map A.1 The 66 Zones in the Twin Cities Metropolitan Area



Map A.2 The Zones in the Central Part of the Twin Cities Metropolitan Area

The tables on the following pages expand on the tables and maps in the text by showing the full results by zone for the various costs that were analyzed. The first two tables show some detail on how land uses are different from the year 2000 in each of the scenarios, and the resulting job to worker ratios. The next three tables show congestion overall, for freeways only, and for non-freeways, expressed as a percent delay from free-flow times. The final three tables show average commute times in minutes, pollution levels as a ratio to the baseline level of LL zone 1, and accessibility levels, measured as defined in the text.

Zone	Population % change from 2000			Job % change from 2000			
	Low	Medium	High	Low	Medium	High	Balanced
1	34.6	-6.6	0	75.2	25.3	0	70.9
2	65.6	-7.8	0	56.4	30.1	0	70.3
3	-4.7	18.5	0	38.3	29.2	0	68
4	31.8	2.1	0	34	26.4	0	71.1
5	33.2	7.6	0	29.6	15.8	0	65.6
6	0.4	5	9.4	18.8	24.2	0	3
7	36.3	28	0	40.8	41.4	0	0
8	58.7	34.3	0	31.2	35.1	0	0
9	33.9	27.4	0	142.8	85.1	0	0
10	79.3	79.1	0	96.8	74.7	0	0
11	6.8	9.7	0	31.2	23.9	0	0
12	51.5	51.8	0	38.3	28.9	0	0
13	52.4	-2.5	0	9.1	13.8	0	0
14	10.6	22.9	8.4	19	13.5	0	0
15	52.1	39.8	104.9	51.8	41.8	0	0
16	5.2	13.9	60.5	11.1	15.5	0	0
17	20.3	66.1	235.5	41.7	31.8	0	0
18	187.1	197.8	2497.3	4.9	6.9	0	0
19	0.3	8.5	0	-37.9	-39.1	0	0
20	0.7	7.9	18	-16.1	-16.7	0	0
21	1.7	13.9	2.2	-35.3	-33.1	0	0
22	-0.4	11.3	21.9	-13.1	-10.1	0	0
23	-3.3	41	45.3	-1.2	5.8	0	0
24	0.4	16.1	2.1	-20.5	-18.1	0	0
25	-2.9	5.6	23	-22.5	-22.6	0	0
26	19.4	28.2	84.4	-32	-31.7	0	0
27	-0.5	70.6	108.4	23.5	33.5	31.9	0
28	-5.4	4.4	42.4	-42.2	-38.3	0	0
29	-0.5	8.1	15.8	-15	-12.4	0	0
30	4.7	15.5	76.5	-34.7	-33.1	0	0
31	1.6	9.5	0.8	11	13.5	0	0
32	31	28.3	0	-6.3	-5.1	0	0
33	6	7.3	0	4.6	8.8	0	0
34	0.7	9.9	1.1	2.5	7.4	0	0
35	6.1	0.4	0	30.4	19	0	0
36	9.4	16.8	14.8	21.9	27.9	0	0
37	-7.9	-7.8	4.8	23.4	17.1	0	0
38	20	6.9	0	27.5	20.2	0	0
39	11.7	41.9	6.3	21.2	15.7	0	65.6
40	15.8	44.5	0	9.3	3.3	0	71.1
41	1.4	12.9	79.4	3	9	0	72.3
42	4.8	19.7	4.6	17.4	23.2	0	69.4
43	2.2	7.7	9	10.2	13	0	64.8
44	18.2	67.6	0	45	37.2	0	68.4
45	-12.7	-0.7	0	27.1	19.7	0	66.2
46	46.7	52.3	0	54.6	74.6	352.6	69.3
47	52.7	24.3	0	29.2	44.7	0	29.4
48	7.5	3.6	398.2	-7.7	0	61.7	0
49	7.2	11.5	109.4	-6	-1.2	112.5	0
50	7.4	14.1	24.8	16.9	22.6	0	0
51	2.6	10.3	17.9	-0.5	3.2	0	0
52	-3.2	3.8	29.6	-5.6	-3.3	0	0
53	2.4	9.1	8	-6.8	-4.6	0	0
54	-2.1	7.5	60	-1	6.9	0	0
55	2.9	9.4	52.6	29.3	21.9	0	11.7
56	13.2	34.6	60.9	26.9	24.5	0	64.8
57	10.5	8.1	8.4	17.7	10.9	0	69.5
58	12.5	-1.1	9.1	40.6	34.2	271.1	5.4
59	1.9	8.8	5.1	27.2	28.9	176.4	0
60	41	34.5	0	70.6	42.3	0	0
61	86.3	39.2	0	56.3	39.1	0	0
62	40.7	31.2	11.6	31.2	19.8	0	0
63	55.3	37	18.7	56.9	54.3	0	67.2
64	39.5	4.4	29.1	56.2	49.6	0	24.6
65	37.7	7.4	0	26.6	25.5	0	69.5
66	61.1	15.5	0	29.5	22.3	0	68

Table A.1 Population and job percent change from 2000

Zone	LL	MM	HL	LH	LB	HH	Year 2000
1	0.2	0.2	0.3	0.1	0.2	0.2	0.2
2	0.2	0.3	0.4	0.1	0.2	0.2	0.2
3	0.8	0.6	0.7	0.5	0.9	0.5	0.5
4	0.8	1.0	1.1	0.6	1.0	0.8	0.8
5	0.5	0.6	0.7	0.4	0.6	0.5	0.5
6	1.3	1.3	1.2	1.1	1.1	1.0	1.1
7	0.5	0.6	0.7	0.4	0.4	0.5	0.5
8	0.8	1.0	1.3	0.6	0.6	1.0	1.0
9	0.6	0.5	0.8	0.2	0.2	0.3	0.3
10	0.4	0.4	0.8	0.2	0.2	0.4	0.4
11	1.2	1.1	1.3	0.9	0.9	1.0	1.0
12	0.5	0.4	0.7	0.3	0.3	0.5	0.5
13	0.5	0.9	0.8	0.5	0.5	0.7	0.7
14	1.2	1.0	1.2	1.0	1.0	1.0	1.1
15	0.4	0.4	0.3	0.3	0.3	0.2	0.4
16	0.7	0.7	0.5	0.6	0.6	0.4	0.7
17	1.3	0.9	0.5	0.9	0.9	0.3	1.1
18	41.6	40.9	4.6	39.7	39.7	4.4	113.9
19	0.1	0.1	0.1	0.2	0.2	0.2	0.2
20	0.3	0.2	0.2	0.3	0.3	0.3	0.3
21	0.1	0.1	0.1	0.2	0.2	0.2	0.2
22	0.8	0.7	0.6	0.9	0.9	0.7	0.9
23	3.1	2.3	2.1	3.2	3.2	2.1	3.1
24	1.0	0.9	1.0	1.3	1.3	1.2	1.3
25	0.6	0.5	0.4	0.7	0.7	0.6	0.7
26	0.3	0.3	0.2	0.5	0.5	0.3	0.6
27	16.6	10.5	7.9	17.8	13.5	8.5	13.4
28	0.7	0.7	0.5	1.2	1.2	0.8	1.1
29	0.3	0.3	0.3	0.4	0.4	0.4	0.4
30	0.8	0.8	0.5	1.3	1.3	0.8	1.3
31	0.6	0.5	0.6	0.5	0.5	0.5	0.5
32	2.0	2.1	2.6	2.1	2.1	2.8	2.8
33	1.4	1.4	1.4	1.3	1.3	1.4	1.4
34	2.3	2.2	2.3	2.2	2.2	2.2	2.2
35	2.0	1.9	2.1	1.5	1.5	1.6	1.6
36	1.7	1.7	1.6	1.4	1.4	1.3	1.5
37	1.8	1.7	1.6	1.4	1.4	1.3	1.3
38	0.6	0.6	0.7	0.4	0.4	0.5	0.5
39	2.2	1.6	2.3	1.8	3.0	1.9	2.0
40	0.7	0.5	0.8	0.6	1.1	0.7	0.7
41	1.8	1.7	1.0	1.7	3.0	1.0	1.8
42	0.9	0.8	0.9	0.7	1.3	0.7	0.8
43	1.3	1.2	1.2	1.1	1.9	1.1	1.2
44	0.4	0.3	0.5	0.3	0.5	0.3	0.3
45	1.6	1.3	1.4	1.3	2.1	1.1	1.1
46	0.6	0.7	0.9	1.8	0.7	2.7	0.6
47	0.4	0.5	0.6	0.3	0.4	0.4	0.4
48	13.4	15.1	2.9	23.5	14.5	5.1	15.6
49	0.5	0.5	0.3	1.2	0.5	0.6	0.6
50	0.5	0.5	0.4	0.4	0.4	0.4	0.5
51	0.7	0.7	0.6	0.7	0.7	0.6	0.7
52	0.7	0.7	0.5	0.8	0.8	0.6	0.7
53	0.5	0.5	0.5	0.5	0.5	0.5	0.5
54	3.2	3.2	2.0	3.3	3.3	2.0	3.2
55	1.2	1.0	0.8	0.9	1.0	0.6	0.9
56	2.0	1.6	1.4	1.6	2.6	1.1	1.8
57	0.7	0.7	0.7	0.6	1.0	0.6	0.6
58	1.2	1.4	1.3	3.3	0.9	3.4	1.0
59	1.0	0.9	0.9	2.1	0.8	2.0	0.8
60	0.7	0.6	1.0	0.4	0.4	0.6	0.6
61	0.6	0.7	1.1	0.4	0.4	0.7	0.7
62	0.4	0.3	0.4	0.3	0.3	0.3	0.4
63	0.4	0.4	0.5	0.3	0.4	0.3	0.4
64	1.0	1.3	1.1	0.6	0.8	0.7	0.9
65	0.9	1.2	1.3	0.7	1.2	1.0	1.0
66	0.4	0.6	0.7	0.3	0.5	0.5	0.5

Table A.2 Job to worker ratio

Zone	Worst Scenario	Best Scenario	LL	MM	HL	LH	LB	HH
1	4	3	66.7	61.4	53.5	190.9	114.0	174.2
2	4	3	49.7	17.0	14.1	64.6	52.5	22.1
3	4	6	117.8	96.2	81.8	132.7	119.6	73.3
4	4	3	81.3	56.4	38.3	102.1	76.8	45.6
5	4	3	51.6	25.0	20.6	74.7	50.0	26.4
6	4	3	62.1	45.1	36.9	91.7	66.3	46.5
7	4	2	37.3	34.3	40.8	51.8	50.2	41.2
8	5	3	28.3	23.7	15.2	48.0	50.3	18.5
9	4	3	42.9	34.1	12.5	75.9	72.6	23.9
10	5	3	28.3	25.7	15.2	49.4	51.9	18.5
11	5	2	36.5	36.3	37.7	67.5	69.1	39.2
12	5	3	50.2	36.2	17.4	94.3	96.1	22.0
13	4	2	58.0	45.3	58.0	112.8	101.5	87.4
14	5	2	39.4	34.2	45.1	66.3	66.9	44.2
15	4	2	40.9	27.4	40.2	54.3	47.5	37.4
16	4	2	74.3	51.5	105.4	109.3	108.1	101.7
17	4	1	26.3	26.9	31.9	37.8	34.9	28.0
18	3	2	52.0	51.1	66.0	64.5	65.3	58.0
19	5	3	61.5	57.0	46.2	107.0	110.4	53.1
20	3	1	24.2	25.1	47.2	27.3	26.8	36.2
21	6	1	31.9	34.6	41.9	45.3	33.2	47.1
22	4	3	31.1	33.6	28.2	53.6	33.0	47.7
23	3	5	56.7	63.5	70.0	54.8	40.0	57.1
24	4	3	34.1	35.5	33.8	50.4	41.2	40.5
25	3	1	14.6	16.0	24.6	17.8	16.6	22.0
26	1	5	63.9	58.3	62.6	63.8	45.0	49.1
27	2	6	62.4	65.9	64.7	58.4	54.0	53.4
28	3	1	27.5	29.6	35.2	31.3	31.7	32.6
29	4	3	42.1	41.2	34.2	49.9	34.8	39.8
30	3	5	73.7	68.8	83.2	77.5	63.9	77.4
31	3	6	66.1	71.6	82.1	73.5	76.6	62.4
32	4	2	51.7	45.5	68.7	80.2	76.2	68.1
33	5	3	52.4	55.4	44.6	78.4	89.2	52.4
34	5	2	47.2	45.6	53.7	63.3	64.9	46.8
35	1	2	68.1	51.5	60.1	62.0	63.0	57.6
36	4	6	37.0	31.9	28.8	50.2	49.5	28.8
37	4	6	75.3	63.7	76.4	95.6	87.3	56.8
38	5	3	17.7	15.4	13.5	27.8	28.7	17.1
39	5	6	40.0	35.3	37.2	38.3	46.9	31.3
40	6	3	21.7	20.9	17.1	49.6	28.5	63.1
41	4	3	42.1	43.2	29.9	73.2	50.0	51.7
42	4	3	46.5	43.5	36.5	70.6	48.4	58.7
43	5	6	43.1	36.6	38.9	38.2	47.0	31.5
44	4	3	48.7	49.2	26.1	53.4	53.2	30.1
45	6	5	47.3	41.8	39.6	57.0	31.0	59.5
46	5	6	34.1	30.9	29.4	40.1	42.2	27.9
47	4	3	54.6	53.6	28.5	55.6	47.3	31.7
48	2	5	79.6	86.4	67.0	72.2	52.1	55.3
49	4	3	54.1	43.8	43.7	103.5	54.8	74.6
50	4	2	28.3	22.7	25.4	35.7	25.0	27.4
51	1	5	118.8	95.4	118.5	87.1	82.6	83.7
52	6	2	28.5	25.7	35.8	38.6	39.0	39.4
53	3	2	35.6	33.2	48.8	36.5	43.1	39.0
54	2	6	58.3	59.0	54.8	53.9	49.1	45.5
55	4	3	35.7	22.5	22.1	68.3	43.5	43.6
56	5	2	36.7	27.3	31.6	53.9	58.1	39.1
57	4	2	41.0	29.6	32.6	116.2	47.2	112.4
58	4	2	62.3	45.0	46.7	74.8	53.7	45.4
59	4	2	44.3	38.8	38.9	56.5	44.4	39.6
60	4	3	16.2	16.5	11.1	35.6	29.6	26.5
61	5	3	44.0	43.1	21.3	81.8	85.9	29.4
62	4	3	36.9	24.7	21.5	64.6	55.5	31.6
63	4	3	57.6	42.4	32.0	99.6	92.6	49.9
64	4	3	22.4	15.8	14.2	48.3	39.3	17.6
65	4	2	22.0	19.2	25.9	28.6	26.8	28.6
66	4	3	34.3	20.6	18.2	47.7	29.9	25.7

Table A.3 Overall congestion (percent delay from free flow)

Zone	Worst Scenario	Best Scenario	LL	MM	HL	LH	LB	HH
1	5	3	151.5	147.9	125.7	253.4	287.0	167.7
2	0	0	0.0	0.0	0.0	0.0	0.0	0.0
3	4	1	19.6	20.5	27.6	46.5	35.6	32.8
4	3	2	26.1	19.3	41.8	20.1	38.3	29.0
5	4	2	38.8	32.5	33.5	56.1	42.3	33.9
6	4	2	59.6	41.2	44.0	92.1	63.8	57.2
7	4	2	143.3	118.0	159.9	176.6	152.4	153.5
8	4	3	32.8	31.4	21.6	61.0	56.0	29.9
9	5	3	131.6	135.0	33.7	244.7	245.5	67.4
10	4	3	48.3	48.3	28.4	102.4	96.0	32.5
11	4	2	46.9	44.5	47.9	85.0	84.6	60.6
12	4	2	11.5	10.0	14.6	49.4	26.3	23.5
13	6	2	355.5	298.9	492.6	641.9	516.1	716.5
14	5	2	58.7	52.0	61.9	98.1	99.5	67.0
15	4	6	46.8	32.2	35.0	51.5	34.0	30.6
16	5	3	31.4	32.2	31.3	45.0	45.7	38.6
17	5	3	29.9	24.5	24.1	39.0	40.4	24.6
18	3	1	46.7	46.7	69.9	62.4	64.7	61.2
19	5	3	104.2	96.2	69.4	191.3	202.0	83.3
20	0	0	0.0	0.0	0.0	0.0	0.0	0.0
21	3	4	45.3	46.6	70.4	38.4	38.5	42.6
22	4	3	65.5	69.1	36.2	112.3	91.1	76.5
23	3	5	28.6	28.1	47.8	28.4	25.5	35.0
24	4	3	66.4	68.5	32.5	123.0	93.3	75.0
25	0	0	0.0	0.0	0.0	0.0	0.0	0.0
26	4	6	14.4	9.4	5.0	21.3	16.6	4.8
27	5	2	60.2	55.7	63.3	73.3	76.4	58.7
28	5	2	30.8	27.9	41.3	43.2	45.2	33.7
29	2	5	50.6	53.5	43.4	52.4	30.3	36.3
30	3	5	71.4	59.4	96.3	59.8	46.3	67.3
31	3	1	53.9	56.0	80.7	63.9	72.8	54.0
32	4	2	60.7	49.6	84.1	100.2	93.3	84.5
33	5	3	62.7	61.0	39.4	118.3	135.0	59.0
34	5	2	51.8	50.8	60.0	77.9	81.3	55.4
35	5	1	30.2	30.3	32.7	45.0	48.4	31.6
36	1	6	41.7	33.9	32.7	37.6	36.4	27.5
37	4	3	40.7	30.5	22.8	70.4	54.0	30.4
38	4	2	38.8	34.2	48.9	55.9	44.3	54.6
39	1	6	43.5	35.0	33.2	35.5	39.3	25.8
40	1	6	23.5	21.7	21.3	8.4	14.6	8.2
41	4	3	47.3	42.3	31.0	66.4	49.7	31.4
42	1	6	68.0	64.7	55.4	35.3	48.1	32.7
43	5	2	46.7	35.6	47.2	44.6	60.2	36.7
44	4	3	42.9	46.4	20.9	66.1	60.6	30.2
45	1	6	51.3	39.2	39.1	27.0	33.7	17.9
46	1	6	34.2	31.1	30.3	29.5	30.7	20.6
47	1	3	81.0	70.0	43.8	80.8	77.8	47.9
48	4	2	65.2	42.8	52.4	126.3	74.8	88.3
49	4	2	44.6	34.8	38.0	90.9	44.6	59.5
50	4	3	27.2	21.3	19.1	36.2	20.4	22.6
51	3	2	80.3	69.4	109.2	101.1	91.5	98.8
52	5	2	41.1	37.2	54.1	54.5	61.0	57.1
53	3	2	62.9	51.5	85.4	55.9	51.7	58.2
54	4	5	71.1	70.5	64.1	90.8	55.0	68.1
55	4	3	50.8	31.9	29.8	101.1	58.9	62.4
56	4	2	44.3	28.3	30.6	76.9	60.9	42.9
57	6	2	69.6	50.1	58.4	105.7	69.9	106.3
58	4	2	29.9	20.7	28.4	43.4	40.3	33.7
59	4	2	46.6	35.0	43.7	59.7	55.3	42.8
60	5	3	47.1	52.6	16.3	109.9	122.6	58.7
61	5	3	33.0	31.7	11.7	65.7	73.2	29.2
62	4	2	26.5	16.1	23.2	48.3	39.2	44.9
63	4	3	44.6	40.5	25.8	99.1	89.1	50.0
64	4	3	24.1	21.0	15.2	67.0	56.9	18.5
65	4	2	2.8	1.4	1.9	5.1	3.1	3.2
66	4	3	54.7	51.2	45.6	85.2	50.4	66.9

Table A.4 Freeway congestion (percent delay from free flow)

Zone	Worst Scenario	Best Scenario	LL	MM	HL	LH	LB	HH
1	6	3	33.6	17.2	16.6	165.8	39.6	177.5
2	4	3	49.7	17.0	14.1	64.6	52.5	22.1
3	4	6	134.1	112.9	95.8	147.5	134.0	83.4
4	4	3	85.2	59.3	38.0	107.7	79.7	47.1
5	4	3	53.6	23.6	17.7	77.5	51.3	24.8
6	4	3	64.0	48.0	30.9	91.4	68.2	37.2
7	5	3	12.5	13.8	6.1	22.4	26.9	7.7
8	5	3	27.4	22.1	13.8	45.1	49.1	15.8
9	4	3	30.4	17.3	9.2	48.3	44.9	16.0
10	5	3	20.6	17.3	9.7	26.8	33.5	12.1
11	5	6	33.6	34.1	34.9	62.5	64.7	32.6
12	5	3	51.8	37.2	17.6	96.3	99.1	21.9
13	4	6	40.5	26.9	18.4	75.5	74.7	17.1
14	5	2	29.1	25.0	36.0	48.8	48.9	30.9
15	4	2	38.7	25.7	41.9	55.4	52.1	39.7
16	5	2	96.8	61.7	136.9	140.1	140.2	128.9
17	4	1	25.3	27.5	34.2	37.5	33.4	28.9
18	1	6	78.0	73.2	48.7	74.7	68.6	44.5
19	4	3	37.7	35.6	33.1	60.5	58.3	36.3
20	3	1	24.2	25.1	47.2	27.3	26.8	36.2
21	6	1	29.3	32.3	36.4	46.4	32.4	47.9
22	4	5	27.0	29.4	27.4	46.8	26.0	44.6
23	2	5	77.6	88.2	85.5	74.2	51.8	72.4
24	3	1	24.2	25.2	34.1	26.0	24.8	29.4
25	3	1	14.6	16.0	24.6	17.8	16.6	22.0
26	1	5	81.1	73.7	80.3	79.6	55.9	64.1
27	2	5	63.7	71.8	65.5	49.4	39.5	50.4
28	3	1	26.9	29.9	34.3	29.2	29.5	32.4
29	4	3	36.6	33.2	28.9	48.5	37.3	41.7
30	4	5	75.1	74.6	75.2	88.3	74.2	83.3
31	2	6	80.9	89.7	83.6	85.3	81.3	72.6
32	5	1	35.1	38.4	38.5	42.5	44.6	36.4
33	5	1	45.8	51.9	48.0	51.0	58.3	48.0
34	3	6	42.4	40.1	46.9	46.7	46.3	36.8
35	1	2	101.5	70.6	85.1	77.0	75.5	81.7
36	4	3	33.1	30.2	25.5	60.5	59.9	30.1
37	4	6	99.0	86.5	113.0	113.2	110.1	75.9
38	5	3	15.6	13.4	8.7	25.3	27.3	12.6
39	5	2	37.3	35.5	40.3	40.5	52.2	35.7
40	6	3	21.2	20.7	16.1	58.1	30.9	74.6
41	4	3	38.0	43.8	29.1	78.5	50.2	67.4
42	4	3	40.7	37.8	31.3	79.9	48.4	65.7
43	1	6	40.3	37.3	32.7	33.1	36.3	27.5
44	5	3	49.4	49.5	26.8	51.9	52.4	30.0
45	6	5	42.9	44.6	40.1	91.4	27.9	100.8
46	5	3	34.0	30.8	29.0	44.9	47.4	31.5
47	2	3	44.5	46.5	21.3	46.3	36.0	24.2
48	2	5	82.5	95.4	70.1	61.2	47.2	48.6
49	4	3	60.7	49.9	47.4	111.4	61.4	83.4
50	4	2	28.7	23.2	27.2	35.6	26.6	28.8
51	1	6	137.6	108.1	122.9	80.2	78.4	76.4
52	4	2	20.8	18.5	24.5	28.9	25.9	28.2
53	5	1	27.2	27.9	37.8	30.7	40.7	33.6
54	2	4	50.7	52.3	49.6	30.6	45.7	32.3
55	4	2	26.1	16.4	17.6	46.0	33.7	31.4
56	5	2	30.9	26.7	32.2	35.2	56.0	36.5
57	4	2	33.4	23.5	25.2	118.7	41.4	114.0
58	4	6	77.2	57.3	55.8	89.1	59.9	51.4
59	4	3	42.6	41.6	35.2	54.1	36.1	37.2
60	4	3	13.3	12.9	10.6	27.0	19.5	22.3
61	5	3	45.5	44.7	22.7	84.0	87.6	29.4
62	4	3	42.0	29.5	20.5	73.4	64.0	21.8
63	4	3	60.5	42.8	33.7	99.7	93.5	49.9
64	4	2	20.8	10.8	13.3	31.1	23.9	16.8
65	6	2	24.4	21.4	29.1	32.2	29.6	32.9
66	4	3	30.6	12.8	10.9	40.8	26.3	14.8

Table A.5 Non-freeway congestion (percent delay from free flow)

Zone	Worst Scenario	Best Scenario	LL	MM	HL	LH	LB	HH
1	4	3	47.7	37.9	33.5	60.8	44.9	41.6
2	4	3	42.0	31.3	27.1	52.4	38.0	33.4
3	4	3	29.4	25.7	21.5	35.5	24.5	25.9
4	4	3	36.2	27.2	23.0	46.2	32.6	29.7
5	4	3	29.9	24.9	23.3	35.3	27.0	26.4
6	1	3	20.0	19.2	17.9	19.6	18.5	17.9
7	5	3	26.8	26.0	21.9	35.8	35.9	26.8
8	5	3	22.2	21.0	17.5	29.8	29.8	21.4
9	4	3	31.9	31.2	23.3	49.4	49.2	33.0
10	5	3	28.7	29.1	20.1	44.5	45.3	27.9
11	5	3	25.0	25.4	20.5	34.8	36.1	25.3
12	4	3	28.7	27.9	21.4	41.9	41.8	26.9
13	4	3	31.2	25.1	22.1	41.0	40.8	27.3
14	5	3	22.9	23.4	21.9	29.0	29.1	24.1
15	4	1	22.8	22.9	26.6	28.8	28.4	27.7
16	3	2	21.6	21.5	26.6	25.3	25.5	26.0
17	3	1	21.8	22.4	26.9	26.3	26.3	26.4
18	5	6	19.7	19.9	8.0	20.6	20.9	7.7
19	3	4	20.7	21.2	22.4	20.5	20.7	20.5
20	3	4	20.1	20.4	21.7	19.7	19.7	19.9
21	3	4	19.6	20.1	21.5	18.4	18.8	19.0
22	3	4	19.8	20.3	22.3	18.4	19.0	19.5
23	3	4	15.7	16.2	18.6	14.2	14.5	15.9
24	3	4	16.2	16.7	17.9	14.5	15.0	15.4
25	3	4	18.3	18.8	20.7	17.1	17.3	18.5
26	3	5	18.8	19.2	20.9	17.2	16.1	18.8
27	2	6	15.0	15.2	15.2	13.1	14.0	13.0
28	3	5	17.5	17.7	18.8	15.2	15.2	15.8
29	3	5	21.4	21.7	22.0	20.1	18.1	20.5
30	2	6	20.6	20.7	17.9	18.6	18.4	16.0
31	5	1	18.6	18.9	19.3	19.2	19.5	18.7
32	5	2	17.5	17.1	18.1	18.8	18.8	18.4
33	5	3	19.4	18.9	17.8	21.8	22.0	19.0
34	4	2	16.6	16.4	16.8	17.1	16.9	16.4
35	4	3	19.7	18.8	17.1	24.7	24.5	19.8
36	4	3	16.8	16.8	16.7	17.8	16.7	17.0
37	4	3	18.1	18.1	16.7	20.7	19.9	18.1
38	4	3	25.2	24.4	21.2	31.2	30.5	24.8
39	4	5	18.6	19.0	17.1	19.6	16.5	18.0
40	1	5	20.8	20.7	18.6	20.3	17.7	18.8
41	3	5	18.8	18.9	19.3	18.2	14.7	18.7
42	1	5	19.3	19.2	18.5	18.7	15.0	18.7
43	1	5	21.8	21.5	19.9	21.3	18.0	20.0
44	2	5	24.4	24.7	20.5	24.7	20.1	21.4
45	1	5	20.6	20.3	18.3	20.2	16.6	18.9
46	1	6	25.0	22.9	20.1	21.0	22.1	17.3
47	4	3	29.3	26.8	22.9	30.7	26.0	24.9
48	3	4	15.8	15.2	18.4	13.5	16.2	15.9
49	4	2	22.2	20.6	20.9	25.2	23.5	21.1
50	6	2	21.6	20.6	24.4	23.6	22.4	24.6
51	3	4	18.7	18.3	22.3	17.8	18.5	19.9
52	3	4	19.6	19.5	24.5	18.8	20.3	21.3
53	3	4	20.7	20.8	25.6	20.0	21.1	22.1
54	3	4	17.3	17.1	19.9	16.2	16.3	17.5
55	6	2	21.1	19.9	22.6	24.2	21.3	24.5
56	3	5	18.5	17.7	20.0	18.4	17.3	19.3
57	4	2	24.1	21.4	22.8	28.0	22.4	25.8
58	1	2	21.1	19.3	20.5	21.1	20.3	20.2
59	1	4	19.3	18.7	19.0	17.6	18.4	17.7
60	5	3	27.2	27.1	20.2	41.7	42.6	28.0
61	5	3	26.6	26.0	18.7	38.3	39.6	25.0
62	4	3	36.5	31.3	30.2	48.4	45.5	33.1
63	4	2	32.2	26.9	28.1	42.4	36.8	31.4
64	4	2	23.8	21.3	23.7	30.1	24.6	27.6
65	4	2	23.6	18.9	19.8	29.7	20.7	24.1
66	4	3	34.5	28.9	28.8	40.9	30.9	33.7

Table A.6 Commute times

Zone	Worst Scenario	Best Scenario	LL	MM	HL	LH	LB	HH
1	4	3	1.0	0.8	0.8	1.2	1.1	0.9
2	4	2	2.4	1.4	1.4	2.5	2.5	1.5
3	4	3	12.9	9.4	9.2	14.4	13.4	9.4
4	4	3	5.3	4.1	3.6	5.6	5.3	3.8
5	4	3	5.1	3.6	3.4	5.7	5.1	3.6
6	4	3	23.3	21.0	19.4	27.0	24.4	21.2
7	5	6	0.3	0.3	0.3	0.3	0.3	0.3
8	5	6	4.4	4.1	3.4	4.8	4.9	3.4
9	4	3	0.6	0.5	0.4	0.6	0.6	0.4
10	4	6	4.1	3.9	3.0	4.5	4.4	3.0
11	5	3	11.0	10.8	10.4	12.9	13.1	10.4
12	5	6	5.2	4.6	3.4	6.3	6.3	3.4
13	5	3	3.5	2.7	2.5	4.0	4.0	2.5
14	4	2	10.8	10.1	10.9	12.5	12.5	10.5
15	4	2	8.9	7.6	8.7	9.9	9.6	8.1
16	4	2	19.0	17.5	20.3	23.0	22.3	21.4
17	3	1	7.5	7.6	9.3	8.3	7.9	8.5
18	3	2	10.0	10.0	12.3	10.9	11.1	11.1
19	5	3	26.9	26.2	24.0	33.1	34.1	25.7
20	3	1	7.3	7.6	9.0	7.7	7.8	8.5
21	4	1	25.6	26.5	27.8	27.9	26.2	27.6
22	4	1	12.8	13.4	12.9	15.7	14.1	15.1
23	3	5	66.4	69.4	71.9	66.3	60.5	68.3
24	4	3	42.9	42.2	39.5	49.3	46.2	42.9
25	6	1	6.3	6.6	7.5	7.0	6.8	7.7
26	4	6	36.2	34.8	35.3	37.5	35.7	34.8
27	4	5	131.9	134.4	135.7	138.9	130.2	134.7
28	6	1	25.3	25.9	28.2	27.0	26.8	28.2
29	4	5	21.5	21.6	20.3	22.6	20.1	21.1
30	3	5	23.7	22.3	26.1	23.6	22.3	24.6
31	5	6	35.2	36.5	36.7	38.0	38.5	33.3
32	4	2	33.0	31.4	35.1	39.1	38.7	34.9
33	5	3	12.0	12.1	11.4	13.9	14.4	11.8
34	5	6	23.7	23.1	24.2	25.7	26.2	23.0
35	5	6	8.9	8.6	8.4	9.5	9.7	8.2
36	5	6	28.0	26.2	25.1	30.0	30.1	25.0
37	5	3	13.5	12.6	11.6	15.8	16.1	12.2
38	5	3	1.8	1.6	1.4	1.9	2.0	1.4
39	5	6	15.1	14.7	14.1	14.3	16.0	13.2
40	5	3	5.3	5.4	4.7	5.4	6.1	5.0
41	4	3	24.6	23.9	22.6	27.6	25.5	24.9
42	5	3	17.8	17.7	16.4	17.6	18.6	17.1
43	5	6	19.2	18.1	17.5	19.0	20.6	17.4
44	4	3	9.2	9.4	7.1	9.7	9.5	7.8
45	4	3	33.6	29.9	26.9	35.2	31.6	29.1
46	5	6	5.6	5.3	5.0	5.8	5.9	5.0
47	4	3	1.7	1.5	1.1	1.7	1.6	1.2
48	4	2	66.4	62.9	68.3	76.6	69.1	70.4
49	4	2	14.6	13.5	15.4	18.4	14.4	17.2
50	4	2	18.2	16.3	17.1	19.8	18.7	18.0
51	6	2	23.3	22.2	25.9	25.3	24.6	26.3
52	4	2	25.1	24.2	27.3	28.4	28.1	28.1
53	3	1	18.2	18.2	20.8	19.0	19.2	19.8
54	3	5	25.4	25.5	26.4	25.3	25.1	25.6
55	4	2	20.7	17.5	18.1	25.4	22.0	21.3
56	4	2	23.6	21.5	22.0	26.4	26.2	23.2
57	4	2	5.9	4.9	5.1	7.7	6.2	6.7
58	4	2	14.7	11.6	12.3	17.7	14.9	14.4
59	4	3	21.0	19.0	18.9	24.0	21.0	20.1
60	4	6	0.6	0.5	0.5	0.6	0.6	0.4
61	5	3	4.8	4.5	3.5	5.5	5.7	3.5
62	4	3	2.9	2.4	2.2	3.5	3.4	2.4
63	4	3	3.8	3.1	2.8	4.6	4.5	3.0
64	4	6	5.8	5.1	4.9	6.6	6.4	4.9
65	5	6	2.7	2.0	2.0	2.7	2.8	2.0
66	4	3	0.9	0.6	0.6	1.0	0.9	0.7

Table A.7 Pollution level as ratio of LL zone 1 baseline

Zone	Worst Scenario	Best Scenario	Year 2000	LL	MM	HL	LH	LB	HH
1	4	3	12.5	3.4	7.1	9.0	1.9	4.0	6.6
2	4	3	23.3	5.7	12.6	17.3	2.7	7.0	13.4
3	4	3	32.9	16.3	21.5	28.6	12.0	23.2	26.7
4	4	3	22.7	6.9	12.9	19.4	3.8	9.5	15.1
5	4	6	34.9	21.6	29.3	30.8	18.4	27.1	31.6
6	1	5	45.3	44.3	46.4	45.1	49.0	50.3	50.2
7	5	3	11.9	10.6	11.2	16.4	5.0	4.8	11.4
8	4	3	28.1	26.8	28.1	36.5	14.5	15.0	28.2
9	4	3	19.1	8.6	9.7	16.7	3.3	3.4	10.7
10	5	3	31.2	16.2	16.5	32.5	5.4	5.3	21.6
11	5	3	37.5	31.1	30.4	41.2	14.4	13.9	32.1
12	4	3	36.7	20.3	21.6	33.0	8.0	8.2	24.3
13	4	3	19.5	6.0	10.5	12.7	2.8	2.9	8.8
14	5	1	43.6	37.1	36.6	37.0	24.3	23.7	31.4
15	4	2	41.4	34.7	35.4	27.6	24.7	24.7	24.8
16	6	2	44.6	38.8	39.6	27.1	31.3	30.4	26.2
17	6	1	48.7	44.3	43.4	32.7	36.0	34.6	31.7
18	5	1	52.8	55.4	55.1	52.3	51.5	51.1	51.6
19	4	1	52.1	56.8	56.3	55.1	54.2	54.3	54.6
20	4	1	52.1	57.8	57.4	56.0	55.9	56.9	56.2
21	3	1	54.1	59.8	59.5	57.1	59.4	59.3	58.8
22	3	4	53.7	57.2	57.0	53.1	58.3	57.1	56.5
23	3	4	56.2	61.5	61.6	56.4	63.9	63.2	61.3
24	3	4	56.4	63.5	63.4	60.5	64.6	64.5	63.5
25	3	5	54.4	60.9	60.7	57.3	61.1	61.8	59.1
26	3	5	54.2	59.0	58.9	55.7	60.2	63.0	58.4
27	3	5	56.4	64.0	63.9	60.9	65.4	65.6	63.9
28	3	5	55.4	59.7	60.0	54.1	62.9	62.9	59.8
29	3	5	49.9	53.4	53.2	52.1	55.4	58.8	55.5
30	3	5	51.1	52.7	53.2	49.1	56.8	56.9	55.2
31	4	1	52.0	57.5	57.1	57.3	53.2	53.3	55.0
32	5	3	48.5	52.2	51.9	53.1	46.2	45.9	49.8
33	4	3	46.2	50.0	50.0	53.2	41.1	41.7	47.3
34	4	3	50.6	58.0	57.7	58.3	53.1	55.1	55.4
35	4	3	41.6	44.3	45.4	49.7	32.5	34.7	42.8
36	4	3	49.8	58.0	57.7	58.4	54.1	57.9	56.5
37	4	3	43.5	49.8	49.4	52.6	42.6	46.3	48.6
38	4	3	28.1	25.7	26.7	33.0	17.9	20.0	28.0
39	4	5	42.9	47.5	46.9	50.2	44.6	50.3	49.3
40	2	6	42.7	43.4	43.0	47.4	43.1	48.2	48.5
41	2	5	50.6	54.7	54.1	54.1	55.0	60.0	55.7
42	2	5	47.8	50.4	50.1	51.0	52.3	57.6	53.3
43	1	5	44.0	47.4	47.8	49.3	49.8	55.0	52.4
44	2	6	39.9	36.5	34.9	43.7	38.0	45.2	46.3
45	2	5	42.8	43.4	43.3	47.1	45.5	51.3	49.8
46	1	6	35.7	32.5	33.5	40.6	34.8	39.0	43.1
47	4	6	27.8	21.3	23.3	30.7	21.1	27.4	31.3
48	3	2	49.3	49.3	51.1	33.4	50.7	46.7	36.5
49	3	2	40.4	35.5	38.8	21.8	30.6	32.1	21.9
50	3	2	42.5	38.4	40.7	32.0	36.5	37.1	33.3
51	3	4	49.9	49.3	50.3	41.0	52.0	48.9	47.0
52	3	4	50.3	49.8	50.3	40.2	50.8	47.1	45.2
53	3	4	52.5	52.2	52.3	44.1	53.2	50.3	49.1
54	3	4	52.7	54.4	55.2	47.5	57.7	55.6	53.9
55	3	2	42.0	37.7	41.2	33.6	35.5	38.0	34.3
56	3	4	50.0	49.2	50.9	44.3	52.7	51.9	50.4
57	4	2	36.7	29.6	34.7	29.9	26.7	31.7	29.5
58	3	6	44.8	40.6	45.2	40.4	43.6	45.0	45.2
59	3	6	46.8	45.1	47.4	44.5	51.1	50.5	51.1
60	5	3	18.1	14.2	15.1	25.4	5.3	4.9	16.1
61	5	3	29.2	23.8	25.1	39.0	9.4	8.7	27.6
62	4	3	30.2	9.8	15.0	16.5	4.6	5.6	13.1
63	4	2	30.2	16.7	23.3	20.6	9.7	12.5	17.6
64	4	2	31.1	26.3	31.9	24.9	20.2	24.5	22.1
65	4	2	21.2	15.8	21.0	17.8	10.5	15.9	14.8
66	4	2	18.0	11.3	16.5	16.4	7.9	13.5	14.6

Table A.8 Job accessibility