Identification and Development of User Requirements to Support Robust Corridor Investment Models

Final Report—September 2004

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16. Abstract

The purpose of the project was to develop useable techniques to integrate a broader range of potential impacts of transportation investments into transportation planning and decision-making. The research project described in this report developed a multi-attribute framework that can be used to assist in organizing and synthesizing information to measure costs and benefits, both monetary and non-monetary, of highway corridor investments. A modular approach was taken to developing individual techniques to quantify the potential impacts that could be utilized within the framework. The framework is flexible enough to accommodate the incorporation of additional techniques over time. To determine the range of potential impacts to consider, the values and needs of various stakeholders in highway corridors were taken into account and incorporated into variables, or indicators, to be used in a comprehensive system for evaluating impacts, costs, and benefits. Example techniques include a consideration and demonstration of the utility of geographic information systems (GIS) to organize data for use with the hedonic land valuation method. A prediction map was generated from this process, indicating the price consumers are willing to pay for a house in relation to its location with respect to highway corridors. This information is useful in analyzing the impact of competing corridor alternatives. In order to measure other indicators, the project also assessed the utility of high-resolution satellite remote sensing (RS) image data to provide highly accurate inputs necessary for economic models and as a means of measuring success after investments have been made. A methodology was developed to identify commercial and industrial origins and destinations from impervious surfaces. This, in turn, was translated into a calculation of average travel distances that could be used to quantify accessibility impacts associated with corridor alternatives. Remote sensing and GIS were assessed because of the spatial nature of transportation investments and their potential as a measuring tool for the transportation indicators. This multi-attribute framework is consistent with the Missouri Department of Transportation's (MoDOT's) overall planning direction of including the perspectives of more individuals/groups and potential impacts in decision making. This overall planning direction is seen in the Planning Framework and the Long-Range Transportation Plan (LRTP).

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The authors wish to acknowledge the financial support of the Midwest Transportation Consortium and the Missouri Department of Transportation for the conduct of this research. We also wish to acknowledge Raytheon as the original funding source for the purchase of the remote sensing image data and the development of the land cover classification used in this project.

This research could not have been conducted without the time and effort invested by a number of individuals. Ernie Perry, from the Missouri Department of Transportation, served as the Project Technical Monitor. The members of the Advisory Panel, identified in Table 1, provided invaluable information as to the spectrum of transportation impacts. Employees of the Missouri Department of Transportation, who served as members of the Advisory Panel, provided the perspective of the state transportation agency. The members of the Focus Group, identified in Table 6, provided important insights by testing and commenting on the AHP structure and components. At the University of Missouri-Columbia, Charles Nemmers, Cynthia Wilson Orndoff, and Yeesook Shin also contributed their insights and expertise.

EXECUTIVE SUMMARY

The purpose of the project was to develop useable techniques to integrate a broader range of potential impacts of transportation investments into transportation planning and decision-making. The research project described in this report developed a multi-attribute framework that can be used to assist in organizing and synthesizing information to measure costs and benefits, both monetary and non-monetary, of highway corridor investments. A modular approach was taken to developing individual techniques to quantify the potential impacts that could be utilized within the framework. The framework is flexible enough to accommodate the incorporation of additional techniques over time. To determine the range of potential impacts to consider, the values and needs of various stakeholders in highway corridors were taken into account and incorporated into variables, or indicators, to be used in a comprehensive system for evaluating impacts, costs, and benefits. Example techniques include a consideration and demonstration of the utility of geographic information systems (GIS) to organize data for use with the hedonic land valuation method. A prediction map was generated from this process, indicating the price consumers are willing to pay for a house in relation to its location with respect to highway corridors. This information is useful in analyzing the impact of competing corridor alternatives. In order to measure other indicators, the project also assessed the utility of high-resolution satellite remote sensing (RS) image data to provide highly accurate inputs necessary for economic models and as a means of measuring success after investments have been made. A methodology was developed to identify commercial and industrial origins and destinations from impervious surfaces. This, in turn, was translated into a calculation of average travel distances that could be used to quantify accessibility impacts associated with corridor alternatives. Remote sensing and GIS were assessed because of the spatial nature of transportation investments and their potential as a measuring tool for the transportation indicators. This multi-attribute framework is consistent with the Missouri Department of Transportation's (MoDOT's) overall planning direction of including the perspectives of more individuals/groups and potential impacts in decision making. This overall planning direction is seen in the Planning Framework and the Long-Range Transportation Plan (LRTP).

Specific findings of the project are:

(1) An Advisory Panel of transportation stakeholders provided information that was processed into a list of measurable indicators of the nature of the impacts. The value of the indicators for a given transportation alternative can be used in decision making to select alternatives that provide the most overall benefits.

(2) A conceptual framework for assessing the benefits of alternative highway corridor (and other) investment strategies was developed in order to compare the benefits of transportation investments in general and between various alternative corridors. The overall framework is comprehensive and explicit. It is also ambitious—too ambitious to implement in full immediately. But it is also modular in nature. The framework outlines a long list of indicators and suggests ways in which some of them can be measured. This project includes the development and demonstration of two specific techniques to quantify indicators. The framework is immediately useful as a general guide for policy and investment strategies. As a guide for quantitative analysis of investment benefits, it is not immediately applicable in full.

However, some of the indicators can and should be estimated on a regular basis beginning immediately.

(3) IMPLAN is recommended as the tool for MoDOT to use to assess the economic impacts of transportation investments.

(4) High-resolution satellite remote sensing data can provide useful information to quantify indicators, and a methodology was developed to identify commercial and industrial origins and destinations. This, in turn, was translated into average travel distances that could be used to quantify accessibility impacts associated with corridor alternatives. Many other applications, particularly in the environmental area, are anticipated.

(5) The combination of economics, statistics, and GIS led to a consideration and demonstration of the utility of GIS to organize data for use with the hedonic statistical method. A dynamic prediction map was generated from this process, indicating the price consumers are willing to pay for a house in relation to its location with respect to highway corridors. The results generated from this procedure have numerous applications: (a) it can assess the contribution to potential economic growth and development of infrastructure investments; (b) it can be used to determine optimum levels of public service provision within rural or urban communities; (c) it helps to evaluate people’s perception of value with respect to various housing characteristics, such as conditions and qualities of the house, size of land parcel, number of bedrooms, distance to nearest highways, or distance to nearest streams and public parks; and (d) it provides transportation decision-makers and stakeholders with quantitative and visualized analysis tools to allocate limited economic resources properly.

1.0 INTRODUCTION

Many government agencies, including DOTs, are asked to justify their expenditures in terms of net benefits to residents and taxpayers. Considerable effort has been expended by researchers to address aspects of this requirement, and various partial solutions have been suggested. For some time, the Missouri Department of Transportation (MoDOT) had considered adopting one of the generally available economic impact models (REMI (Regional Economic Models, Inc.), RIMSII (U.S. Department of Commerce, Bureau of Economic Analysis, 1997), or IMPLAN (Minnesota IMPLAN Group, Inc.)) to support transportation planning, but they determined that these models did not generate the kind of information that was needed. Discussions between the University of Missouri researchers and MoDOT focused on the development of a research project that would lead to a strategy for basing corridor investment decisions on a more robust and inclusive evaluation procedure.

In 2001, the authors of the report wrote a preliminary proposal and submitted it to the Midwest Transportation Consortium for funding. Originally, it was proposed that various economic impact models would be screened and a preferred system would be chosen for use in corridor investment analysis. However, during preliminary discussions between University and Department representatives, it became clear that what was needed, before a preferred evaluation system could be adopted, was a thorough enumeration of the many categories of benefits and costs that flow from transportation development. Furthermore, it was important that these categories of benefits and costs be organized into a comprehensive framework that would include, in an appropriate way, each of these categories. The objectives of the study were thus expanded and the project undertaken.

The ultimate direction of the project better suits MoDOT's real objective, which is to quantify the multiple impacts (monetary and non-monetary) of transportation investments in order to better inform its decision-making process, and thus make the best use of transportation resources (i.e., provide the most benefits to, or increase the well-being of, individuals and communities). In order to do this, the project employed three strategies: (1) to utilize an advisory panel of highway corridor stakeholders in order to develop a set of indicators of values and needs with respect to transportation infrastructure, (2) to explore the use of remote sensing and GIS to measure those indicators, and (3) to build and "test-drive" a framework for decision making that includes the necessary range of attributes to satisfy selected indicators.

2.0 OBJECTIVES

To implement the strategies above, five objectives were established for the project. These objectives were the following:

1. Determine what information must be made available from economic models and other information sources to support decision making with respect to highway corridor investments.

2. Create a conceptual framework for organizing and synthesizing information to measure costs and benefits (monetary and non-monetary) of highway corridor investments.
3. Evaluate the two or three most readily available modeling approaches.
4. Assess the utility of high-resolution remote sensing (RS) data sources to provide widespread, highly accurate inputs necessary for the economic models and as a means of measuring success after investments have been made.
5. Assess the utility of a geographic information system to organize model inputs and represent model outputs because of the geographic nature of transportation investments.

Recent literature has suggested that highway investment decisions facing transportation departments must address more complex questions within a climate of greater public accountability and fewer dollars. The research project described in this report developed a multi-attribute framework that can be used to assist in organizing and synthesizing information to measure costs and benefits, both monetary and non-monetary, of highway corridor investments. To accomplish this, the values and needs of the various stakeholders in highway corridors were taken into account and incorporated into variables, or indicators, to be used in a comprehensive system for evaluating impacts, costs, and benefits. In order to measure these indicators, the project also assessed the utility of high-resolution satellite remote sensing (RS) image data to provide highly accurate inputs necessary for economic models and as a means of measuring success after investments have been made. In addition, the utility of a geographic information system (GIS) to organize model inputs and represent model outputs was assessed and demonstrated. Remote sensing and GIS are being assessed because of the spatial nature of transportation investments and their potential as a measuring tool for the transportation indicators.

3.0 PRESENT CONDITIONS

3.1 Missouri Department of Transportation

As indicated in Section 1.0, the current situation is that MoDOT makes decisions about the allocation of transportation resources in accordance with various plans and procedures to fulfill the needs of the people of Missouri to provide a safe and effective transportation system. At the same time, MoDOT desires to improve the current process. One way to improve the process would be through the use of a framework that identifies and organizes all of the areas in which benefits and costs accrue from transportation investments. In addition, the framework would need to provide a roadmap for quantifying these benefits and costs. This framework could improve decision-making because the current process may not be taking into account all of the benefits and costs that accrue from transportation investments.

Newer technologies, including commercial satellite RS and GIS, were also considered for inclusion in this decision-making/evaluation framework. High-resolution remote sensing image data from commercial satellites have only been available since 2000 and thus are not currently incorporated into MoDOT planning or decision-making.

GIS is currently incorporated in the agency's Transportation Management System to organize various pieces of information specifically related to individual roadways and in the Department's environmental work for National Environmental Policy Act (NEPA) clearance. GIS is not being used for analyses to describe or organize information about the communities being served in a planning context or in a manner that would relate to the identification and quantification of benefits and costs.

3.2 Other Midwest States

Conference calls were held between project participants (Tom Johnson, Charlie Nemmers, and Kate Trauth) and transportation personnel from other states in the Midwest Transportation Consortium, as well as from Illinois and from the Federal Highway Administration in Illinois, in order to understand and document the corridor issues in nearby states. These conference calls were held on February 9, 2004 and April 27, 2004. In general, other midwest state DOTs contacted are in a similar situation, and thus this work can inform not only MoDOT decision making, but that in other states as well. The conference calls and the issues raised are documented in Appendix A. Appendix B contains the information that was distributed to participants prior to the conference calls.

4.0 TECHNICAL APPROACH

Step 1: Form an interdisciplinary team to conduct the research

An interdisciplinary research team was formed from faculty and students in the Community Policy Analysis Center (in the Social Science Unit of the College of Agriculture, Food and Natural Resources) and the Department of Civil and Environmental Engineering. Weekly team meetings were held to plan, execute plans, and evaluate results, as well as to brainstorm together on how best to go about research objectives.

Step 2: Literature review

The literature on highway corridor investment analysis was reviewed to find out what had previously been accomplished in creating a comprehensive framework. The results of this literature review are incorporated into the Results and Discussion section.

Step 3: Stakeholder Advisory Panel meetings

A stakeholder group was identified and invited to be involved in the project, and the members are shown in Table 1. The stakeholders were queried to determine their desires and objectives and how they assess the extent to which their needs are being met by particular transportation investments. MoDOT representatives were included in the stakeholder process so that their constraints, responsibilities, and knowledge could be considered as well.

The advisory panel members were selected based upon representation of various users of highway corridors. In selecting individuals to serve on the advisory panel, a broad representation of users and stakeholders of highway corridors was desired, as well as a broad geographic representation within the state. The transportation user groups represented were agriculture, real estate and development, tourism, economic development, freight transport, neighborhoods, pedestrian and bicycle networks, environment, emergency transportation, and road construction. Also included on the advisory panel are several regional planning commissions and MoDOT personnel. Some knowledge and experience with transportation issues were also taken into account. The broad range of stakeholder interests was intended to provide input that included not only the concerns of those who primarily view the economic benefits of highway corridors, but also those who primarily view environmental and social impacts of highway corridors. Experience with group dynamics suggested that at least eight individuals were needed for the panel, with a maximum of twelve, in order to facilitate productive discussions. After reviewing the list of potential candidates with MoDOT's contract monitor Ernie Perry, the research team invited twelve individuals representing various stakeholders and geographic areas, as shown in Table 1, to serve on the advisory panel.

The role of the stakeholder advisory panel was primarily to provide input from users and stakeholders of highways corridors in the development of a highway corridor investment model. This input was used to develop a framework and to make adjustments to the framework based upon feedback received. The advisory panel also provided a sounding board when presented with a variety of tools developed to provide measurable impacts of highway corridor investments.

Table 1. Membership in the advisory panel

Name	Represented Area	Organization/Agency
Don Copenhaver	Agriculture	MFA, Inc., President
John Peterson	Economic Development	City of Rolla – Office of Community Development
Rob Jackson	Emergency Access and Safety	UM Hospitals, Paramedic
Chris Hamilton	Environment	USDA Natural Resources Conservation Service, Wildlife Biologist
Dwane Quick	Freight	Hubbell Power Systems, Inc.
Donovan Mouton	Neighborhoods	Mayor's Office of Neighborhood Advocate, Neighborhood Advocate
Chip Cooper	Pedestrian and Bicycling Networks	Missouri Innovation Center, Director; PedNet Board President
Jim Alabach	Real Estate and Development	The Kroenke Group, Director of Leasing and Development
Robert Hain	Tourism	Missouri Division of Tourism, Deputy Director
Larry Moore	Road Construction	The Harold Johnson Co., CEO
Garry Taylor	Regional Planning Organization	Mid-Missouri Regional Planning Council, Director
Mell Henderson	Regional Planning Organization	Mid-America Regional Council, Director of Transportation
Ernie Perry	Research, Development and Technology	MoDOT Member
Mike Shea	Research, Development and Technology	MoDOT Member
Kent Van Landuyt	Transportation Planning	MoDOT Member
Scott Taylor	Transportation Planning	MoDOT Member
Jason Knipp	Transportation Planning	MoDOT Member
Lynn Stacy	Transportation Planning	MoDOT Member
Kim Horton	Transportation Planning – GIS	MoDOT Member
Paula Gough	Transportation Planning – District	MoDOT Member
Charlie Nemmers	Ex-Officio Advisory Panel Member	Transportation Infrastructure Center, Director, UMC
Kate Trauth	Researcher – Principle Investigator	Civil and Environmental Engineering, UMC
Cynthia Wilson Orndoff	Researcher – Consultant	Civil and Environmental Engineering, UMC
Scott Adams	Researcher	Civil and Environmental Engineering, UMC – Student
Hao Wang	Researcher	Civil and Environmental Engineering, UMC – Student
Tom Johnson	Co-principle Investigator	Community Policy Analysis Center, Director, UMC
Vickie Rightmyre	Researcher	Community Policy Analysis Center
Guohua Li	Researcher	Community Policy Analysis Center – Student
Ira Altman	Researcher	Community Policy Analysis Center – Student

Step 4: Develop a conceptual framework for assessing transportation investments

The stakeholder advisory panel was asked to discuss all costs and benefits that they attribute to transportation and transportation corridors. Many potential benefits (and costs) of transportation corridors were identified and discussed. The research team interpreted these contributions, and grouped them into 41 ways in which transportation contributes to the economy and quality of life of residents. Indicators of these 41 contributions were organized into the general categories of accessibility, economic development, environmental impacts, social/psychological impacts, safety, and cash flow. The team also identified methods of measuring each of the indicators and described the units in which these measurements can be expressed. Finally, data sources and means of predicting the changes in these variables under alternative scenarios were identified.

This was the basis for the assessment framework that will be described in the Results and Discussion section. The key to using this assessment is being able to weight the relative importance of each goal. The literature review identified alternative ways of working with a multi-attribute problem of this nature. Of the various methods described, a methodology called the Analytical Hierarchy Procedure (AHP) was chosen for this project. AHP is a procedure used to calculate relative weights on the basis of pair-wise comparisons among goals. These relative weights are then used to prioritize factors as they relate to the issue. AHP was tested in the project using a focus group approach.

The large number and wide variety of indicators and variables identified in the comprehensive assessment framework creates a need for a variety of predictive tools to generate data on the consequences of alternative strategies. The literature review conducted by the research team considered alternative methods for predicting the impacts of alternative investment strategies on each of the indicators (economic development, accessibility, etc.). Among the tools identified were economic impact tools (discussed in the next step), remote sensing, geographic information systems, and hedonic land value estimation. For those indicators for which other tools are either unavailable or prohibitively expensive, the method of benefits transfer is suggested (discussed in Section 5.6). Several of these tools were then employed to demonstrate the utility of plugging information into this framework. Each of these tools is introduced in this section and discussed more thoroughly in the Results and Discussion section.

Step 5: Assess transportation investment assessment models

In this step, the research team conducted a literature review to determine what economic impact tools were available for transportation investment assessment. Three main economic impact tools were identified and evaluated from the perspective of a state Department of Transportation. The criteria used included cost of purchase and operation, ease of use, flexibility, accuracy, and information generated.

Step 6: Assess the utility of remote sensing for transportation investment assessment

One of the objectives of the research was to develop and demonstrate an application of the use of remote sensing image data to support improving corridor investment decision-making. To achieve this objective, the research team created an interdisciplinary sub-team to explore the use of remote sensing data in solving some of the information needs identified in the comprehensive assessment framework. The problem of identifying origins and destinations and calculating travel distances between the origins and destinations was chosen as a test of this information resource. Travel distance and the related parameter of travel time are factors that impact accessibility assessments.

Step 7: Assess the utility of GIS for transportation investment assessment

As with remote sensing, GIS was to be tested for its efficacy in informing transportation investment decision-making. Again, a sub-team was charged with exploring the use of GIS in solving some of the information needs in the comprehensive assessment framework. The problem of determining the spatial impacts of transportation on land values was chosen as a test of GIS.

Step 8: Test the conceptual framework

The conceptual framework was used as the basis of an analytic hierarchy procedure (AHP) exercise administered to a focus group of transportation users. Expert Choice © software was used to organize and analyze the preferences of the focus group participants for a limited set of transportation benefit indicators. Expert Choice calculated the consistency of responses from the focus group and calculated weights for each indicator. AHP and Expert Choice are discussed extensively in Section 5.7.

Step 9: Make recommendations

The research team brought together the results from each of the previous 8 steps and developed a set of recommendations for MoDOT and the Departments of Transportation in the other Midwest Transportation Consortium states.

5.0 RESULTS AND DISCUSSION

5.1 Cross-Disciplinary Research Team

This project demonstrates the advantages of working with a cross-disciplinary team, combining the talents of faculty, staff, and graduate students from two departments at the University of Missouri–Columbia. Disciplines represented by the team members included civil and environmental engineering, transportation economics, and community economic development.

The benefits of such a diverse team are evident when problems in one field are solved using methods brought from the other field. The introduction of GIS and remote sensing information to assist in solving the economic / well-being aspects of transportation planning, as well as simply including those aspects into the transportation design field, is of great benefit.

5.2 Advisory Panel of Highway Corridor Users and Stakeholders

The involvement of highway corridor stakeholders in identifying variables for developing a multi-attribute framework provided invaluable information.

Three advisory panel meetings were held. The first advisory panel meeting was held on March 4, 2002 and included members of the research and planning division of MoDOT. After introductions and a description of the research project, a MoDOT staff member provided the context for investment planning and decision-making within which the Department operated. These included current initiatives, procedures, and constraints to the planning process.

A facilitated brainstorming session in the afternoon led to over one hundred ideas on considerations for highway corridor investments, which included impacts on those using highways, as well as impacts on neighborhoods and the environment. Panel members were asked to write their ideas on paper first. A facilitator then asked each member to read from his or her list of ideas, until all ideas were recorded on a flip chart. The brainstorming session was also tape recorded for accuracy of verbal statements made.

After the advisory panel meeting, the next task involved sorting the statements on uses and impacts of highway corridors into categories. These categories were: accessibility, economic development, environment, social/psychological, safety, and cash flow. A matrix of the statements, organized by category, can be found in Table 2. The statements were also assessed and categorized based on whether indicators could be developed, what unit of measurement might be used, and how accessible data were that could be used in the development and measurement of indicators. This process resulted in forty-one indicators of transportation impacts, each allocated to one of the six categories that are displayed in Table 3. Types of impacts that could not be measured were included in a category labeled, “Things to consider when planning highway corridors” and are shown in Table 4.

Table 2. List of advisory panel comments by category

Accessibility		
	What was said	**What was meant**
1.	Intermodal availability—accessibility to other major transportation modes and connections (airport, train, waterway)	Choice of various transportation modes
2.	Access to available transportation services (roads, sidewalks, bicycle paths, bus, or passenger rail lines)	
3.	Proximity of access points to community's town center	Travel time related to distances between origins and destinations
4.	Access to markets/jobs	
5.	Will new infrastructure create a problem for access (bypass of a small community)	
6.	Convenience to the retail consumer	
7.	Timeliness of construction (delays, lack of access)	
8.	Traffic flow/congestion reduction	
9.	Road system capacity expansion	
10.	Reliability	High probability that the highway is open and un-congested when needed
11.	Ease of access for new development	Can the corridor accommodate and enhance future development?
12.	National and international functions	
	12.a Connectivity	How well transportation connects between states as well as other countries
	12.b Defense	Can military move quickly?
	12.c Exporting	Can goods be exported?

Economic Development		
	What was said	**What was meant**
13.	Is the community's existing tax base able to take advantage of the new transportation development? Benefits to tax base	Impacts of transportation development on tax base
14.	Quality of Air and Water	Impact on property values
15.	Help Employment, Create Jobs	Changes in job choices—variety of jobs: how does transportation have an impact on types of jobs created to match community's planning goals?
16.	Benefit Growth	Population growth, employment growth
17.	Local level economic development planning	Impacts of transportation system on the effectiveness of local economic development efforts
18.	Move goods and services	Transportation – time and costs
19.	Quality Construction	Durability, life span of road surface
20.	Personal Finances (discretionary income for car)	Personal travel costs
21.	Amenities	Access to cultural and recreational facilities
22.	Property Values	Impact of transportation on property values. Private property values taken for transportation infrastructure
23.	Business Market Reach (change in business sales and market size)	Business travel costs

Environment		
	What was said	**What was meant**
24.	Impacts to terrestrial and aquatic resources – local and watershed scale	How does the corridor effect the viability of plants and animals in the corridor and downstream?
25.	Traffic Noise	Noise generated by vehicles
26.	Quality of Air and Water	See indicators
27.	Solid waste: abandoned spoil tips and rubble from road works, waste oil	Waste generated
Safety		
	What was said	**What was meant**
28.	Access to emergency vehicles	Travel Time from emergency vehicle origin to destination
29.	Health and safety of community	
30.	Individual safety	
31.	Accidents and costs to society	
32.	Less stressful driving environments	
33.	Improved conditions for cyclists and pedestrians	Ease of access within short distances from residential areas. Distance and locations of designated bicycle paths, sidewalks, and crosswalks.

Social/Psychological		
	What was said	**What was meant**
34.	Structural Barriers—freedom of access to and from jobs, schools, residences within the community—breakdown in community	Accessibility
35.	Psychological Barriers—ease and convenience, peace of mind, mobility of youth, alienation	Accessibility; Relocation of households; Restriction of movement
36.	Visual Quality	Visually appealing
37.	Traffic Noise	Impact of traffic noise nuisance
38.	Quality of Life	Enjoyment, security, and safety of the road
39.	Intrinsic/Scenic Value	Visually appealing
40.	Crime Movement	Those involved in criminal action are able to move in and out of the area easily
41.	Aesthetics	Visually appealing
42.	Pleasant footprint – Transportation can be a positive to environment if looked at with a broader perspective	Positive impacts, Scenic value
43.	Compatible with other functions, such as parks	Quality of Life
44.	Vitality of a community (sprawl)	Social networks. Informal community interactions
Cash Flow		
	What was said	**What was meant**
45.	The ability to service the mode for weather conditions, i.e., snow	Cost of Maintenance
46.	Rehabilitation, Resurfacing	Materials costs, human value

Table 3. List of indicators of transportation impacts

Accessibility				
	Indicators	**Unit**	**Necessary Data Source**	**Proposed Methods**
1.	Weighted average travel time from origin to destination (O/D) pairs	Person Hours	-Matrix of O/D pairs -Traffic analysis zones -Time of trip between O/D pair -Average Speed limit -Number of trips from/to O/D pairs per day -Number of people per trip	GIS Travel Demand Model Gravity Model
2.	Number of vehicles that the most restrictive portion of the corridor can accommodate per hour	Vehicle Hours	-Traffic count – number of vehicles -Speed limit	MoDOT for traffic Count
3.	Expected vehicle hours that will be delayed during the construction period.	Vehicle Hours	-Traffic count -Construction speed limit -Actual stops per hour -Nature of construction	Need a traffic generator model

Economic Development				
	Indicators	**Unit**	**Necessary Data Source**	**Proposed Methods**
4.	Reductions in freight cost	Dollars per year	Average freight rate times tonnage from origin/destination	Collect freight rates from MoDOT and estimated mileage and volume from trucking companies
5.	Change in total tax revenues at state level or for regions within corridor	Dollars per year	-Appropriate tax rate -Changed value of property -Changed value of retail sales -Changed household income -City/County census data	Hedonic Model GIS
6.	Change in wage rate - regional level	Dollars per year	Wage levels for various skills/profession	Economic development model
7.	Change in unemployment rate - statewide	Change in Percentage	Unemployment rate from state Dept. of Labor	Economic development model
8.	Change in under-employment rate	Change in Percentage	People who are overqualified for jobs due to their skill level	Projection method to be estimated
9.	Gross regional product - State level	Dollars per year	-Total product purchased by households, investment in government, export minus import -State Govt.	Regression between transportation investment and GSP
10.	Changes in personal travel cost	Dollars per year	-Cost per mile (gas, depreciation of vehicle, insurance) -Annual vehicle miles	Cost estimated method

Social/Psychological				
	Indicators	**Unit**	**Necessary Data Source**	**Proposed Methods**
11.	Rating of alternative transportation options, particularly for those without vehicles	Rating scale	Survey – rating availability and quality of alternative transportation options	Contingent Valuation
12.	Changes in social interaction	Frequency of social interactions	Survey Results	Contingent Valuation
13.	Changes in activity outside home as car commuting time decreases	Frequency of activities	-Survey Results -Number of activities done by using a car per month or year per family	Contingent Valuation
14.	Visual preferences of scenic value and willingness to pay	Ranking Dollar value	Visual Preference Survey	Contingent Valuation
15.	Alternative roadside amenities and willingness to pay	Dollar value	Amenities Preference Survey	Contingent Valuation
16.	Changes in activity types outside home as highway accessibility improves		-Survey results -List of activities done with improved highway accessibility	Contingent Valuation

Environment				
	Indicators	**Unit**	**Necessary Data Source**	**Proposed Methods**
17.	Change in land cover -with road construction only -with expected development	Acres	Multi-spectral remote sensing imagery for current conditions. Use zoning, etc., to estimate future land cover particularly impervious surface	Land cover classification
18.	Change in storm hydrograph: peak discharge (for a given rainfall) -with road construction only -with expected development	Cubic feet per second at critical locations	1. Land cover classification from remote sensing or conventional 2. Soils map available from MSDIS 3. Topographic map from remote sensing or USGS map	Hydrologic modeling (e.g., HEC-HMS)
19.	Change in storm hydrograph: total volume of runoff (for a given rainfall) -with road construction only -with expected development	Acre-feet	1. Land cover classification from remote sensing or conventional 2. Soils map available from MSDIS 3. Topographic map from remote sensing or USGS map	Hydrologic modeling (e.g., HEC-HMS)
20.	Wetlands in the vicinity of corridor project	Acres and locations	National Wetlands Inventory for scoping, and/or Corps of Engineers Wetlands Delineation Manual information requirements	Corps of Engineers Wetlands Delineation Manual
21.	Wetlands destroyed (drained and/or paved) -with various alternatives	Acres	Map of existing wetlands Map of proposed project	

22.	Wetlands impacted (change in supply of water)	Acres	1. Digital elevation model (watershed and channel) 2. Soil survey 3. Land cover classification (watershed and channel)	Hydrologic modeling (e.g., HEC-HMS) Calculations to determine depth of flow and area of inundation
23.	Potential new wetlands	Acres	1. Digital elevation model (watershed and channel) 2. Soil survey 3. Land cover classification (watershed and channel)	Hydrologic modeling (e.g., HEC-HMS) Calculations to determine depth of flow and area of inundation
24.	Contaminant transport to streams - current - with road construction only - with expected development	Mega-grams per hectare of contaminant	Above modeling information with field survey	Pollutant loading model such as AGNPS
25.	Change in noise levels at location of interest - current (peak, sustained)	Decibels	Current: recorded noise levels Expected: estimated traffic volumes and average vehicle noise	Scoping calculations
26.	Change in air pollutants generated at a location or over a stretch of roadway - current (peak, mean usage)	Parts per million of contaminants	Current: air quality samples or traffic volumes, travel times, and average emissions Expected: estimated traffic volumes, travel times, and average emissions	Scoping calculations or air quality modeling
27.	Solid waste generated (construction)	Tons or cubic yards (total and/or per mile)	Waste generation per mile for various road types	Scoping Calculations

28	Solid waste generated (maintenance; could be greater or lesser due to considering other roads)	Tons or cubic yards (total and/or per mile)	Waste generation per mile for various road types	Scoping Calculations
29.	Hazardous waste generated (construction)	Weight or volume of specific contaminants	Waste generation per mile for various road types	Scoping Calculations
30.	Hazardous waste generated (maintenance; could be greater or lesser due to considering other roads)	Weight or volume of specific contaminants	Waste generation per mile for various road types	Scoping Calculations
		Safety		
	Indicators	**Unit**	**Necessary Data Source**	**Proposed Methods**
31.	Increase in bicycle accessibility with alternative designs	Longest continuous distance, Number of destinations accessible	Scoping Calculations	GIS
32.	Increase/decrease in vehicle usage of selected roadways	Number and type of vehicles	Traffic model for impact of road improvements	GIS
33.	Increase in pedestrian accessibility in and or through the specific locations with alternative designs	Distance and or time to travel through intersections /roadways	Scoping Calculations	GIS
34.	Travel time from locations of interest to hospitals and fire stations	People minutes	- Street distances weighted by density. - Appropriate emergency speed on specific types of roads.	GIS organization of road information

Cash Flow				
	Indicators	**Unit**	**Necessary Data Source**	**Proposed Methods**
35.	Expected vehicle reduction due to alternative mode of transportation	Vehicle miles	- Number of miles that were used by alternative mode of transportation. - Number of vehicles reduced from highway	MoDOT or O/D pairs Model to estimate vehicle reduction
36.	Initial investment value on highway project	Dollars	MoDOT	Stats from MoDOT
37.	Maintenance cost and frequency of repair	Dollars per year	-Cost of raw material - Cost of labor - Repair frequency	Stats from MoDOT
38.	Disposal costs of waste materials: - construction and maintenance - hazardous and non-hazardous	Dollars per mile Dollars per year	Cost of disposal Quantity generated by environment	Scoping calculations
39.	Present worth of improvements	Dollars	- Distribution of construction costs (labor, equipment, and materials) over the life of the project. - Interest rate to use for analysis	Engineering economics
40.	Change in maintenance costs - increase on new roadway - decrease on improved roadway - decrease on less used roadway	Dollars per year	Personnel hours Materials Equipment	GIS
41.	Average road life	Dollars per year	MoDOT	Depreciation Model

Table 4. Other consideration when planning highway corridors

- Think of transportation more broadly
- What is the existing condition of the investments made—not just highways
- Transportation investments—diverse stakeholders—different levels of governments, working together can be improved
- Flexibility in design standards to accommodate these factors—content sensitive design
- Transportation increases possibilities—impact on quality of life factors
- What is the intended purpose from communities' point of view? Differences between individual and community
- Protect growth we have
- Sustainability
- Connectivity
- Is it a local fix or does it have statewide significance?
- Other funding sources for multi-modal application
- "Quality of life" differs in each community
- Include cultural paradigms
- Ask the right questions in community forums
- Future needs of area
- Rural perspective: roads mean wealth to a community economic opportunity/jobs
- Current state of community—preservation, conservation and stabilization
- Not cause problems in the future
- Compatible with other public functions
- Excessive use of cars
- Complexity of network
- How does transportation serve regional/statewide areas?
- Public involvement in transportation
- Share information
- Environmental justice?
- Stewardship
- Impact of planning on individuals
- Competitive environments—urban, suburban, and rural. Economics and transportation mode opportunities.
- What is the purpose and expectation from the community of transportation infrastructure?
- Is it complimentary to a particular community's values and lifestyle?
- Engineer driven activities (beware?)
- Preservation of existing system—take care of what we own
- How do we measure things like cohesion? Have to ask people.
- Distribution of benefits—who gets these benefits?
- Consequences—endogenous
- Values—importance, satisfaction, and monetary
- How do we identify what is the community?

During the second advisory panel meeting, held on August 23, 2002, statements that the panel members had made at the first meeting were reviewed. The research team explained how panel members' statements were interpreted from the perspective of what was a measurable indicator. Panel members were asked to correct any misinterpretations that may have been made and to add any additional indicators that were missed at the first meeting.

Also, at the second advisory meeting, several tools being developed using GIS and remote sensing were presented. Their uses in measuring impacts of highway corridors on land values, for example, were demonstrated using data available for Boone County, Missouri. Overall, input received was favorable. One panel member commented that he hadn't realized that MoDOT was considering the broad range of impacts that highway corridors have in their planning strategies and was pleasantly surprised to learn this.

The third, and final, advisory panel meeting was held on April 7, 2003, for the primary purpose of reviewing what had been accomplished during the research project and to solicit feedback from panel members. An issue that the research team had struggled with was brought up by several of the panel members, and that is the proper place of safety in the decision-making process and whether it can be measured accurately. A staff member of MoDOT stated that safety would be the first priority in planning highway corridors and that perhaps it should always be a consideration, but not as an indicator weighed against other highway impacts.

Another key point made at the final advisory panel meeting was the importance of consistency in the definitions used. Again, using safety as an example, safety can be interpreted in a very broad sense, including impact of highway corridors on water quality. In any process or tool used for public input, establishing consistency in the understanding of definitions is necessary.

5.3 Economic Impact Models

MoDOT has considered using one of the commercially available economic impact models in its transportation evaluations. The three primary ready-made economic impact systems available are 1) the Regional Input-output Modeling System version 2 (RIMS II), 2) the Impact Model for Planning system (IMPLAN), and 3) Regional Economic Models, Inc (REMI).

The authors of this report are familiar with each of these models, as well as with others (not appropriate for Missouri applications, or no longer available). Each of these models is used widely, especially by researchers and consultants. The models vary significantly in cost, ease of use, and flexibility. Each model contains data specific to a state or region, but is not specific to particular applications or issues. Each may be purchased and used by the buyer for whatever purpose they wish. All models must be updated occasionally. All three economic impact models are based on a methodology known as input-output analysis, which generates detailed estimates of sector and place specific economic multipliers. Economic multipliers are ratios of direct changes in a sectors output, income or employment, to the resulting economy-wide output, income or employment. Multipliers reflect the economic interrelationships among sectors.

RIMS II is built and sold by the Bureau of Economic Analysis (BEA) (U.S. Department of Commerce). The BEA is responsible for collecting U.S. intersectoral data and is the basis of the IMPLAN and REMI systems, as well as RIMS II. RIMS II is inexpensive, at $275 per region, including state level models. The major disadvantage with RIMS II is that only multipliers are sold. It is impossible to adjust the underlying assumptions of the model or to introduce unusual scenarios. The BEA provides no information as to who uses RIMS II.

IMPLAN is built and sold by a private sector firm. However, the origins of the model go back more than 25 years to a Congressional mandate to the U.S. Forest Service to calculate the economic impacts of its land use decisions. Unlike RIMS II, IMPLAN is highly flexible and constructed to allow the user to change assumptions and introduce complicated scenarios. IMPLAN costs $1,875 (for data, software, and site license) for the state of Missouri, and each of its counties. The user can create as many regional models as desired by aggregating counties. Thus, if the user wishes to create 7 or more regions, or change the regional breakdown of the state over time, IMPLAN is less expensive than RIMS II.

In Missouri, IMPLAN is being used by the Departments of Economic Development and Health and Human Services. In addition, there are IMPLAN users at the University of Missouri – Columbia, University of Missouri – St. Louis, St. Louis University, and Webster University. IMPLAN is also used by state Departments of Transportation in Maryland, Virginia, and Wisconsin.

REMI is a highly sophisticated general equilibrium economic impact model. The model builders will customize models to suit the needs of the client. REMI incorporates most standard applications into the model construction, making it easy for less experienced users to apply it to standard scenarios. However, once the model is built, it isn't easy to adapt it for unusual scenarios. REMI is very expensive, costing tens of thousands of dollars for even simple models.

The Missouri Financial Development Board, the Department of Economic Development, and the State Auditor's Office use REMI. According to REMI, three state Departments of Transportation use REMI: Iowa, Louisiana, and Wisconsin.

Based on a comparison of the three systems' strengths and limitations, and information gathered during interviews with transportation planners in neighboring states, the authors of this report believe that IMPLAN is the best tool given the framework developed herein. It will require a significant degree of expertise to use, but it will be much more flexible and consistent with the proposed framework.

5.4 GIS-Based Land Valuation (Hedonic Analysis)

GIS provides the spatial framework for the highway corridor analysis strategy. However, GIS does not generate data. GIS organizes data and information and has to be used along with appropriate models for decision-making support.

Input-Output (IO) models, such as REMI, RIMS II, and IMPLAN, generate projections of economic impact over a certain period. IMPLAN generates projections of sectoral output (or gross output excluding intra-industry transactions), income, and employment, and REMI and RIMS II generate overall projections of output, income, and employment. These impact models have no spatial or decision-support characteristics themselves. As previously mentioned, identifying the components (types of data) in a complete decision-support system is essential. It is also necessary to identify ways of generating and measuring these data, in addition to determining the location of these impacts.

Several important questions need to be answered in any transportation development project. These questions center on the impacts of transportation infrastructure on income, employment, property values, and the environment, and on where the impacts will occur. The relevance of GIS is that it is useful for organizing the inputs into the economic models and then "locating" the economic projections from the models in order to display the information for decision-making. This is important, because the “non-spatial” models do not accept spatial information.

A hedonic value model is a statistical method used to estimate the implicit price paid by buyers for various characteristics of a differentiated private good, such as housing. It is an appropriate tool to estimate the magnitude of impacts from highway corridor infrastructure development. It is also a useful model to demonstrate the capability of GIS to visualize analytical results. Measuring the relationship between a road network and the real property price will help stakeholders, users, and decision-makers to understand how highway expenditures contribute to potential regional economic growth and to an optimum level of public services.

Because it became clear in the development of this research project that the established economic impact models generated some, but not all, of the information that is needed for decision-making, an economic impact model will constitute just one of several information plug-ins in the final decision-support system. GIS, however, will generate spatial estimates of the inputs needed by the models used (i.e., changes in demand for sectoral output). In the case of construction and maintenance costs, for example, this is simple—how much will be spent on construction and maintenance of the road system by road section. Other information needed is how property values will change by location. Where will businesses locate? Where will people live and work? Hedonic analysis provides a solution, and GIS becomes important in developing a hedonic value model that is useful for transportation planning.

Several issues discerned from the advisory panel depended on estimates of origin-destination patterns. This need led to the development of a method which predicted origin-destination pairs using remote sensing data. In general, high-resolution remote sensing can distinguish locations of impervious surface, for both commercial/industrial and residential areas, indicating, after analysis, the probable locations of travel starts and stops (origins and destinations). Origins and destinations are important in assessing travel distances and, ultimately, travel time. Travel time is a parameter of importance for several indicators, including access to markets/jobs, bypass issues for small communities, and delays and limited access due to construction. By combining the capabilities of GIS, remote sensing, hedonic modeling, economic impact modeling, environmental modeling, etc., this project will lead to the development of a dynamic, spatial, and sectoral transportation framework for decision-making.

A GIS representation of information can be used to provide input to and represent output from a “transportation investment” model, based on a statistical regression equation. The method, hedonic value modeling, demonstrates how “valuable” the transportation and related variables are to the public expressed through local real estate markets. To accomplish this estimation of the value of transportation, land value was regressed against a group of explanatory variables, including several characteristics of the nearby transportation system. The regression coefficients are estimates of the marginal effects (positive or negative) that each explanatory variable has on actual property values. It has been demonstrated that the marginal effect of each explanatory variable is the value of that characteristic to the buyer of the property. This provides us with a quantitative way of aggregating the economic contribution (the benefits) of highway investments to the local economy.

The process involved geocoding, or “mapping”, a list of properties that have recently been sold and determining the distance of each property to the nearest transportation corridor (specifically, each of four different types of highways) and to streams. The list of properties, along with relevant attributes, both spatial (distance to major transportation corridors, distance to streams, etc.) and non-spatial (year of sale, age, size, number of bedrooms/bathrooms, etc.), was then processed, via regression, through the SAS statistical software package. The resulting coefficients were then used to create a “map” equation to determine the spatial effects of major transportation corridors on the real estate market (and thus reveal the marketplace’s reaction to highway investments).

5.4.1 Organization of Model Inputs

The first part of the demonstration was designed to use GIS to organize model inputs. A database was created consisting of “geocoded” points that represent individual properties with their actual sale values. A search was made for inexpensive, digital data. Although the researchers have accessed the exact type of data necessary from Boone County, it was not in a digital format (and would have been time consuming to work with). The State Tax Commission (STC), however, provided data on housing sales, obtained from forms that are submitted voluntarily by the purchasers of houses (it is estimated that there is a fifty percent return rate for this form). The data is available for free and was used as available, accepting the limitation of errors in self-reported data. The data was in the form of a dBase format table and was “cleaned” in the Microsoft Excel spreadsheet program to clear away useless data prior to use (i.e., addresses with no street names or no street numbers, etc.).

This list of addresses was “geocoded” into a point file using ArcInfo’s (Environmental Systems Research Institute) “address-matching” feature and a roads vector file with address-ranges as an attribute. This roads file (obtained from the Missouri Spatial Data Information Service (MSDIS) at the University of Missouri—Columbia) was an updated TIGER/Line file (Census road vectors), specifically tailored for address matching. This process added a location attribute to each house record, and the result was a set of points that could be shown on a map (Figure 1). Out of 4875 addresses in the original STC database for the study area, 2985 were matched successfully and used in the analysis.

The original housing database included many non-spatial attributes, such as the size and condition of each house. The new point database also needed spatial attributes that included the distance from each point to the nearest of each type of highway. To accomplish this, four vector coverages of highways were required, one for each major type of highway: state interstate highways, state US highways, state Missouri highways, and state Missouri lettered routes. These were downloaded from the MSDIS website. Each of these coverages contained the entire

Missouri road network (for a specific type of highway) on the state level. A county boundary file (also obtained from MSDIS) was used to clip the highway coverages from the state level to the county level for ease of use. The ArcInfo “near” command was then used to compute the distance (“as the crow flies”) from each point in the coverage to the nearest arc in each of the four highway coverages. This same process was used to determine distance to hydrography (streams), which was also obtained from MSDIS. Hydrography was added due to its spatial nature and the assumption that some of the variation in price of a house could be due to nearness of streams. The point coverage’s attribute table, including the new distances, was then exported as a dbf file and again cleaned within Microsoft Excel. This cleaning process included removing addresses that either lacked or had erroneous attribute data.

5.4.2 Property Values Regression Analysis

The second part of the demonstration was to use SAS to regress property values against spatial and non-spatial explanatory variables to estimate the coefficients in order to create a descriptive equation. A reduced form equation was used to estimate the increase in consumer and producer benefits due to transportation investment:

> Real Property Value = f (sales year, house style, living quarters size, house condition, number of bedrooms, number of bathrooms, age, lot size, distance to interstate highways, distance to US highways, distance to state highways, distance to state lettered routes, and distance to hydrography).

The researchers recognized the need to consider time series in the database, which consisted of the 2985 observations covering the years 1991 to 2000, by deflating the sales price via the Consumer Price Index (base=2000). The explicit time-variable method was used to incorporate time dummy variables in the data. This took into account the changing value of property as the economy grows and fluctuates each year. Not surprisingly, the regression showed a significantly increasing pattern of property price over the past ten years.

Census block group characteristics, such as population density, family income, and percentage of single-family units, were included in a preliminary regression to determine whether population diversification would have any influence on the property price. The results showed that none of these characteristics are significant in the study area of Boone County, MO, nor do they contribute to the variance in property values. However, if there were an increase in the size of the study area to the state level, for example, these attributes might have significant impacts.

Of particular interest for this project were five of the explanatory variables, specifically the spatial variables—distance of property to interstate highways, to US highways, to state highways, to state lettered routes, and to hydrography (streams). The linear, quadratic, and interaction terms of these variables were added to the equation, consistent with a speculation that the change in property values is not a perfect linear relationship with the distance to the road network. Multi-collinearity thus becomes a concern in the model, mainly because of the quadratic and interaction terms. Collinearity diagnostics, such as variance inflation factors, condition indices, and variance proportions, did not indicate the presence of near linear dependencies among the different explanatory variables except the quadratic and interaction terms. Theoretically, the multi-collinearity problem will generate unbiased estimates, but with large variances. However, the large sample size significantly reduces the risk of multi-collinearity by providing smaller sample variances. At the same time, the Durbin-Watson test was performed to make sure that there was no positive auto-correlation problem in the dataset. Because spatial variables were present, spatial-autocorrelation is another issue that needs to be examined in the future.

The regression equation explained a significant amount of the variance in property values. The adjusted R-square was .7957 (which means the model explained almost 80 percent of the variation in property values). Because the goal is to predict the relative effects of alternative highway investments, instead of predicting property values precisely, this method seems adequate. Most of the independent variables (40 of the 72), including spatial and non-spatial attributes, are statistically significant at a 0.10 level, which means that there is at least a 90 percent confidence that these attributes have the estimated relationship with property price. Table 5 shows the coefficients and significance levels for the transportation and hydrographic variables. Appendix C contains the full list of variables and their descriptive statistics.

The analysis confirms that there exists a close nonlinear relationship between property price and the nearby transportation system. Each of the four variables—distance to interstate highways, distance to US highways, distance to state highways, and distance to state lettered routes—had a spatially sensitive pattern of impact on property values. Benefits are largest within a close proximity to the road network, but get smaller and even negative when moving too far away. However, properties that are far away from one type of road are often close to another road, leading to a complex array of impacts.

Property is valued highest when at an optimum distance from a road or highway. The market values land lower when it is either too far from or too near to a component of the transportation system. People clearly prefer the benefits of accessibility but prefer not to deal with the noise, danger, odors and other drawbacks of living very near a road or highway.

5.4.3 Demonstration of Dynamic Prediction Map

The third and final part of the GIS/hedonics demonstration was to use the resulting coefficients as weights in a spatial equation in order to create a prediction "map" (Figure 2). Each spatial variable was turned into a raster grid (its value was calculated for a grid of points on the county map) and ArcView's (Environmental Systems Research Institute) map calculator was used to "add" these spatial layers via the equation. The non-spatial attributes (structural aspects of each house) were averaged and entered into the equation as a constant (the intercept). The spatial components, as mentioned, include squared terms and interaction terms to account for the non-linear nature of the data. The resulting map, therefore, shows the spatial impact of highways and streams on the value of an average house at that location. The blue, purple, and red areas of the figure represent the locations where highways and streams add more value to a house than in the green, yellow, and orange areas. This figure, however, does not represent the actual value of houses, as the structural aspect of each house within neighborhoods also contributes to the value of a house.

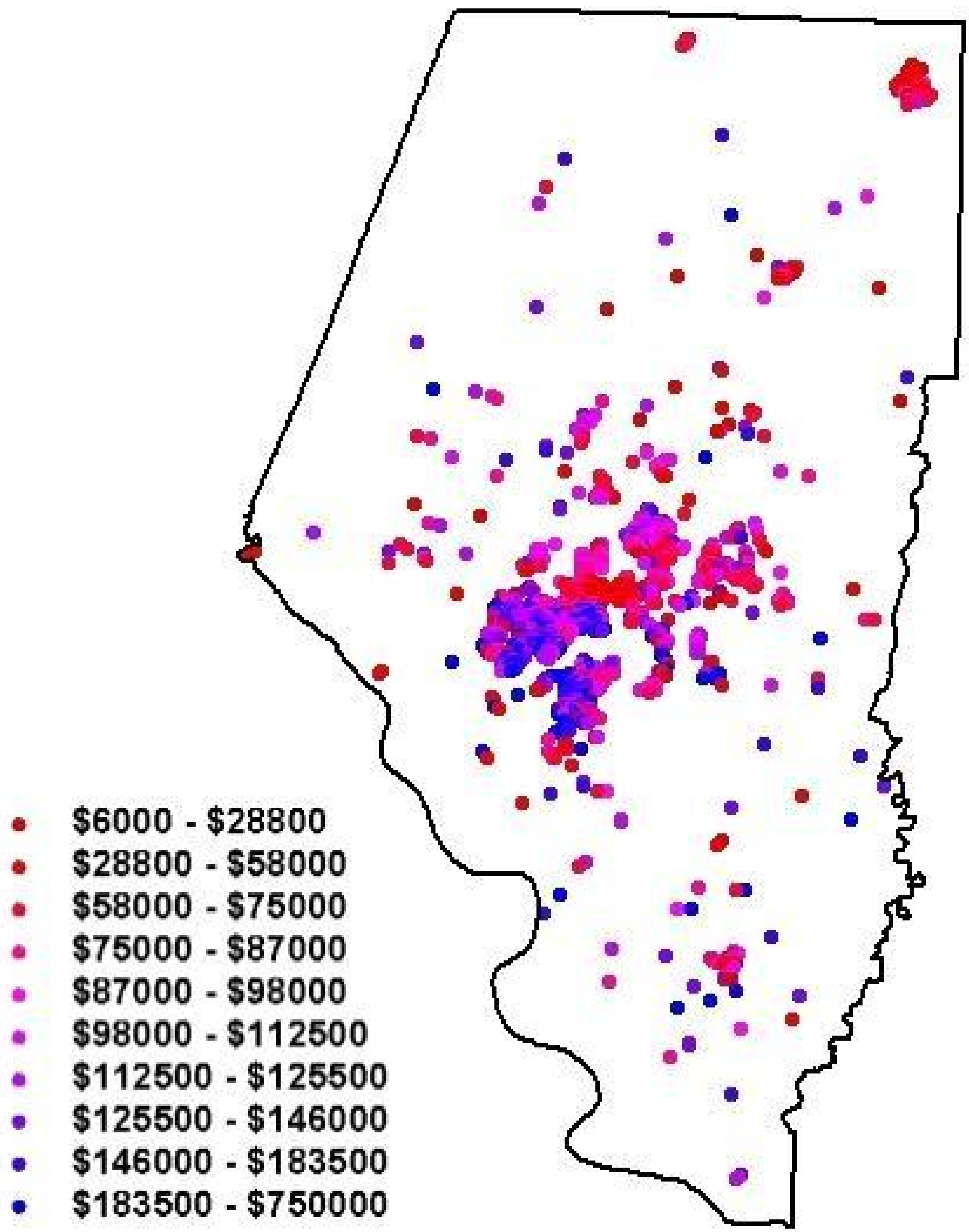

Figure 1. Regression analysis data points

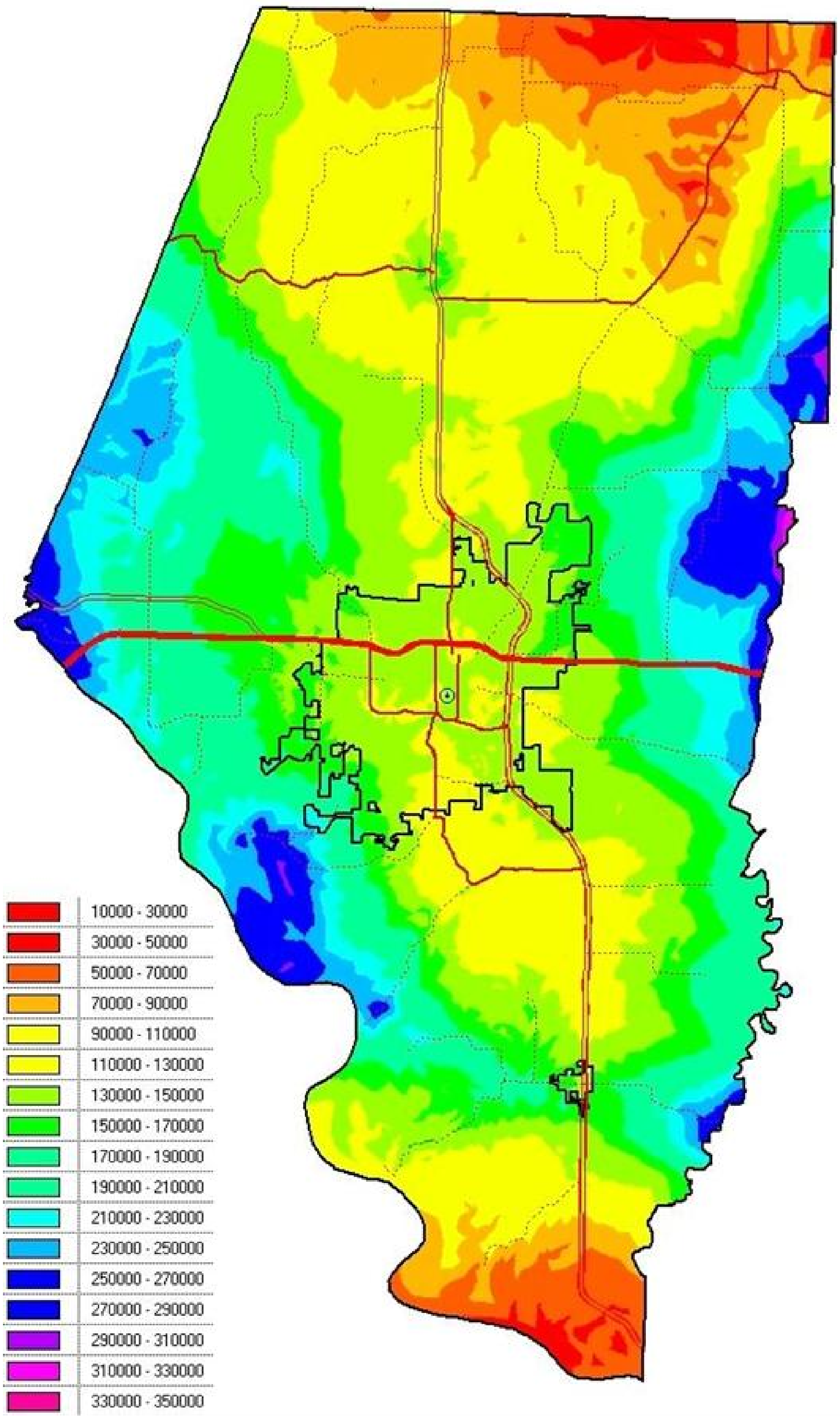

Figure 2. Land value prediction map

Table 5. Coefficients and significance levels for transportation and hydrographic variables in hedonic regression

Variable	Parameter Estimates	t-value	Pr> |t|	*5% **10%
Lot size	0.13863	6.6	<.0001	*
Lot size squared	-6.02E-08	-4.78	<.0001	*
Distance to CBD	-5.3102	-1.48	0.1381	
Distance to CBD squared	0.000499	2.16	0.0307	*
Distance to CBD X Distance to Missouri River	0.00036	1.67	0.0942	**
Distance to CBD X Distance to interstate	-0.0005	-1.54	0.1236	
Distance to CBD X Distance to interstate	-0.00054	-1.72	0.0863	**
Distance to CBD X Distance to interstate	-0.00123	-2.66	0.008	*
Distance to CBD X Distance to interstate	0.00065	1	0.3172	
Distance to CBD X Distance to interstate	-0.00238	-1.14	0.2534	
Distance to Missouri River	-3.46941	-2.08	0.038	*
Distance to Missouri River Squared	8.11E-05	1.36	0.1726	
Distance to Missouri River X Distance to interstate	-0.00026	-1.46	0.144	
Distance to Missouri River X Distance to US highway	-2.7E-05	-0.23	0.8187	
Distance to Missouri River X Distance to state highway	-0.00027	-1.72	0.0847	**
Distance to Missouri River X Distance to lettered routes	-0.00027	-0.94	0.3454	
Distance to Missouri River X Distance to hydrography	-0.0009	-1.18	0.2385	
Distance to interstate hwy	4.30341	1.59	0.1121	
Distance to interstate hwy Squared	-4.8E-05	-0.27	0.7863	
Distance to interstate hwy X Distance to US highway	-8.5E-05	-0.34	0.7326	
Distance to interstate hwy X Distance to state highway	0.00094	2.95	0.0032	*
Distance to interstate hwy X Distance to lettered routes	-0.00011	-0.22	0.8291	
Distance to interstate hwy X Distance to hydrography	0.00263	1.6	0.1089	
Distance to US highway	-1.87088	-0.85	0.3971	
Distance to US highway Squared	0.000535	2.76	0.0059	*
Distance to US highway X Distance to state highway	0.00109	3.93	<.0001	*
Distance to US highway X Distance to lettered route	-0.001	-1.94	0.052	**
Distance to US highway X Distance to hydrography	0.00179	1.14	0.2532	
Distance to state highway	3.6609	1.34	0.1818	
Distance to state highway Squared	0.000826	2.55	0.0109	*
Distance to state highway X Distance to lettered route	-0.00162	-2.07	0.0388	*
Distance to state highway X Distance to hydrography	-0.00038	-0.17	0.8638	
Distance to lettered route	10.80715	1.85	0.0637	**
Distance to lettered route Squared	-0.00071	-0.59	0.5533	
Distance to lettered route X Distance to hydrography	-0.00831	-1.67	0.0949	**
Distance to hydrography	36.70773	2.66	0.0078	*
Distance to hydrography Squared	-0.01143	-1.21	0.226	

5.5 Origins and Destinations Model

Stakeholders identified origins and destinations (O/D) and the associated travel distances/travel times as impacting several of the indicators discussed previously. Origins and destinations indicate those locations that are the beginning and/or ending points for a trip. In transportation planning, knowing where individuals are departing from and where they are traveling to are useful parameters to indicate what the impact of infrastructure improvements will be on existing parts of the community. An up-to-date assessment of O/D is particularly useful in planning for communities experiencing rapid growth. Questions arise such as where to locate new roads to facilitate access to various destinations (e.g., jobs, schools, shopping, and recreation), and where to establish new community infrastructure, such as fire stations, to minimize distances from critical services. In addition, one may wish to know the impacts of various construction projects. For this reason, the research team selected the issue of determining O/D, specifically commercial and industrial locations, as a test case for incorporating remote sensing into the decision framework.

The goal of this portion of the research was to develop a remote sensing (RS)-based algorithm to distinguish travel origins and destinations (O/D). The O/D algorithm was first developed to distinguish commercial and industrial (C&I) O/D because of the greater uniformity of land cover. Some assumptions were made to facilitate the analysis. Many C&I (including certain entertainment locations) O/D are associated with impervious surfaces because of the large buildings, parking spaces for employees and customers, and associated road access. In the construction of commercial and industrial facilities, planning includes providing sufficient parking facilities for employees and customers, while attempting to limit over-building that would increase expenditures for the purchase of land and for the construction and maintenance of the parking spaces. The number of parking spaces provided is an indicator of the number and duration of trips to and from that enterprise, as established by the experience of the marketplace. The first assumption, then, is that C&I locations are areas with a high percentage of impervious surfaces.

Once O/D have been identified, their frequency and distribution throughout the community can be utilized to essentially apply a weighting factor to the average travel distances between O/D pairs, based on the extent to which a location represents a significant C&I area. Locations with intense C&I development can be given a higher weighting factor and contribute more to average travel distance calculations. Establishing the relative trip importance requires additional information and is beyond the scope of this research effort.

Not every impervious surface area is C&I, and the algorithm must distinguish between C&I and non-C&I locations. The designation of a pixel as being part of a C&I location is not only based on the percent impervious surface of a specific site, but also on an assessment of the land uses in the vicinity, that is, in relation to the activities in the surrounding areas (indicated by impervious surfaces). The context is necessary because any C&I area can still contain pervious areas where grass or trees are used to improve the appearance of the facility. The second assumption, then, is that C&I areas are those that are highly impervious and that are located in the midst of other highly impervious areas.

The O/D effort (described in Appendix D) produced a methodology that is highly accurate in determining C&I O/D. The methodology is automatic in that it relies on characteristics of C&I O/D in an urban/urbanizing area and does not require the analyst to have specific knowledge of the characteristics of the location of interest. This methodology could be used in place of traditional O/D studies to support planning and design functions.

5.6 Benefit Transfer Models

The comprehensive approach described in this report requires estimates of costs and benefits for numerous criteria (economic, environmental, safety, accessibility, and cash flow indicators are identified below). Many of these indicators will require extensive research before they can be directly estimated for Missouri. Benefit transfer methods offer an indirect alternative for some of these criteria.

Many criteria in the decision-making matrix are measured in monetary terms (e.g., freight costs, value of time savings). While some of these monetary values are relatively easily measured (e.g., freight costs), other monetary values are not readily available because they are nonmarket goods. Nonmarket goods are not directly bought and sold on any market; therefore, their monetary value is unavailable. However, economists have developed numerous reliable and proven methodologies to place a monetary value on nonmarket goods.

Time savings, air pollution impacts, and wetlands preservation are nonmarket goods. Primary research to monetize changes in these goods due to transportation investments is possible, but can be costly. Inexpensive and practical valuation methods exist, and they rely on existing data or previous studies. That is, they use studies “off-the-shelf” to obtain values for a new analysis.

The most popular and practical method used to estimate nonmarket benefits for social cost-benefit analyses is known as the “benefit transfer” method (Willis and Garrod 1995). In a benefit transfer, the analyst uses existing studies of the monetary value of relevant and comparable nonmarket goods to estimate the monetary value of the change at hand. Benefit transfer uses estimates of nonmarket benefits measured at one site, known as the study site, to estimate nonmarket benefits at a second site, known as the policy site. Because the method makes use of secondary data in estimating the benefits at a new site, the method is less expensive and time intensive than primary research. These factors account for the method’s popularity.

There are two main approaches to transferring benefit estimates. The first is the “simple transfer” approach, which transfers a point estimate and/or the confidence interval of benefits from the study site to the policy site (Parsons and Kealy 1994). The second approach is the benefit function transfer, or model transfer approach (Loomis 1992; Desvousges et al. 1992). Under this approach, the benefit model from the study site (including functional form, model specification, and parameter estimates) is combined with site-specific data describing the population and other characteristics of the policy site. Then, the benefits at the policy site are simulated. By replacing the levels of the characteristics in the study site benefit function with characteristics from the policy site benefit function, the model transfer approach accounts for some of the differences in site characteristics across the two sites.

The simple transfer approach could be easily applied to monetize the nonmarket goods considered in this decision-making model, e.g., time savings, air pollution changes, changes in noise levels, and changes in wetlands. Among the indicators that might be monetized using the benefit transfer method are the following:

- Indicators of Accessibility
    - Value of travel time
    - Value of time spent in traffic delays
- Indicators of Environmental Impacts
    - Value of wetlands
    - Cost of noise pollution
    - Cost of air pollution

In the future research, researchers could develop a database of existing studies and estimates that would be appropriate to use in benefit transfers for transportation decision-making in Missouri (e.g., Chattopadhyay 1999; Cohen and Southworth 1999; and Peterson and Randall 1984). This database would assemble studies and value estimates that represent conditions that are comparable to those in Missouri. It would be a source of relevant and transferable benefit estimates that could inform future decision analyses.

In this way, it would be possible to incorporate more, or all, of the indicators identified as desirable components of a comprehensive highway corridor investment system without having to conduct the time consuming and expensive research to develop Missouri-based estimates for each of these components.

5.7 The Proposed Multi-Attribute Decision-Making Framework: The Analytic Hierarchy Procedure

One of the goals of this project was to create a conceptual framework for organizing and synthesizing information with which the Department can measure costs and benefits (monetary and non-monetary) of highway corridor investments. In this section, we address this goal by proposing a framework which can be expanded to include almost any number of criteria. The framework employs the Analytic Hierarchy Procedure.

5.7.1 AHP Model by Expert Choice Software

Expert Choice is a company that developed software, also called Expert Choice, to exploit the method of Analytic Hierarchy Procedure (AHP).

In the robust highway corridor project, the researchers challenged the advisory panel members to identify relevant factors that a decision maker should consider when designing transportation systems. From these factors, the project team developed the list of 41 specific measurable indicators within one of the six general impacts—accessibility, economic development, environmental impacts, social/psychological impacts, and safety.

But which of these indicators are the most important? One of our primary goals was to provide a list of people's preference weightings for all these indicators. AHP fits our needs for two reasons: first, it is a powerful tool developed for calculating people's priorities and, second, through the first two stages of our project, we have already set up a basic hierarchy structure, as shown in Figure 3.

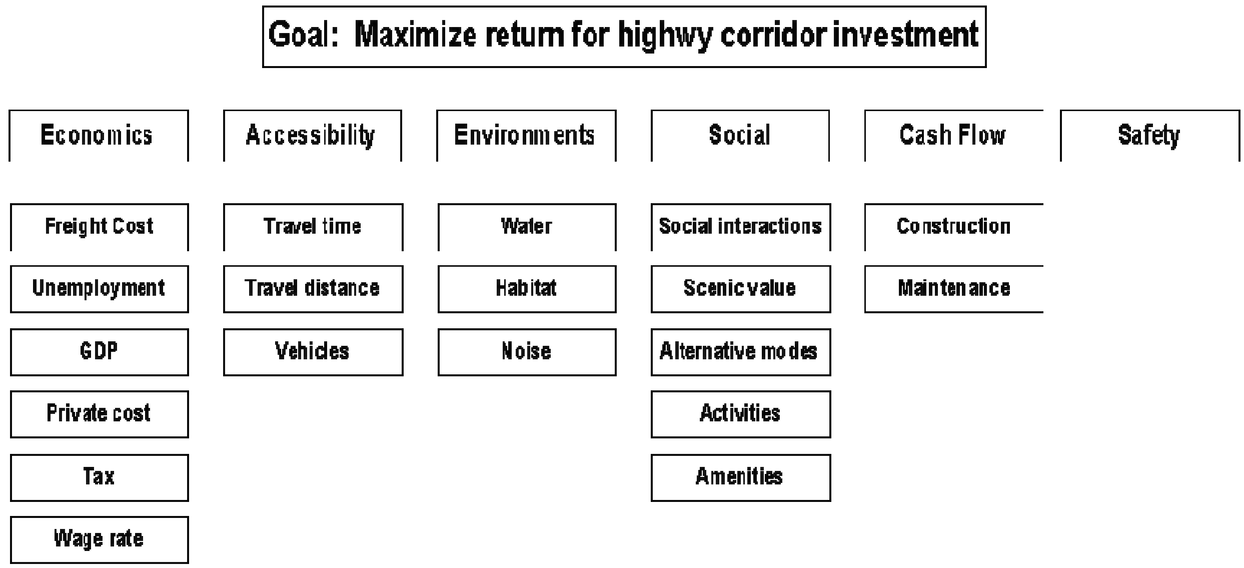

Figure 3. Goal hierarchy for corridor investment decision making

With maximizing returns for Missouri highway corridor investments as our ultimate goal, we constructed our AHP model using Expert Choice in the way described below.

The model shown above is a simplified one, in the sense that the third (lowest) level contains only a subset of our indicators. The remaining indicators have been left out for the sake of simplicity.

Once the model is set up in Expert Choice, individual decision makers make comparisons between each pair of the factors at each level. For example, at the highest level, each decision maker will compare economic impacts with environmental impacts. The decision maker will express this preference as a ratio—one to two if the first is twice as important, one to one and half if it is only 50 percent more important. Decision makers do this for each pair and then go on to the next level where they compare all pairs. When the decision maker gets down to the third level with measurable indicators, each indicator is expressed with numeric units to make them comparable with each other. For instance, with regard to economic impacts, savings in freight cost are measured by total dollar value per year, and savings in private cost are measured by total dollar value per year.

After the pair-wise comparisons are complete, Expert Choice calculates the consistency among the pair-wise comparisons and the weights implied by the decision maker's preferences for each of the components in the model.

Consistency of preferences refers to the property of transitivity of preferences. Inconsistency means that the ordering and magnitudes of an individual's preferences are intransitive in someway. For instance, transitivity or consistency of preferences implies if you like apples better than oranges and oranges better than bananas, then you should like apples better than bananas. And if you like apples twice as much as oranges and oranges one and half times as much as bananas, then you should like apples three times as much as bananas. If the comparisons that a person makes conflict with one another, or if the sizes of those preferences don't agree, then they will be inconsistent. A little bit of inconsistency is expected. These comparisons are somewhat arbitrary, so perfect consistency is rare, but too much inconsistency leads to unreliable weights.

The Expert Choice software compares an individual's comparisons at all levels and calculates an "inconsistency ratio" for each level. Values of the ratio are from zero to one. A zero inconsistency means that the choices agree completely among themselves. An inconsistency ratio of one means that there is no agreement at all. However, when expressing one's preferences, there are no correct answers, nor are one person's preferences compared with those of others to calculate the inconsistency ratio.

Another important consideration when applying AHP is that the alternatives or choices that decision makers are comparing are indeed comparable. If the magnitudes of the choices are not clear, it will be impossible for the decision maker to express meaningful preferences. For example, it is impossible to accurately compare some apples with some oranges. The quantity, size, quality, and characteristics of the choices must be explicit to assure meaningful weights.

5.7.2 Group Expert Choice

Group decision-making is more common than individual decision-making, especially at the level of public investment decisions. In the Missouri robust corridor investment project, we developed a framework that will enable representatives of all stakeholders to express their preferences.

A group decision-making AHP model is very similar to the individual one. The most important difference between individual and group decision making is that a group AHP exercise must combine each person's weight, on each indicator, into a final one. In other words, it must average individuals' weights. Empirically, several ways of averaging have been used, in particular, arithmetic means, geometric means, and weighted arithmetic means.

Expert Choice does offer a version of their software called Group Expert Choice, which utilizes a computer network to incorporate each person's weighting into group weights. Expert Choice has offered to hold a one- or two-day workshop in Missouri to demonstrate Group Expert Choice.

5.7.3 Focus Group Test of AHP

To test the use of Expert Choice as a way of developing preference weights, a focus group approach was employed. A survey was developed to elicit the preferences and measure the individual weights for transportation outcomes.

The AHP model developed for this project includes five general impacts of transportation in the second layer of the hierarchy—economics, accessibility, environment, safety, and cash flows.

Thirteen indicators are included at the third layer of the hierarchy:

Economics:

1. Reduction in aggregated freight cost—dollars per year
2. Decrease in statewide unemployment rate—percentage
3. Increase in Gross Domestic Product (GDP) at State level—dollars per year
4. Decrease in private cost—dollars per year

Environment:

1. Water quality—Units of miles of stream impacted
2. Habitat—Units of acres
3. Noise reduction—Units of decibel*hours*person.

Accessibility:

1. Reduced average travel time from origin to destination—persons*hours
2. Increased number of vehicles per hour that the most restricted portion of corridor can accommodate (stress factor at bottlenecks)
3. Reduced average travel distance from origin to destination—miles
4. Reduced travel time from location of interest to hospitals and fire stations—vehicle * hours

Cash Flows:

1. Savings in annual construction cost (annualized investment amount)—dollars/year
2. Savings in maintenance cost pear year—dollars/year

Safety: has always been a primary concern, but a precise measurable indicator has not emerged yet and was omitted from the model.

Fifteen individuals were selected for the focus group based upon their familiarity with transportation issues. These individuals are identified in Table 6. The majority of focus group participants had professional responsibilities related to transportation, such as planners, city administrators, economic developers, and engineers. The majority of participants were located in central Missouri, as it was determined that differences in geographic location would not affect our ability to test the procedure (although it is possible and likely that geography would be important to the results themselves).

Table 6. List of individuals involved in the focus group

Name	Affiliation
Ken Effink	City of Ashland
Gayla Neumeyer	Rocheport City Council
Lynn Behrns	City of Centralia
Dave Mink	Boone County Public Works
Bernie Andrews	Regional Economic Development Inc.
Mitch Skov	City of Columbia
Richard Stone	City of Columbia Traffic Eng.
Julie Nolfo	Crawford, Bunte & Brammeirer
Mike Crist	Enterprise Development, Inc.
Bill Canton	Columbia Neighborhood Response
Thad Yonke	Boone County Planning & Zoning
Kathy McDougal	City of Fayette
Tabitha Madzura	Ag Engineering
Verel Benson	Food and Agricultural Policy Research Institute
Mark Kross	Missouri Department of Transportation

On March 17, 2003, the focus group met on the UM-Columbia campus. Members of the research team provided a brief overview of the research project and the primary goals for the evening. Before the survey was distributed, time was taken to tell the "story" behind each of the factors that focus group members would be weighting. One of the potential benefits of using a decision-support tool is the opportunity to broaden the understanding among professionals and community residents regarding the multiple impacts of highway corridors. Following the presentation and instructions, participants of the focus group were asked to make pair-wise comparisons among the list of 13 indicators.

After participants completed the surveys, their responses were tabulated using the Expert Choice software for single users. Four laptops were used to process the results within a short time period. One of the observations from this process was that all of the participants responded with high consistency rates. Had their responses been inconsistent, it would have been necessary to ask them to revise their survey answers.

The focus group approach proved to be very successful. Almost every participant satisfied the consistency test. At the end of the meeting, we organized each member's input into our established model of AHP by Expert Choice.

5.7.4 AHP Survey Results

Participants were asked to provide feedback on the tool. One of the concerns expressed was that because the tool provided quantitative feedback on preferences, it may be used to justify a decision, rather than be used as part of a larger decision-making process. Another feedback was related to the possibility of putting more weight on a preference to counter the preferences of others. For example, if one felt that the preferences of developers would lean heavily towards economic benefits of a highway corridor, he or she could weigh preferences that benefit the environment at a higher level. It would be difficult to control for this kind of survey response, other than to emphasize the importance of giving responses that accurately reflect one's preferences.

In the absence of Group Expert Choice software, the arithmetic average over all group members was found. The group average weighting scores and a rank of these thirteen indicators and the five general impacts are shown in Tables 7 and 8, respectively. The tables of survey results indicate that the Expert Choice Software can be successfully utilized to obtain individual preferences. The preferences were enunciated after a short, but focused, training session, with the individuals expressing internally consistent opinions within the allotted time. These results suggest that MoDOT could utilize the process within a single, facilitated meeting to obtain stakeholder preferences for planning and decision-making.

Table 7. Average scores and rankings of the benefit categories

Category	Score	Rank
Environments	0.267	1
Accessibility	0.228	2
Safety	0.224	3
Economics	0.149	4
Cash Flow	0.132	5

Table 8. Average scores and rankings of the benefit indicators

Category	Score	Rank
Habitat	0.1093	1
Water Quality	0.1023	2
Maintenance Savings	0.0753	3
Travel Time	0.0748	4
Construction Savings	0.0567	5
Noise level	0.0559	6
Vehicles at Bottleneck	0.0512	7
Travel Distance	0.0511	8
Emergency	0.0506	9
Private Cost	0.0499	10
GDP-State level	0.0357	11
Unemployment Rate	0.0331	12
Freight Cost	0.0303	13

AHP is one of several means that institutions, firms, and agencies use to make decisions when there are many competing goals. This project has demonstrated the utility of multi-attribute decision-making and AHP in particular in highway corridor investment planning. This procedure could be used by MoDOT to establish statewide, regional, or even local priorities. We believe that a tool such as this would encourage citizens to get involved in transportation planning, would help them understand the opinions and preferences of others, would give them a greater sense of influence over the process, and would give them a greater stake in the results.

6.0 CONCLUSIONS

This project began with a concept for assisting transportation decision-makers in using appropriate models to improve the way they make decisions and to enhance their investment decision-making. During the course of this project, these objectives evolved into one developing a decision-making framework incorporating multiple attributes and relying on several methods of organizing data for both input and output. The formation of an advisory panel of highway corridor stakeholders led to an interchange of information that was beneficial in the construction and development of diverse indicators of the values and needs of those stakeholders.

The cross-disciplinary team made possible several advances in the project, through the use of advanced knowledge in economics and statistics, as well as in GIS and remote sensing.

6.1 Determination of Information Needs

Through the use of the Advisory Panel, the project elicited a list of statements regarding transportation impacts and processed the list into measurable indicators of the nature of the impacts. The value of the indicators for a given transportation alternative can be used in decision-making to select alternatives that provide the most overall benefits.

6.2 Creation of a Conceptual Framework

This project has developed a conceptual framework for assessing the benefits of alternative highway corridor (and other) investments strategies. In this way, one can compare the benefits of transportation investments in general and between various alternative corridors. The framework is based on inputs from a literature review, stakeholder meetings, as well as on close communication with Missouri DOT employees.

The overall framework is comprehensive and explicit. It is also ambitious—too ambitious to implement in full immediately. But it is also modular in nature. The framework outlines a long list of indicators and suggests ways in which some of them can be measured. This project includes the development and demonstration of two specific techniques to quantify indicators.

The research team believes that the framework is immediately useful as a general guide for policy and investment strategies. As a guide for quantitative analysis of investment benefits, it is not immediately applicable in full. However, some of the indicators can and should be estimated on a regular basis beginning immediately.

In the longer term, the framework does provide a blue print for future research and investigation.

6.3 Evaluation of Readily Available Modeling Approaches

The three most commonly used tools for economic impacts of transportation investments—RIMSII, REMI, and IMPLAN—were reviewed for their applicability to the issues faced by state departments of transportation. While each has unique and attractive features, it was the conclusion in this project that IMPLAN was the most useful for this purpose. It is particularly attractive given the modular nature of the proposed framework.

6.4 Assessment of the Utility of High-Resolution Remote Sensing Data Sources

High-resolution remote sensing data was also analyzed as to its ability to provide useful information, and a methodology was developed to identify commercial and industrial origins and destinations. This, in turn, was translated into average travel distances. Such a methodology can also be used to determine accessibility impacts of alternative investments ultimately, as well as during construction. While the use of remote sensing data for transportation decision making was evaluated from the accessibility perspective, this data source has many other applications, particularly in the environmental area.

6.5 Assessment of the Utility of a Geographic Information System

The combination of economics, statistics, and GIS led to a consideration and demonstration of the utility of GIS to organize data for use with the hedonic statistical method. A dynamic prediction map was generated from this process, indicating the price consumers are willing to pay for a house in relation to its location with respect to highway corridors. The results generated from this procedure have numerous applications: (a) it can assess the contribution to potential economic growth and development of infrastructure investments; (b) it can be used to determine optimum levels of public service provision within rural or urban communities; (c) it helps to evaluate people’s perception of value with respect to various housing characteristics, such as conditions and qualities of the house, size of land parcel, number of bedrooms, distance to nearest highways, or distance to nearest streams and public parks; and (d) it provides transportation decision-makers and stakeholders with quantitative and visualized analysis tools to allocate limited economic resources properly.

GIS was also utilized in the origins and destinations analysis, further highlighting its applicability for multiple purposes.

7.0 RECOMMENDATIONS

Based on this project, we recommend that the Missouri Department of Transportation consider the following actions:

1. That the Department adopts a master framework for evaluating investments in transportation. This framework embodies the theme, “Missouri Department of Transportation Builds Communities.”
2. That the Department evaluates Group Expert Choice as a means to eliciting the preferences of state residents. This approach would become part of the Department’s program for stakeholder involvement and the regionalization of policies. This approach should consider the differential preferences of various regions and stakeholder groups in the state.
3. That the Department adopts the IMPLAN economic impact assessment system as a central component in the implementation of the master framework.
4. That the Department forms a stakeholder advisory panel to develop an implementation plan for the master framework. This implementation plan will include the following:
    a. A short-list of indicators to be included in the initial evaluation system
    b. Prioritization of indicators for future incorporation into the system
    c. Proxy benefits and costs based on the benefit-transfer approach described in this report
    d. A plan for the development of Missouri-specific evaluation procedures over time
    e. A procedure for weighting the transportation preferences of various stakeholder groups and various regions of the state
5. That the Department develops an educational program to inform state residents of their broad mission and the many benefits flowing from transportation. This educational program should do the following:
    a. Inform state residents that their preferences for transportation investments are considered in this framework
    b. Incorporate the preference elicitation process (Group Expert Choice)
    c. Include a package of demonstration material which educates residents about the role of transportation in their communities
6. That the Department adopts the goal of becoming a learning organization. Achievement of this goal will involve the following activities:
    a. Integration of the Department’s many data into a spatially articulated and easily accessed information system
    b. Use of the global positioning system (GPS), remote sensing, and distributed data collection techniques for the collection of data
    c. Use of geographic information systems (GIS) for most data organization and analysis
    d. Use of GIS, visual simulations, and e-government techniques for public education programs
    e. Integration of information and knowledge into every decision
    f. Development of the capacity to measure additional indicators as identified by the Advisory Panel

These recommendations are consistent with the concept of the Department's Long Run Transportation Plan. Recommendation 4, in particular, describes a process whereby the Department can formalize the process of stakeholder involvement and integrate it into its priority setting and investment process. This approach is particularly important when the resources available are unlikely to ever approach those necessary to achieve all demands on the system. This approach incorporates both the trade-offs between goals and the absolute constraint on fiscal resources.

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APPENDIX A: CONFERENCE CALLS TO ASSESS PRESENT CONDITION IN OTHER MIDWEST STATES

Logistics:

Conference call participants were suggested by Charlie Nemmers, Director of the University of Missouri-Columbia, Transportation Infrastructure Center, who also scheduled the call. A conference call was selected rather than individual telephone interviews in the hope that the perspectives and experiences of the various participants would enhance the discussion. The morning of the conference call, participants were sent an email (Appendix B) that outlined the project itself, as well as the goals for the conference call. In addition, the participants were emailed a copy of the project proposal and files containing the table of indicators for each transportation impact and the table listing specific means of measurement for the indicators that had been developed from the input provided by the Advisory Panel.

The conference call started out with everyone introducing themselves and a general introduction to why the conference call was taking place. The context for the research project was stated as frustration on the part of MoDOT in not being able to accurately assess transportation impacts (e.g., bypasses). Off-the-shelf economic models are narrow in the indicators they incorporate, and the results are aggregated.

Conference Call 1
Monday February 9, 2004
Project participants: Kate Trauth, Tom Johnson, Charlie Nemmers

Transportation officials:

Jim Brewer, Kansas Department of Transportation (responsible for all aspects of preliminary engineering from authorization of the project to construction letting, including management and roadway design, public involvement, and environmental documentation)

Jon-Paul Kohler, Federal Highway Administration, Illinois (Planning and Program Development Manager, with a staff of nine, addressing both Planning and Environment and Safety and Mobility)

Keith Sherman, Illinois Department of Transportation (Chief of Planning and System Analysis, addressing condition rating and analysis, economic development/enhancement program, scenic byway planning, and long range planning)

The call itself lasted approximately 1 1/2 hours.

Issues mentioned by the participants include the following:

- Access is an important “flashpoint” for businesses, with retail and industrial sectors reacting differently. Understanding the impact of bypasses is of importance, and Kansas has completed two studies of bypasses (Dr. Michael W. Babcock, Economic Department, Kansas State University and Dr. David Burress, Research Economist-Policy Research Institute, University of Kansas, with Dr. Babcock also completing a study on the economic impacts of construction projects).

- In Kansas, a state-wide and some project-level telephone surveys of the public have been conducted to determine transportation priorities, with impacts relating to safety, mobility, economics, and the environment being identified as the order of priorities.
- Recognition of differences in priorities from region to region
- Districts in urban areas, e.g., Chicago, operate differently than other Districts. They collect information for decision making from correspondence, listening to politicians, and cooperating with planning organizations.
- Most studies of corridors are either traffic demand studies or land use studies. The case of the Peoria – Chicago corridor indicates that REMI and the Fantus Corporation model were used, although the alternative with the highest economic benefits was not selected.
- It is important to understand the macro-economic circumstances when making economic impact projections (e.g., what is happening in general with national or international economies), which necessitates performing with and without analyses including alternative assumptions about the broader economic context.
- Economic factors pale in comparison with other priorities, such as maintaining the infrastructure, and residents may be more concerned with current impacts rather than future economic benefits.
- Because of politics and the need to distribute funds spatially, decision-making does not involve comparing projects between regions of a state.
- Limited budgets, combined with the need to maintain existing infrastructure, prevent departments from having much flexibility in investment choices.
- Decisions on corridor projects may not rely solely on the project attributes, but also on the local support, specifically financial support, that is generated.
- On some projects, despite collecting a lot of information, performing a lot of studies, and conducting public involvement, decisions are sometimes influenced strongly by local officials involved in the process. This is not necessarily bad, but what is important is for the DOTs to continue the analysis (economic and engineering) so as to provide support for evidence-based decision-making. This is a long-term thing.

In order to bring closure to the discussion at the end of the call, the researchers reiterated what they thought they had heard (specifically related to the research questions of in what areas do transportation investment benefits and costs accrue, what information about these benefits and costs is used for decision making, and how the information is incorporated into decision making) in order to confirm the responses. Those responses are combined with information gleaned from the conference call to come up with the following:

- The specific categories of transportation investment impacts (safety, mobility, economics, and environment) mentioned by the participants are consistent with the impacts as derived from the Advisory Panel input. The transportation officials also believe that social impacts are discovered and addressed during public involvement and involvement with local officials. Depending on the level of documentation needed, it may be covered in the environmental document. When raised, these issues may come under such areas as community cohesion, long range land use planning, environmental justice, right-of-way-acquisition, etc.

- Citizens and business interests in various portions of a state can, and do, desire different benefits from transportation.
- Responding to these different desires supports context sensitive design, even if the context is to put more focus on safety and mobility over economic or environmental issues.
- It is appropriate to respond with different types of projects in response to different priorities.
- In order to respond appropriately to priorities, state agencies collect information through mechanisms such as state-wide surveys, open houses, consultation with political leaders, and outreach with other agencies.
- Various economic tools are used, although there is some discomfort with the results from "black boxes."
- Decisions transcend/go beyond the economic impacts, and incorporate many factors: spatial distribution of resources, political will, and maintaining the existing infrastructure.
- There is currently no tool that helps to bring all of the information together.
- Look for other (non-transportation based) measures for where economic development will occur.
- Such a tool would be useful, as long as it was simple; still only one piece of the puzzle.
- The frustrations experienced by MoDOT are not unique to them, as both Kansas and Illinois indicated that they had similar difficulties with the commercial models.
- Litigation also directs land use and transportation decisions.
- Wisconsin DOT (along with Cambridge Systematics) completed a statewide study (or perhaps a major corridor study—Hwy 12 and/or Hwy 29/10) that may be of value.
- Illinois Prairie Parkway (http://www.prairie-parkway.com/) also shows how the system works where the need for a corridor is clear in the data but the location rests more heavily on the possibilities of getting it built, and here the political process comes in stronger.

Conference Call 2
Tuesday April 27, 2004
Project participants: Kate Trauth, Tom Johnson

Transportation officials:

Steve Andrle, Center for Transportation Research and Education at Iowa State University

A transportation official from Nebraska was scheduled to participate but a schedule change did not permit him to do so. Potential alternates were not able to participate.

The call itself lasted approximately 1 hour.

Issues mentioned by the participant include the following:

- General discussion of the REMI model as might be applied to Iowa (one difficulty is in being able to distinguish the benefits of an interstate highway, but not the benefits of improvements to the interstate).
- Limitation of current economic models in not being able to distinguish secondary and tertiary economic benefit differences between projects in a rigorous way.
- Recognition that transportation is a means to an end, a derived demand based on its support of other goals, and that an accounting of benefits needs to incorporate meeting these other goals (e.g., safety, maintaining prairie grasses).
- Transportation project decisions can be driven by funding constraints and the need to complete critical projects.
- Iowa takes a traditional engineering approach to project justification.
- Currently, social and environmental impacts are addressed through compliance with the National Environmental Policy Act (NEPA) requirements, generally through categorical exclusions and environmental impact assessments.
- Expressed the desirability of a framework (not yet available).
- Corridor projects may be analyzed with respect to safety benefits and travel time benefits, with safety benefits receiving the greatest weight.
- Evaluating benefits/allocating resources issues in Iowa are not limited to roadway decisions, but relate to questions of other transportation investments (e.g., railroad improvements versus improvements to the lock and dam system, small airports).
- Don’t have a system to routinely perform the above analyses.
- Sees value in having the tools to provide the information for decision making.

APPENDIX B: INFORMATION DISTRIBUTED PRIOR TO CONFERENCE CALLS

BACKGROUND

Many government agencies are asked to justify their expenditures in terms of net benefits to residents and taxpayers. Considerable effort has been expended by researchers to address aspects of this requirement, and various partial solutions have been suggested. For some time, the Missouri Department of Transportation (MoDOT) had considered adopting one of the generally available models (REMI, RIMS II, and IMPLAN) to support transportation planning, but they determined that these models did not generate the kind of information that was needed. Discussions between the University of Missouri researchers and MoDOT focused on the development of a research project that would lead to a strategy for basing corridor investment decisions on a more robust evaluation procedure.

In 2001 the authors of the report wrote a preliminary proposal and submitted it to the Midwest Transportation Consortium for funding. Originally, it was proposed that various economic impact models would be screened and a preferred system would be chosen for use in corridor investment analysis. However, during preliminary discussions between University and Department representatives it became clear that what was needed, before a preferred evaluation system could be adopted, was a thorough enumeration of the many categories of benefits and costs that flow from a transportation corridor. Furthermore, it was important that these categories of benefits and costs be organized into a comprehensive framework that would include in a appropriate way, each of these categories. The objectives of the study were thus expanded and the project undertaken.

The ultimate direction of the project better suits MoDOT’s real objective, which is to quantify the multiple impacts (monetary and non-monetary) of transportation investments in order better inform its decision-making process, and thus make the best use of transportation resources (i.e., provide the most benefits to or increase the well-being of individuals and communities). In order to do this, the project employed three strategies: (1) to utilize an advisory panel of highway corridor stakeholders in order to develop a set of indicators of values and needs with respect to transportation infrastructure, (2) to explore the use of remote sensing and GIS to measure those indicators, and (c) to build and “test-drive” a framework for decision making that includes the necessary range of attributes to satisfy selected indicators.

The research project seeks to develop a multi-attribute framework that can be used to assist in organizing and synthesizing information to measure costs and benefits, both monetary and non-monetary, of highway corridor investments.

The specific objectives of the project (original proposal attached) are to:

1) Determine what information must be made available from economic models to support decision making with respect to highway corridor investments,
2) Create a conceptual framework for how to organize and synthesize information to measure costs and benefits (monetary and non-monetary) of highway corridor investments,
3) Evaluate the two or three most readily available modeling approaches,

4) Assess the utility of high-resolution remote sensing (RS) data sources to provide widespread, highly accurate inputs necessary for the economic models and as a means of measuring success after investments have been made, and
5) Assess the utility of a geographic information system to organize model inputs and represent model outputs because of the geographic nature of transportation investments.

Research progress to date includes consultation with an advisory panel of highway corridor stakeholders for the development of diverse indicators of the values and needs of those stakeholders with respect to transportation impacts. A cross-disciplinary team made possible several advancements in the project, stemming from the use of advanced knowledge in economics and statistics and well as GIS and remote sensing. This led to a consideration and demonstration of the utility of GIS to organize data for use with the hedonic statistical method. A dynamic prediction map was generated from this process, indicating the price consumers are willing to pay for a house in relation to its location with respect to highway corridors. High-resolution remote sensing data was also analyzed as to its ability to provide useful information as model input, and a methodology was developed to identify commercial and industrial origins and destinations from impervious surfaces.

One of the tools explored in assisting with decision making was the Analytical Hierarchy Process (AHP) from Expert Choice, a software company. AHP provides a method for assigning weights to comparative choices and has been used as a decision support tool in a variety of fields. A survey was developed that would measure the weight in which a person would choose one variable in comparison to another. The research team wanted to test this tool for consistency and ease of understanding. A focus group was chosen as the method for testing the survey tool and the AHP software.

CONFERENCE CALL

With this conference call, we are conducting the portion of the research associated with assessing the information sources and how the information sources are incorporated into decision-making for states/agencies in the vicinity of Missouri.

Part I: Introduce the research we have conducted

Goal: Develop a framework within which to quantify and incorporate information from multiple sources and of different types for transportation decision making (i.e., highway corridor investments)

1. Determine what information must be made available to decision makers with respect to highway corridor investments (i.e., what are the potential impacts of highway corridor investments)

What are the potential impacts of highway corridor investments
Benefits and costs
Monetary and non-monetary

Transportation impacts (from Advisory Panel of transportation users and producers):

· *Users—private and public entities whose function uses transportation*
· *Producers—state department of transportation personnel*

- *Accessibility*
- *Economic Development*
- *Environment*
- *Safety*
- *Social/Psychological Factors*

(I will email you the specific measures, indicators, within these categories of impacts as soon as I send this email.)

2. Develop a conceptual framework for how to organize information to measure benefits and costs (monetary and non-monetary) of highway corridor investments
Expressing preferences for types and magnitudes of impacts

Analytical Hierarchy Procedure (AHP)
Applying preferences
Requirement for internal consistency in preferences
Can be utilized by transportation producers or users
Existing models that record individuals or group preferences

3. Assess how remote sensing (RS) and geographic information systems (GIS) can be incorporated into this decision making framework

Part II: Questions that we will be asking

1. What types of information do you use in your decision making for corridor investments?
2. How do you collect the information?
3. How do you incorporate various pieces of information in the decision making?
4. Do you incorporate any of the information categories suggested by our Advisory Panel in your decision making?
   - list of indicators
5. Are any of the above issues similar to what your stakeholders have been telling you are important?

APPENDIX C: COEFFICIENTS AND SIGNIFICANCE LEVELS OF HEDONIC REGRESSION VARIABLES

Table C.1. Descriptive statistics

Variable	Mean	Std. Dev	Minimum	Maximum
	117113.9	63663.41	6500	750000
Sale year 2000	0.311688	0.463274	0	1
Sale year 1999	0.37623	0.484534	0	1
Sale year 1998	0.031484	0.174655	0	1
Sale year 1997	0.0366	0.187814	0	1
Sale year 1996	0.052735	0.223548	0	1
Sale year 1995	0.053522	0.225117	0	1
Sale year 1994	0.056277	0.230501	0	1
Sale year 1993	0.038174	0.191654	0	1
Sale year 1992	0.03109	0.173596	0	1
Style (bi-level)	0.090909	0.287536	0	1
Style (split-level)	0.0488	0.215491	0	1
Style (TC)	0.000394	0.019838	0	1
Living quarters size	1865.68	769.4273	512	6440
Quality - very good	0.012594	0.111534	0	1
Quality - good	0.153876	0.360901	0	1
Quality - low	0.002361	0.048545	0	1
Quality - fair	0.058638	0.234993	0	1
Condition - excellent	0.266431	0.442179	0	1
Condition - very good	0.217631	0.412716	0	1
Condition - good	0.239276	0.426725	0	1
Condition - worn out	0.000394	0.019838	0	1
Condition - badly worn	0.004723	0.068572	0	1
Condition - fair	0.035813	0.185859	0	1
Number of bedrooms	3.217631	0.787863	1	12
Number of full bathrooms	1.975207	0.71855	0	6
Age	18.71743	19.84681	0	86
Lot size	25245.89	91958.03	1125	2221560
Population density	1207.58	1606.82	0	14252
Median family income	32735.34	17792.78	0	70011
% of single family units	53.67887	33.41277	0	100
Within Columbia	0.77135	0.420046	0	1
Within Ashland	0.022039	0.146838	0	1
Within Sturgeon	0.001181	0.034347	0	1
Within Rocheport	0.001968	0.044324	0	1
Within Hallsville	0.007871	0.088386	0	1
Within Centralia	0.027942	0.164838	0	1
Distance to CBD	6762.93	6198.54	632	34590
Distance to Missouri River	13406.85	7089.43	160	45267.93
Distance to Instate Highway	5000.51	5904.73	22.3607	32600.22
Distance to US Highway	4306.71	2901.49	80	17376.03
Distance to State Highway	2261.15	2225.73	0	12816.46

Distance to Lettered Route	1145.46	740.2057	0	5313.12
Distance to hydrography	342.3959	226.3138	0	1419.05

Table C. 2. Quadratic model regression results

Variable	Parameter Estimates	t-value	Pr> |t|	*5% **10%
Intercept	25454	1.24	0.214	
Sale year 2000	45703	8.35	<.0001	*
Sale year 1999	38589	7.07	<.0001	*
Sale year 1998	22880	3.62	0.0003	*
Sale year 1997	27796	4.49	<.0001	*
Sale year 1996	23902	4.02	<.0001	*
Sale year 1995	23825	4.01	<.0001	*
Sale year 1994	11740	1.98	0.0475	*
Sale year 1993	11037	1.79	0.073	**
Sale year 1992	4763.473	0.75	0.4526	
Style (bi-level)	-5922.61	-2.73	0.0064	*
Style (split-level)	-1247.13	-0.44	0.6588	
Style (TC)	13999	0.47	0.6383	
Living quarters size	39.94636	26.83	<.0001	*
Quality - very good	110952	18.91	<.0001	*
Quality – good	28093	12.76	<.0001	*
Quality – low	-3984.11	-0.31	0.7574	
Quality – fair	-5188.96	-1.52	0.1283	
Condition – excellent	22101	8.73	<.0001	*
Condition - very good	11692	5.05	<.0001	*
Condition – good	6207.522	3.08	0.0021	*
Condition - worn out	-28168	-0.95	0.3435	
Condition - badly worn	-17282	-1.87	0.061	**
Condition – fair	-7151.85	-1.85	0.0647	**
Number of bedrooms	-2373.85	-2.05	0.0409	*
Number of full bathrooms	2653.295	1.9	0.0574	**
Age	-513.105	-9.46	<.0001	*
Lot size	0.13863	6.6	<.0001	*
Lot size squared	-6.02E-08	-4.78	<.0001	*
Population density	-0.25155	-0.4	0.6871	
Median family income	-0.12617	-1.81	0.07	**
% of single family units	-42.7173	-0.97	0.3339	
Within Columbia	8724.277	2.96	0.0031	*
Within Ashland	-17088	-1.88	0.06	**
Within Sturgeon	-26274	-0.68	0.4951	
Within Rocheport	-55063	-0.82	0.4101	
Within Hallsville	15758	0.87	0.3858	
Within Centralia	1923.464	0.04	0.9682	
Distance to CBD	-5.3102	-1.48	0.1381	

Table C.2. Quadratic model regression results (concluded)

Variable	Parameter Estimates	t-value	Pr> |t|	*5% **10%
Distance to CBD squared	0.000499	2.16	0.0307	*
Distance to CBD X Distance to Missouri River	0.00036	1.67	0.0942	**
Distance to CBD X Distance to interstate	-0.0005	-1.54	0.1236	
Distance to CBD X Distance to interstate	-0.00054	-1.72	0.0863	**
Distance to CBD X Distance to interstate	-0.00123	-2.66	0.008	*
Distance to CBD X Distance to interstate	0.00065	1	0.3172	
Distance to CBD X Distance to interstate	-0.00238	-1.14	0.2534	
Distance to Missouri River	-3.46941	-2.08	0.038	*
Distance to Missouri River Squared	8.11E-05	1.36	0.1726	
Distance to Missouri River X Distance to interstate	-0.00026	-1.46	0.144	
Distance to Missouri River X Distance to US highway	-2.7E-05	-0.23	0.8187	
Distance to Missouri River X Distance to state highway	-0.00027	-1.72	0.0847	**
Distance to Missouri River X Distance to lettered routes	-0.00027	-0.94	0.3454	
Distance to Missouri River X Distance to hydrography	-0.0009	-1.18	0.2385	
Distance to interstate hwy	4.30341	1.59	0.1121	
Distance to interstate hwy Squared	-4.8E-05	-0.27	0.7863	
Distance to interstate hwy X Distance to US highway	-8.5E-05	-0.34	0.7326	
Distance to interstate hwy X Distance to state highway	0.00094	2.95	0.0032	*
Distance to interstate hwy X Distance to lettered routes	-0.00011	-0.22	0.8291	
Distance to interstate hwy X Distance to hydrography	0.00263	1.6	0.1089	
Distance to US highway	-1.87088	-0.85	0.3971	
Distance to US highway Squared	0.000535	2.76	0.0059	*
Distance to US highway X Distance to state highway	0.00109	3.93	<.0001	*
Distance to US highway X Distance to lettered route	-0.001	-1.94	0.052	**
Distance to US highway X Distance to hydrography	0.00179	1.14	0.2532	
Distance to state highway	3.6609	1.34	0.1818	
Distance to state highway Squared	0.000826	2.55	0.0109	*
Distance to state highway X Distance to lettered route	-0.00162	-2.07	0.0388	*
Distance to state highway X Distance to hydrography	-0.00038	-0.17	0.8638	
Distance to lettered route	10.80715	1.85	0.0637	**
Distance to lettered route Squared	-0.00071	-0.59	0.5533	
Distance to lettered route X Distance to hydrography	-0.00831	-1.67	0.0949	**
Distance to hydrography	36.70773	2.66	0.0078	*
Distance to hydrography Squared	-0.01143	-1.21	0.226	

APPENDIX D: DETAILS OF THE ORIGINS AND DESTINATIONS MODEL

D.1 High-Resolution Remote Sensing

Space Imaging's IKONOS earth imaging satellite produces 1-meter black-and-white (panchromatic) (Figure D.1) and 4-meter multi-spectral (blue, green, red, and near infrared) (Figure D.2) images that can be combined in a variety of ways to accommodate a wide range of high-resolution image applications (Space Imaging, Inc.). This research used IKONOS multispectral images where each pixel presents an area of 16 m^2 on the ground.

A land cover classification for the city of Columbia, MO, had already been developed for a separate research effort. This classification, shown in Figure D.3, was developed from the IKONOS multi-spectral data using a maximum likelihood classifier resulting in a 91% overall accuracy (Corrêa et al. 2001). Eight categories of land cover were classified: impervious surface (including roof tops, roads, parking lots, etc.), good grass, crop, brush, wood, water, bare soil type I (unplanted field), and bare soil type II (construction sites).

D.2 Contextual Analysis

The use of context in identifying C&I O/D was achieved through the development of three impervious surface-based parameters. Quantification of the parameters is based on the analysis of blocks (each block containing multiple pixels). For the example described below, a block consisting of 25 pixels was used. Subsequent text discusses the use of different sized blocks.

The three parameters used to describe the imperviousness of a block with respect to evaluating it as constituting an O/D are

1. the percentage of impervious surface of the block itself,
2. the relative imperviousness of the closest eight blocks surrounding the block of interest, and
3. the percentage of impervious surface of the closest 24 blocks (neighbors) (including the eight blocks discussed previously).

These parameters were developed to represent the fact that an O/D is not just an isolated impervious area, but it is impervious areas in the vicinity of surrounding imperviousness (its neighbors) that constitutes a significant area of commercial or industrial activity.

Figure D.4 shows the arrangement of blocks for each of the three parameters (the block itself indicated by the solid square, the eight nearest neighbors indicated by the dashed square, and the nearest 24 neighbors indicated by the dotted square). Each parameter corresponds to one of three colors: parameter one is red, parameter two is green, and parameter three is blue. For this example, the impervious surface of the red parameter is 64%, that for the green parameter is 62%, and that for the blue parameter is 71%. The values of each parameter were converted into color densities, and, upon combination, these three parameters were transformed into a color representation map. Further analysis produced a land cover classification where greater color intensity is used to indicate greater intensity of C&I development. O/D are derived based upon the intensity of C&I development. After the O/D are derived, travel distance calculations can be performed using GIS tools, such as ArcView and its network analysis plug-ins (Environmental Systems Research Institute). The entire process is highly automatic (i.e., requires little manual input or control), making it easier for practical usage.

D.3 Block Analysis

One of the generic image processing techniques commonly performed on pixels is referred to as point processing (Schowengerdt 1983). Pixels are considered as the minimum unit of processing, or the element of the processed image. The designation of a location as being part of an impervious area is based on a “pixel by pixel” operation. In this research, the 4-m ground resolution of the IKONOS multi-spectral image data is too small to identify the corresponding pixel as a part of a C&I site. A larger block of pixels was selected to screen out those small isolated impervious areas that were not part of C&I areas. This is the so-called neighborhood processing technique (Schowengerdt 1983).

Four different processing unit sizes of the area of interest were selected to perform the analysis with 3 by 3, 5 by 5, 7 by 7, and 10 by 10 blocks of pixels. This means that each block of pixels with the same dimension as the selected processing unit size will be processed as one “pixel.” This was done by assigning the average of the values of all pixels in each block as the value of the new “pixel.” For example, if a processing unit size of 5 pixels by 5 pixels was selected, then each 5 by 5 block of pixels (25 pixels) will be reduced to one “pixel” by averaging the value of those 25 pixels. Henceforth the processing unit will be called a “block.” Figure D.5 shows an example of the 5 by 5 processing unit, or block. Each pixel in the original classified image was first identified as either pervious (assigned a value of 0 and the color black) or impervious (assigned a value of 1 and the color white). This is a revised land cover classification used for simplicity in programming that was processed in Adobe Photoshop 7.0 (Adobe System Incorporated). A block grid of 5 by 5 was placed over the pervious/impervious land cover classification and the entire city was divided into 5 pixel by 5 pixel blocks. Each block was then evaluated individually as to imperviousness. The percentage of impervious surface for each block was calculated (the right side of Figure D.5). This analysis creates a block imperviousness parameter.

Table D.1 shows the percentage of target pixels differentiated. From this table, one can see a tendency that the increased analysis unit size generates fewer areas of interest. In terms of a classification accuracy solely based on differentiation percentage, one could say that the 3 pixel by 3 pixel block is the best choice among options. However, the interest is not solely with the impervious pixels themselves, but also on their spatial characteristics.

Table D.1. Pixel differentiation percentages

		Block Size			
Class	Total Impervious Pixel Count in Study Area	3×3	5×5	7×7	10×10
Impervious	2313896	540306	483250	474957	260800
Percentage of Pixels Differentiated		26.35%	20.88%	20.53%	11.27%

For example, if the block size selected is approximately the size of the roof of a residential building, it is very likely that this building could be designated as a potential C&I area because there are usually also other homes, driveways, and streets nearby. Some isolated small business such as gas stations and convenience stores are close to the size of a single 10-by-10 block, so they may have a high value in the red band but low values in the green and blue bands if they are located in a grassy or wooded area. Thus, careful consideration must be made when selecting the appropriate analysis unit when this method is applied. Considering the fact that the 3 by 3 block analysis may have some non-C&I areas included and the fact the 10 by 10 block analysis may miss some C&I areas, the results from the 5 by 5 or the 7 by 7 block sizes are appropriate for travel distance analyses performed later. The 5 by 5 analysis result was selected because it provided the highest differentiation capability between C&I areas and other sites.

D.4 Color Image Composition

Figure D.6 shows the result of the color combination of the three parameters, an indication of large impervious areas. When examining Figure D.6, it is necessary to consider that when the primary colors (red, green, and blue) are superimposed, the color mixing process is known as additive. When these colors with similar intensities are added, they produce a white/whitish image. A very impervious block (represented by the red parameter) with very impervious neighbors (represented by the green and blue parameters) will be represented by the addition of intense red, green, and blue. Thus, impervious areas surrounded by impervious areas are designated by the light areas. An isolated impervious block would show up as dark red, with little contribution of green or blue. An impervious block that was located at the edge of a large impervious area would have intense red with moderate green and blue contributions (half intensity for both green and blue signifying half impervious and half pervious). Residential areas, with a mixture of impervious and impervious surfaces have only moderate additions of red, green, and blue, and thus appear as light red locations. Undeveloped locations with mainly grass, wood, or corps are shown as black because of the absence of impervious areas larger than the analysis block size. Roads can be clearly identified in Figure D.6 as red lines. They are completely impervious, so there is a contribution of intense red for the block of interest. At the same time, roads are often surrounded by grass buffers and lawns, particularly in residential areas, so there is little contribution of green or blue coloration.

Light areas in Figure D.6 indicate highly impervious areas surrounded by highly impervious areas. These locations represent potential commercial or industrial areas because of the concentration of impervious surfaces.

D.5 Reclassification

Once a color representation of imperviousness was developed, it was necessary to determine what colors constitute an O/D. A supervised classification of the imperviousness map was performed using ENVI image processing software (Agresti 1990; Research System, Inc.). This reclassification is necessary because there are multiple combinations of the percent impervious of the red, green, and blue parameters that can constitute a C&I location. Some of this difference in percent impervious is based on whether the block is located in the middle or closer to the edge of a C&I location. Parallelepiped classification was used to perform this kind of reclassification.

Parallelepiped classification uses a simple decision rule to classify multispectral data. The decision boundaries form an n-dimensional parallelepiped in the image data space. The dimensions of the parallelepiped are defined based upon a standard deviation threshold from the mean of each selected class. Each class is from the training site designated by users. For supervised classification, the more uniform the training sites selected, the better the final result. Increasing the number of each class's training sites will generate more accurate pixel differentiation in each class. In this research, the interest is with one class--those areas that are light blue to white. Therefore, large impervious areas like a mall, downtown, and large shopping centers were selected as training sites. In this research, 4 training sites with approximately 5000 pixels in each on were selected in the mall area, downtown, and Broadway Market area. If a pixel value lies above the low threshold and below the high threshold for all n bands being classified, it is assigned to that class. If the pixel value falls in multiple classes, the pixel is assigned to the last class matched. Areas that do not fall within any of the parallelepipeds are designated as unclassified (Richards 1994). The classification was performed for only two classes: C&I areas and non-C&I areas.

Figure D.7 shows the results of the reclassification with blue indicating C&I areas and the remainder of the map constituting non-C&I locations. A comparison of Figures D.7 and D.6 shows that very few areas were deleted from the C&I classification, and these were mainly from locations identified as generally residential areas. Because of their locations in generally residential areas, zoning constraints would establish them as commercial rather than industrial locations. Small-scale commercial enterprises would not contribute as much O/D traffic as a concentrated C&I area such as a shopping mall, and thus would have a smaller contribution to average travel distance. They can legitimately be eliminated from consideration as C&I locations. The small area removed indicates that the training sites were such that they represented the wide variety of C&I development patterns in the test community. Figure D.8 shows the C&I areas derived from the analysis performed based on 5 by 5 analysis unit superimposed over a roads layer from the Missouri Spatial Data Information Service (Missouri Spatial Data Information Service).

D.6 Accuracy Analysis

It is necessary to assess the correctness of the C&I O/D in Figures D.7 and D.8. An accuracy analysis was performed for two datasets. One of them was the entire study area and the other consisted of the C&I areas mapped during this research. The first dataset corresponding to the Columbia study area was partitioned into a 20×15 grid (20 divisions in the east-west direction and 15 divisions in the north-south direction). The land cover/land use type of the block in the center of each partition was examined by superimposing the original land cover classification, the IKONOS 4-m multispectral image, the IKONOS 1-m panchromatic image, and the zoning layer from Boone County, MO.

From the statistical point of view, there are two types of errors that could be produced in testing a hypothesis:

I. A true null hypothesis can be incorrectly rejected
II. A false null hypothesis can fail to be rejected

For the first analysis, because the vast majority of the sampled points were non-C&I locations, the null hypothesis is that a block identified as a non-C&I location is, in fact, a non-C&I location. The two types of errors can be expressed as the following:

I. A non-C&I pixel was incorrectly identified as C&I
II. A C&I pixel was incorrectly identified as non-C&I

Among the 300 pixels examined, there were 13 in which the C&I/non-C&I pixel identification was incorrect. Eleven pixels identified by the procedure as being located in non-C&I areas were in fact, located in C&I areas. Two pixels identified as C&I pixels were, in fact, located in non-C&I areas. Table D.2 is the error matrix generated from the analysis.

Table D. 2. Error matrix resulting from the grid sampled blocks of pixels

		Reference Data (Image and Mapped Data)		
		C&I	Non-C&I	Row Total
Classification Data	C&I	4	2	6
	Non-C&I	11	283	294
	Column Total	15	285	300

The overall accuracy of the random sampling analysis:
Overall accuracy = (283+4)/300 = 287/300 = 95.67%.
The Type I error percentage over the entire sampling pixels:
Type I errors = 2/300 = 0.67%
The Type II error percentage over the entire sampling pixels:
Type II errors = 11/300 = 3.67%
Total error percentage:
Total errors = (2+11)/300 = 13/300 = 4.33%

Very few C&I locations were a part of the grid sampling procedure, so an accuracy assessment of the identified C&I locations was performed. Because only C&I locations were sampled, the null hypothesis is now that a pixel identified as a C&I location is, in fact, a C&I location. The two types of errors can be expressed as:

I. A C&I pixel was incorrectly identified as non-C&I
II. A non-C&I pixel was incorrectly identified as C&I

Two hundred eighty testing points were randomly selected within the C&I areas identified from the procedure. The parcel GIS layer mentioned above, the original multispectral image, and the 7.5-minute digital raster topographic map of Columbia, MO (Missouri Spatial Data Information Service), were used to identify the true land use types of the testing points (Figure D.9). Twenty-three points were found to be non-C&I areas that were incorrectly classified as C&I points. Among the 23 points, 10 points were found to be residential points, 4 points were found to be located at the intersection of large roads far from C&I locations, 3 points were found to be in construction sites, and 6 points were found to be located in bare soil areas. Another 16 points were located in quarries. Although quarries are C&I locations, because of the relatively limited number of trips generated for the large surface area, future analyses may benefit from removing these locations from initial analysis. The error matrix is found in Table D.3. Because only those locations identified as C&I were sampled, there can be no Type I errors in this analysis.

Table D. 3. Error testing matrix from random sampling analysis

	Truth	
Decision	C&I Pixel	Non-C&I Pixel
C&I Pixel	257	23
Non-C&I Pixel	0	0

The overall accuracy of the C&I category from this random sampling analysis:
Overall accuracy = (280-23)/280 = 257/280 = 91.79%.
The Type II error percentage over the entire sampling pixels:
Type II errors = 23/280 = 8.21%
Total errors percentage:
Total errors = 23/280 = 8.21%

It should be noted that the 3 construction points and the 6 bare soil areas were incorrectly classified as impervious surface in the original land cover classification. This result suggests the importance of the original land cover classification.

D.7 Origins and Destinations for Travel Distance Calculations

A strategy was developed to calculate average travel distances between O/D without needing to specify particular origins and destinations. This strategy involves random sampling over all potential C&I sites in the community. The larger an individual C&I area, the greater likelihood that one or more of the random samples will be located in the area. If a sufficiently large number of samples is taken, the greater the likelihood that the arrangement of the sampled points will approximate the arrangement of C&I O/D in the community. Because of the interest in average travel distance, it is not necessary to identify specific O/D, but only regions of activity that would give an indication of roadway distances traveled between various O/D.

While the overall importance of sites can be assessed through the use of RS and GIS technologies, the establishment of probable trips between C&I locations and their expected importance requires the analyses of other types of information. For the research, 500 points were selected randomly over all of the city limits of Columbia. The overlaying resulted in 40 locations representing randomly selected points that are also C&I locations. Average travel distances for the study were considered in and among these 40 C&I locations.

The sampled locations are shown in Figure D.10, with general parts of the community shown in Figure D.11. An analysis of the C&I areas identified by the procedure shows that they correctly include a major mall (A), the business loop of Interstate Highway 70 that runs through the community (B), the downtown area (C), the campus of the University of Missouri-Columbia (D), an industrial park (E), and a major shopping center (F) among other C&I locations. Other, more isolated, O/D locations are indicated to represent C&I locations that are distributed through the community. There were no major O/D (indicated by the close proximity of several sampled points) that were identified by the procedure that were not part of a known location of commercial or industrial activity. The circles are only intended to indicate general locations within the community.

D.8 Average Travel Distances

An independent application program named PathFinder was created by using Borland Delphi 7.0 (Borland Software Corporation), MapObjects 2.1 (ESRI), and NetEngine 1.2 (ESRI). The theory behind this application is Dijkstra's shortest path algorithm (Cormen et al. 2001). ESRI NetEngine provides both encapsulation of functions used to create network topology based on ESRI shape file (*.shp) for further solving and calculating capabilities. By taking account of practical traffic parameters, such as speed limits, stop signs, traffic control lights, the slowing associated with left turns, and one-way roads, NetEngine could let users choose different calculation weights based on those traffic parameters. Based on this framework, PathFinder was developed to be able to solve user-defined traffic network analysis problems. The data format used in this application is the standard network topology data used in ESRI Network Analyst for ArcView which could be converted from ESRI shape files. Weights could be added into the road network topological structure by assigning each segment of the road network values of quantitative weights. The weight of each road segment could be used as a coefficient to derive the relative importance of that road section in the travel distance or travel time of actual trips. The determination of weights is beyond the scope of this research.

This application accepts a coefficient assigned to each segment of the road network as weights when it is used to calculate travel time. This program can provide solutions for the shortest travel distance as well as total travel time calculated by considering different weights. Users could also use this application in traffic detour planning and traffic redirection under construction or accident situations. PathFinder uses MapObjects displaying user interface and user-defined origin or destination problem schemas. Coding focused on setting up the shortest path-solving schema based on the user-defined parameters, solving network problems with NetEngine, and storing final results on disk. Figure D.12 shows the graphic user interface of this application and the calculation of shortest travel distance between two points.

Shortest travel distances between all sampled O/D locations are shown in Table D.4. In this demonstration, all 7 points in region C were taken as origins, and the other 33 points were taken as destinations. Table D.5 lists average travel distances for selected locations.

Table D. 4. Shortest travel distance (ft) for each origin/destination pair

		C						
		1	2	3	4	5	6	7
A	1	4684.18	4983.13	4869.05	5142.38	4672.16	5360.38	5349.14
A	2	4451.93	4750.87	4636.8	4910.13	4439.91	5128.13	5116.89
A	3	4325.88	4591.28	4463.78	4744.09	4294.32	4959.59	4930.19
A	4	3800.69	4099.64	3985.57	4258.89	3788.67	4476.89	4465.66
A	5	4247.96	4546.91	4432.83	4706.16	4235.94	4924.16	4912.92
A	6	4047.85	4346.79	4232.72	4506.05	4035.83	4724.04	4712.81
A	7	3869.08	4164.3	4036.81	4317.12	3857.05	4535.65	4516.9

B	8	3006.3	3264.77	3137.27	3417.58	2967.81	3633.08	3603.68
B	9	2758.82	3017.29	2889.8	3170.11	2720.33	3385.61	3356.2
B	10	2520.29	2778.76	2651.27	2931.58	2481.8	3147.07	3117.67
B	11	2376.62	2635.09	2507.6	2787.91	2338.13	3003.4	2974
B	12	2265.64	2524.11	2396.62	2676.93	2227.15	2892.42	2863.02
B	13	2054.76	2313.23	2185.74	2466.05	2016.27	2681.54	2652.14
B	14	1799.99	2058.45	1930.96	2211.27	1761.49	2426.77	2397.37
B	15	1804.06	2062.53	1935.03	2215.35	1765.57	2430.84	2401.44
B	16	1771.34	2029.8	1902.31	2182.62	1732.84	2382.08	2352.68
B	17	1545.96	1804.43	1676.94	1957.25	1507.47	2164.64	2135.24
B	18	1552.03	1810.5	1683	1810.99	1513.54	1957.05	1927.65
B	19	1994.49	1937.93	1811.74	1790.15	1808.93	1936.21	1906.8
B	20	1787.6	1695.8	1569.61	1548.02	1566.8	1694.08	1664.67
B	21	2002.06	1730.59	1631.25	1582.81	1781.26	1728.87	1588.12
B	22	2272.92	2001.46	1902.12	1853.68	2052.12	1930.7	1472
D	23	1785.11	1650.41	1775.71	1800.08	1945.66	1648	2104.98
D	24	2174.26	2039.55	2164.86	1954.64	2334.8	1737.72	2024.08
D	25	2365.3	2230.6	2355.9	2148.22	2525.85	1931.3	2217.66
E	26	7466.96	7287.73	7446.38	7171.41	6994.35	7002.39	6727.32
E	27	7686.77	7507.53	7666.18	7391.21	7214.15	7222.19	6947.13
E	28	8083.49	7904.25	8062.91	7787.93	7610.88	7618.91	7343.85
E	29	8280.49	8101.25	8259.91	7984.93	7807.88	7815.91	7540.85
F	30	3470.21	3171.27	3276.39	3012.01	3478.16	3019.43	2804.34
F	31	3600.52	3301.57	3406.69	3142.32	3608.46	3149.73	2934.64
G	32	4553.85	4356.01	4921.78	4645.02	4322.12	3745.38	4286.59
G	33	4726.61	4528.77	5094.54	4817.79	4494.88	3918.14	4459.35

Table D. 5. Average travel distance (ft) for sampled origins or destinations (o/d) occurring in clusters

	C							Average
A	4203.939	4497.56	4379.651	4654.974	4189.126	4872.691	4857.787	4522.247
B	2100.859	2244.316	2120.751	2306.82	2016.101	2492.957	2427.512	2244.188
D	2108.223	1973.52	2098.823	1967.647	2268.77	1772.34	2115.573	2043.557
E	7879.428	7700.19	7858.845	7583.87	7406.815	7414.85	7139.788	7569.112
F	3535.365	3236.42	3341.54	3077.165	3543.31	3084.58	2869.49	3241.124
G	4640.23	4442.39	5008.16	4731.405	4408.5	3831.76	4372.97	4490.774

From Table D.5, one can see that the average travel distance between regions C and E is the largest among the pairs, which can be verified by examining Figure D.11. The general distance between regions C and E is larger than the general distances between C and the other locations. In addition, the relatively sparse road network leading to E could also contribute to the larger average travel distances. The smallest average travel distances are between C and B and between C and D, which could be expected based on the locations within the community. Because the interest in assessing travel distance (and thus travel time) is with comparing the impact of two or more roadway investment alternatives, assessing the accuracy of exact travel distances is not required.

This procedure can also be applied to the evaluation of new, alternative transportation infrastructure (i.e., average travel distances resulting from different road improvement alternatives).

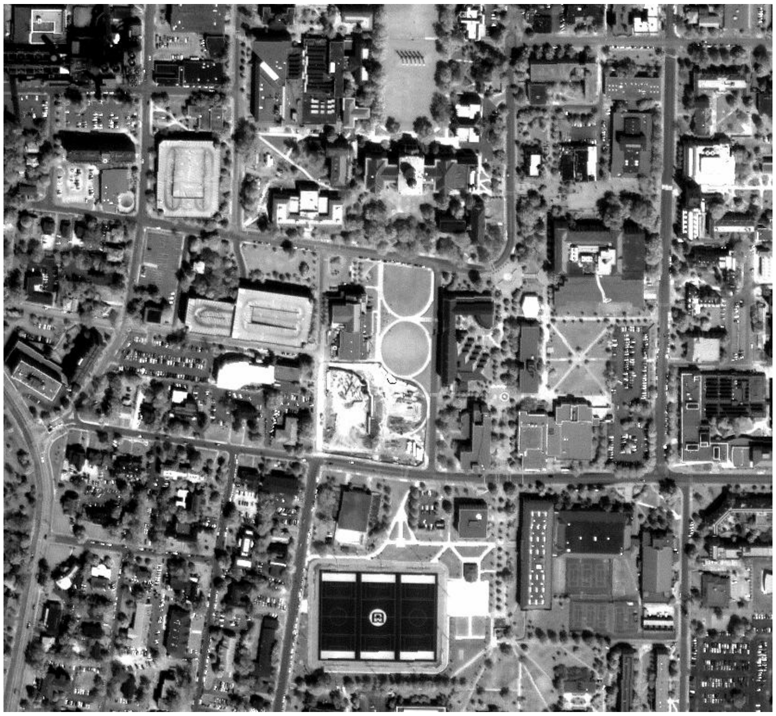

Figure D.1. IKONOS 1m Panchromatic Image (April 21, 2000, Part of the University of Missouri-Columbia Campus, Columbia, Missouri, USA)

Figure D.2. IKONOS 4m Multispectral Image (April 21, 2000, Part of the University of Missouri-Columbia Campus, Columbia, Missouri, USA)

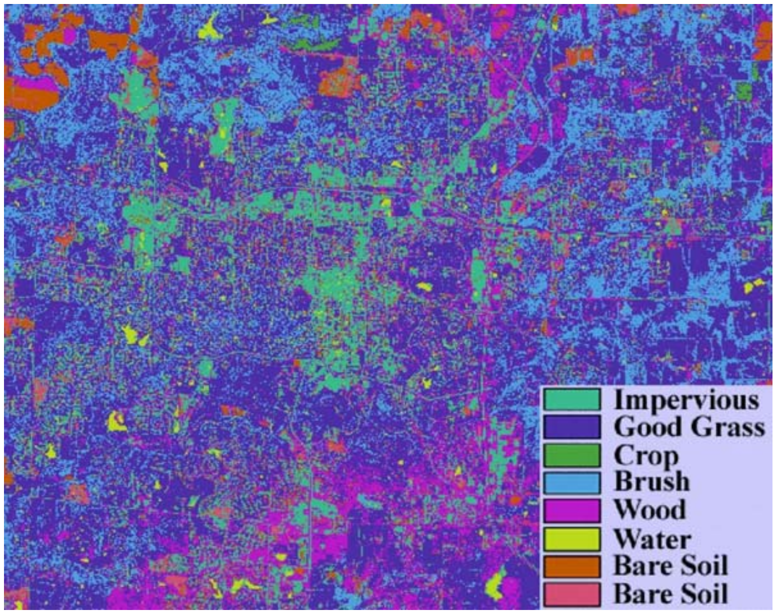

Figure D.3. IKONOS 4m multispectral land cover classification using a maximum likelihood classifier

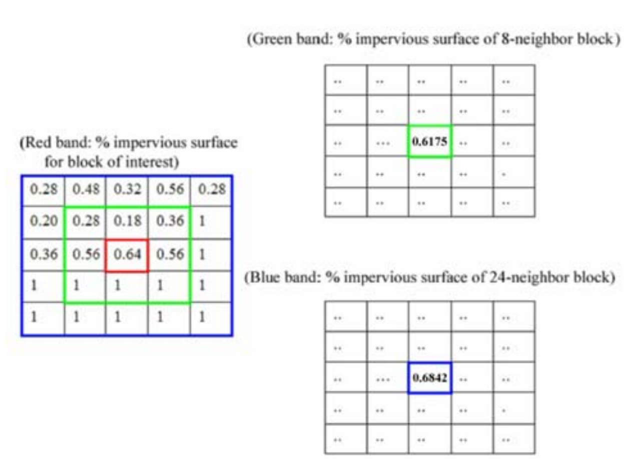

Figure D.4. Arrangement of blocks for the impervious parameters

5×5 Grid

0	1	1	1	1	0	0	1	1	0
0	0	0	0	1	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1
0	0	0	1	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0
1	1	1	1	1	0	0	0	0	0
0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	1	0	0	1	1
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

(Red band: % of impervious areas)

0.28	0.48	0.32	0.56	0.28
0.20	0.28	0.18	0.36	1
0.36	0.56	0.64	0.56	1
1	1	1	1	1
1	1	1	1	1

Figure D.5. Numerical representation of pixel processing unit analysis: percent impervious surface

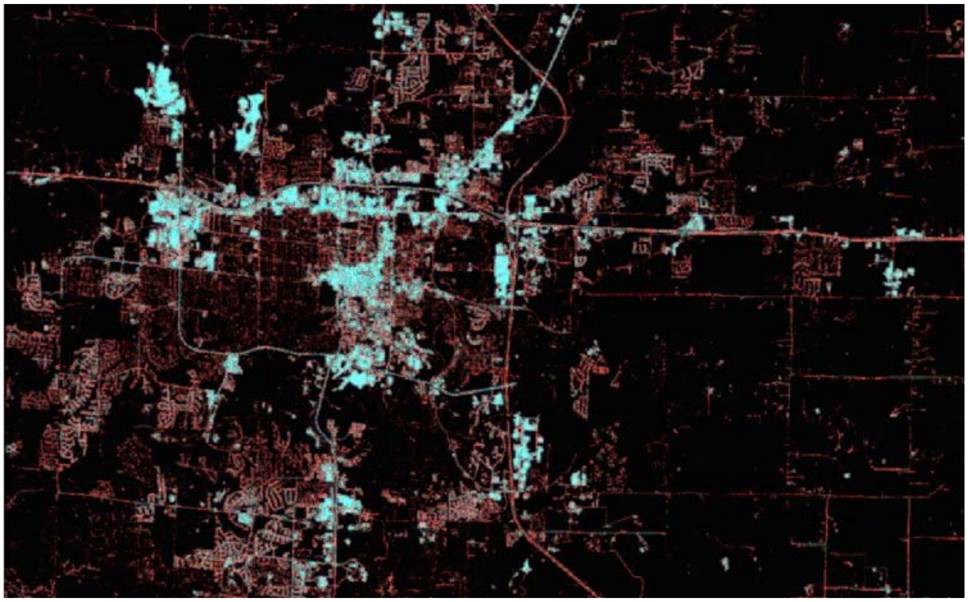

Figure D.6. Color image generated from imperviousness parameters (imperviousness shown in light blue)

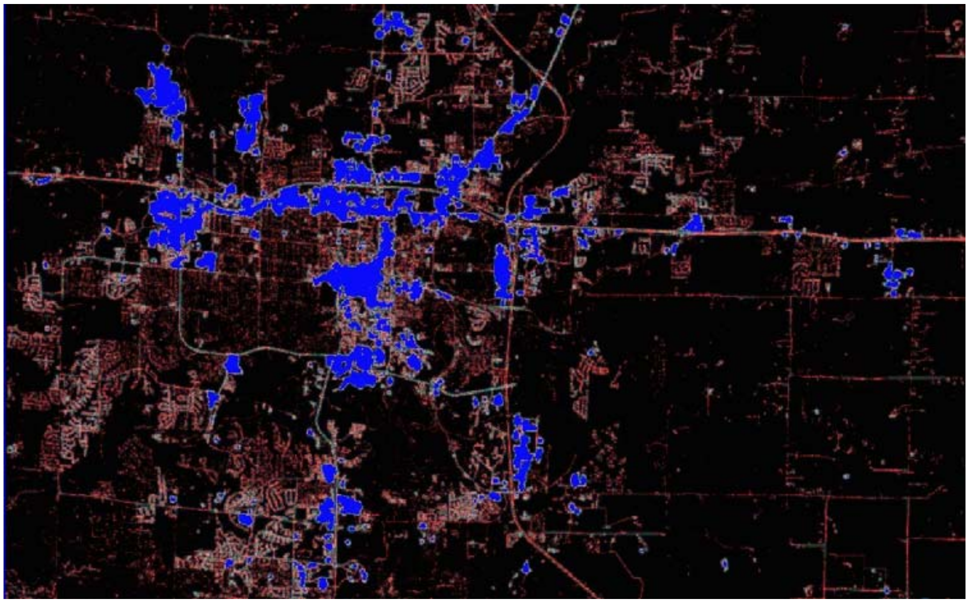

Figure D.7. Reclassification of imperviousness indicating commercial and industrial (C&I) areas superimposed over combined 24-bit color image from imperviousness parameters

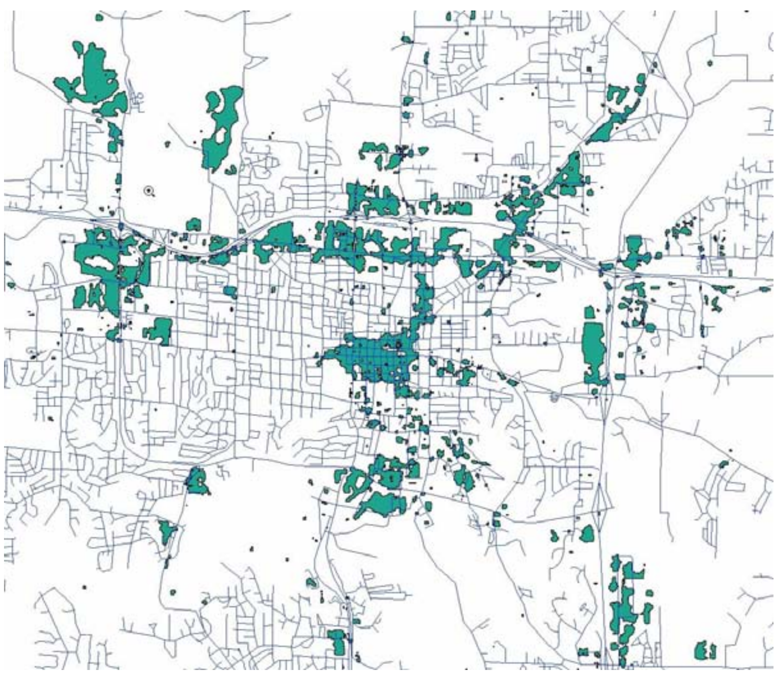

Figure D.8. C&I areas identified from analysis superimposed over a roads layer

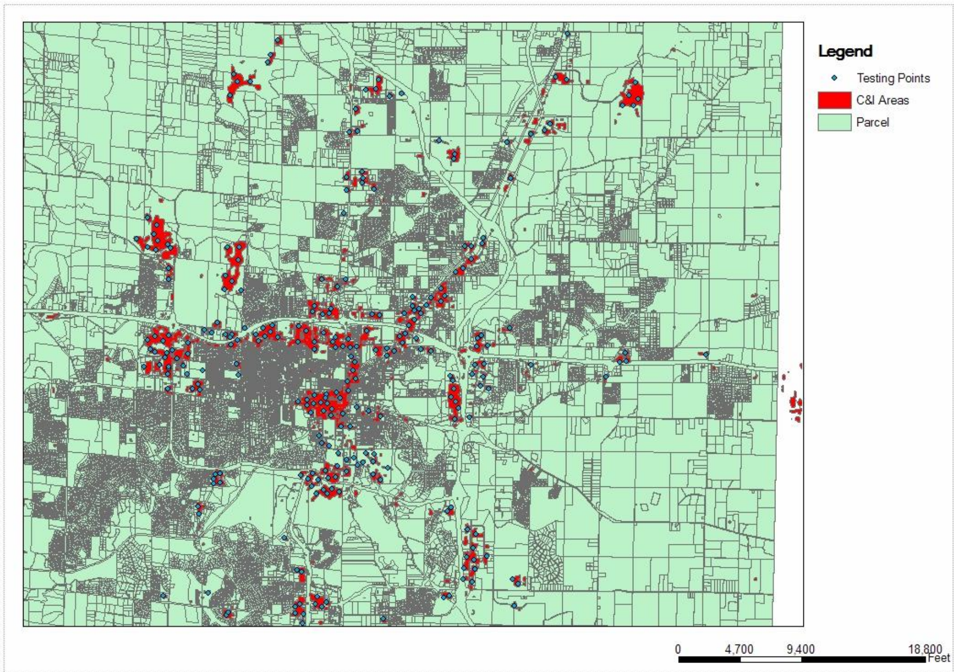

Figure D.9. Testing points overlaying C&I areas and the parcel layer

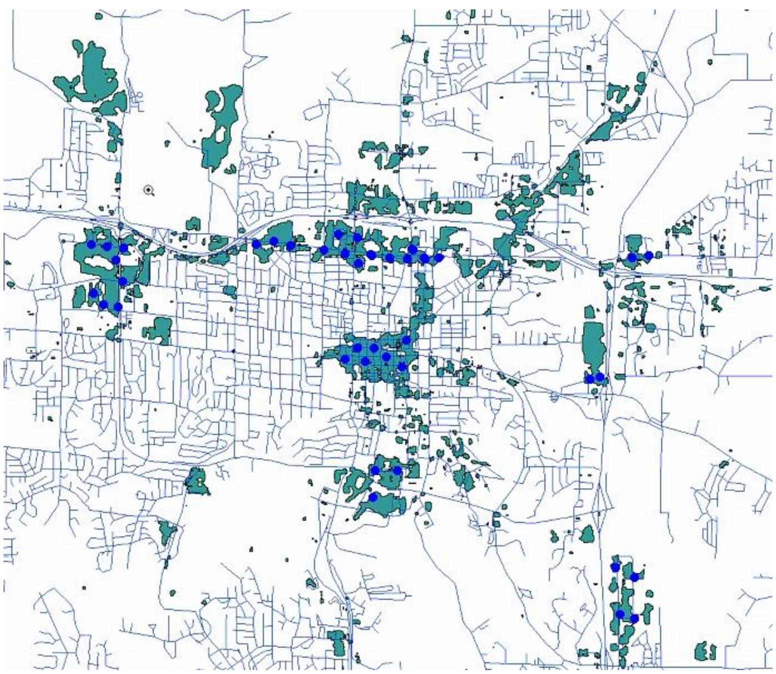

Figure D.10. 40 Reported C&I O/D locations superimposed over a roads layer

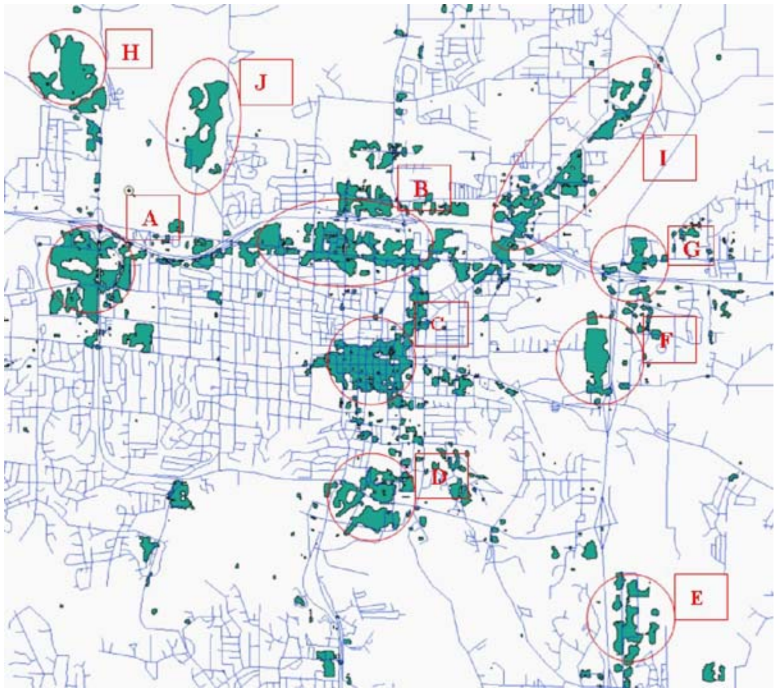

Figure D.11. General partition of commercial and industrial areas in Columbia, MO

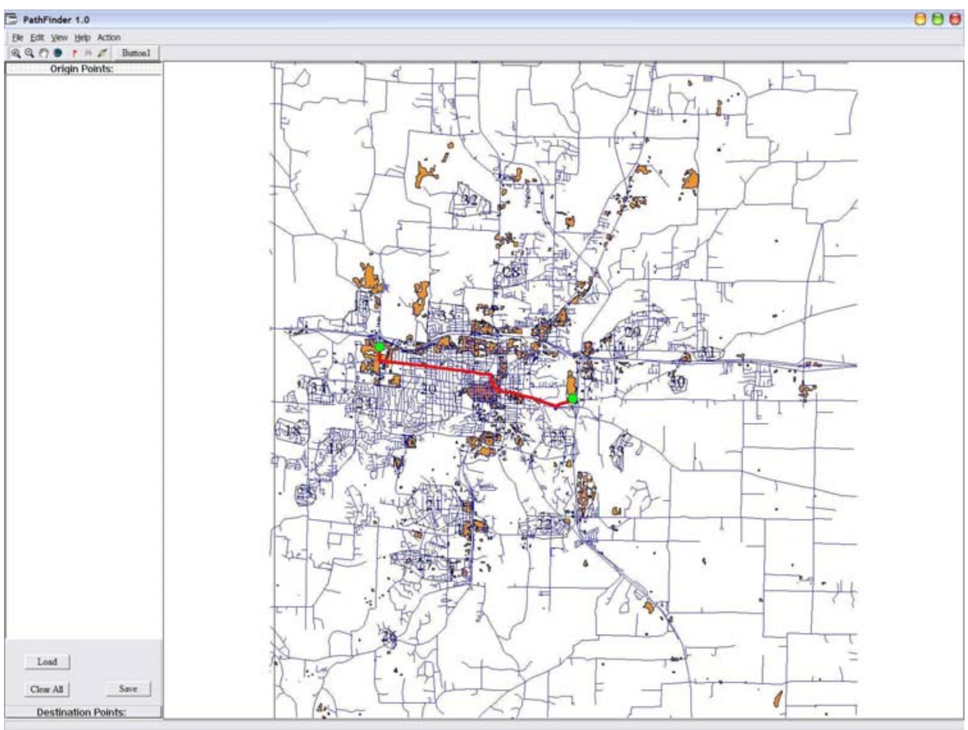

Figure D.12. Calculation of shortest path between 2 points in PathFinder