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Measurement and Monitoring of the Performance of Highway Investment

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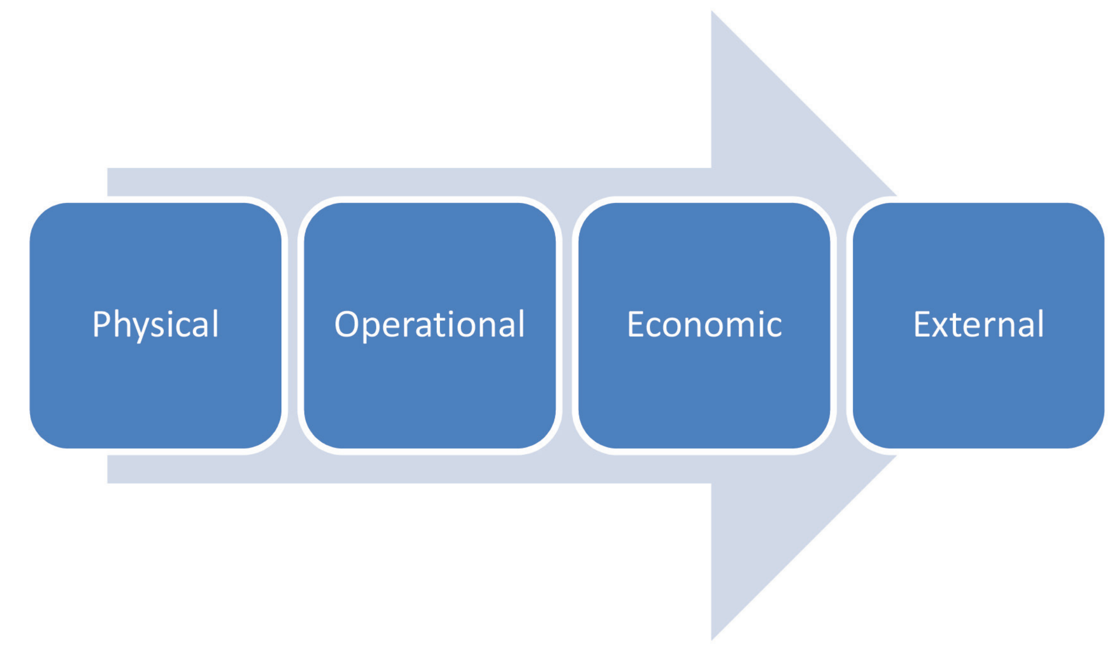

Four levels of return on investment

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16. Abstract

In response to the federal SAFETEA-LU requirements, nearly all state departments of transportation (DOTs) have started to use performance measurement at some point in the planning and/or programming process. Although these performance measures are routinely monitored, they are generally completed during the project development process on a project-by-project basis for anticipated future conditions. No state has a fully developed post-implementation tool to monitor and evaluate capital investment programs at a system (statewide) level. The primary objective of this study is to establish a systematic, comprehensive, and robust tool for the Indiana DOT (INDOT) to routinely perform an ex-post facto appraisal of its investment program at the system level. Using historical highway expenditure and performance data, the link between investment and performance was characterized in four asset areas—pavements, bridges, safety, and mobility. Linear regression models were developed to quantify the relationships. Additionally the short-term economic development impacts, in terms of jobs-created and earnings-added, were estimated for the total investment each year. The most recent surface transportation reauthorization, Moving Ahead for Progress in the 21st Century (MAP-21), sets a precedent for performance-based management of the nation's transportation network. The present study provides a monitoring methodology that can be used to demonstrate the effectiveness of INDOT's investment of surface transportation funds and the improvement program to legislative bodies responsible for funding decisions. It also provides a mechanism to communicate the impacts of transportation investment to the general public.

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EXECUTIVE SUMMARY

MEASUREMENT AND MONITORING OF THE PERFORMANCE OF HIGHWAY INVESTMENT

Introduction

Performance-based programming has become increasingly important because it leads to efficient allocation of constrained resources, facilitates the development and justification of budget proposals, and holds decision makers accountable to the public. The newest surface transportation reauthorization legislation, Moving Ahead for Progress in the 21st Century (MAP-21), specifically addressed transparency and accountability for highway expenditures by tying the highway program to measureable performance goals. Although performance measurement has been widely accepted as an essential tool, no state has a fully developed methodology to routinely monitor and evaluate the effectiveness of highway expenditure at a statewide level. Rather, performance measures are often used on a project-by-project basis and at the planning level. The present study develops a methodology to use performance measures and historical expenditure data to evaluate the effectiveness of the highway investment program after implementation. The established methodology will assist INDOT in addressing the requirements of MAP-21.

There are four levels of measureable impact from highway investments. The first level includes the physical results obtained through investment. The second tier of impacts includes tangible operational improvements such as reductions in the number of crashes and travel time savings. The physical and operational improvements to the system lead to the third level of impacts—economic growth. The final level of return encompasses externalities such as improvements to air quality and reduced energy use, primarily through decreased congestion. The present study considers the first three levels of return—physical, operational, and economic.

Objectives of the study include:

- Establish a systematic, comprehensive, and robust tool for INDOT to measure and monitor physical and operational returns from statewide highway investment
- Model the relationship between performance and expenditures for physical and operational improvements
- Quantify the economic development impacts of statewide highway investment in Indiana

Findings

- In general, the condition of INDOT's physical assets and the performance of INDOT's operational assets have improved over the study period. The pavement condition has steadily improved, with higher proportions of pavements in excellent and acceptable condition, between 2002 and 2009. The overall bridge condition has not changed much during the analysis period. While there has not been an apparent improvement, neither has there been a significant decline in bridge condition. The proportion of sample roadways with congestion during the peak period has steadily decreased since 2002. The number of fatality and non-fatality injury crashes per 100 million vehicle miles traveled has decreased since 2003.
- Investments made by INDOT between 1995 and 2009 have been effective in ensuring that INDOT's pavement condition, bridge condition, and safety performance have been sustained over time.
- The relationships between performance and expenditure appear to be different for different classifications of roadways (Interstates, non-Interstate NHS roadways, and non-NHS roadways).
- Economic impact estimation indicates that INDOT investment in transportation assets between 1995 and 2010 created 179,905 jobs and increased total earnings by $9.53 billion (in 2010 constant dollars) to the state economy.
- In addition to the construction industry, industrial sectors like health care, manufacturing services, retail trade, and government sectors have benefited the most from transportation expenditures.

Implementation

The study has demonstrated that INDOT's investment in the statewide highway network has maintained and improved the system over time. Although some information is readily available via annual reports and the online Indiana Transparency Portal, the data are limited and difficult to gather. INDOT may consider refinements to web-based reporting tools to provide relevant performance and expenditure data to the public.

Additionally, the present study suggests only the first of many potential post-implementation program evaluations. INDOT can compare previously-published estimates of performance with the actual measured performance. This can be routinely performed in the future.

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ABBREVIATIONS

AAD:	Average Annual Daily Traffic
AASHTO:	American Association of State Highway and Transportation Officials
ADT:	Average Daily Traffic
ARRA:	American Recovery and Reinvestment Act
BEA:	Bureau of Economic Analysis
BPI:	Bid Price Index
CPI:	Construction Price Index
DOT:	Department of Transportation
ESAL:	Equivalent Single Axle Load
FHWA:	Federal Highway Administration
GPRA:	Government Performance Results Act
HCM:	Highway Capacity Manual
HPMS:	Highway Performance Monitoring System
HSIP:	Highway Safety Improvement Program
INDOT:	Indiana Department of Transportation
IRI:	International Roughness Index
ISTEA:	Intermodal Surface Transportation Act
ITR:	Indiana Toll Road; Interstate 90
MAP-21:	Moving Ahead for Progress in the 21st Century
MDOT:	Michigan Department of Transportation
MLE:	Maximum Likelihood Estimation
MPO:	Metropolitan Planning Organization
NBI:	National Bridge Inventory
NBIS:	National Bridge Inspection Standards
NEPA:	National Environmental Policy Act
NHCCI:	National Highway Construction Cost Index
NHS:	National Highway System
OLS:	Ordinary Least Squares
RABA:	Revenue Aligned Budget Authority
SAFETEA-LU:	Safe, Accountable, Flexible, Efficient Transportation Act: A Legacy for Users
SPMS:	Scheduling Project Management System
TEA-21:	Transportation Equity Act for the 21st Century
TRB:	Transportation Research Board
USDOT:	United States Department of Transportation
VMT:	Vehicle Miles traveled
VSF:	Volume to Service Flow
WSDOT:	Washington State Department of Transportation

1. INTRODUCTION

1.1 Background

Beginning with the Intermodal Surface Transportation Act (ISTEA) in 1991, surface transportation authorization legislation has allowed transportation agencies more flexibility in allocating transportation funds. ISTEA also required state transportation agencies to set up management systems to ensure that decisions were made based on stated priorities (*1*). The trend of increased flexibility and an emphasis on performance-based planning and programming continued with subsequent passage of the Transportation Equity Act for the 21st Century (TEA-21) in 1998 and the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) in 2005. Performance-based programming has become increasingly important because it leads to efficient allocation of constrained resources, facilitates the development and justification of budget proposals, and holds decision makers accountable to the public (*2*). On July 6, 2012, President Obama signed into law the newest surface transportation reauthorization, Moving Ahead for Progress in the 21st Century (MAP-21) (*3*). MAP-21 specifically addresses transparency and accountability for highway expenditures by tying the highway program to measureable performance goals such as "reducing fatalities, improving road and bridge conditions, reducing congestion, increasing system reliability, and improving freight movement and economic vitality" (*4*).

The exact program development process varies from agency to agency, but common elements include needs assessment, fiscal analysis, project selection and prioritization, and fund allocation. Typically, needs assessment is a natural extension of ongoing planning activities. Maintenance and preservation projects are identified to sustain the existing system. Mobility or capacity expansion projects are identified to meet future demands. During the fiscal analysis, agencies identify anticipated funding available from existing and proposed funding sources. Both federal and state agencies have initiated extensive research into different methods to leverage available funding in the short- and long-term. These include, but are not limited to, indexing the gas tax, public-private partnerships, user fee alternatives to the gas tax, and debt financing (*5,6*). After establishing both the highway needs and the expected funding levels, transportation agencies then evaluate candidate projects and select a subset of projects that make up the financially constrained program. Project selection typically involves a combination of earmarked projects and projects identified using a prioritization process. Many agencies are also required to "spread the work" among different geographical areas within their jurisdiction. During the programming process, tradeoffs between different projects or even different program categories such as pavements and bridges are identified and evaluated. In this manner, decision makers can determine how much can be achieved in one asset area by a unit increase or decrease in expenditures in another area under a given fixed budget (*7*).

The ideal programming process should also have a feedback loop to assess the program's effectiveness. Transportation agencies rarely use available data for a post-implementation assessment to complete this feedback loop (*7*). A well-designed monitoring plan is capable of tracking program implementation times and costs. It is also capable of indicating progress toward agency specified goals and objectives using pre-defined performance measures. Although performance measures are routinely monitored regarding facility condition, congestion, safety, etc., these measures are generally only used in the project development process on a project-by-project basis to determine the costs and anticipated benefits of a specific activity or improvement project. The same performance measures already collected for this purpose can and should be used at a system, or statewide, level to evaluate and improve the programming process itself. Improvements to the programming process can further address shortfalls between needs and available revenues.

There are four levels of measureable return from highway investments, as shown in Figure 1.1. The first level of return includes the physical results obtained through investment. For example, physical returns include improvements to pavement condition and bridge condition, additional lane miles, and intermodal connectivity. The second tier of return includes tangible operational improvements such as reductions in the number of crashes and reduction in congestion. Economic development is the third level of return. The relationship between a safe and efficient transportation network and economic progress is well documented (*8*). The physical and operational achievements made through implementation of the transportation program add value to a state's economy through added jobs, increased productivity through the efficient movement of people and goods, and increased personal income. Finally, the fourth level of return encompasses externalities such as improvements to air quality and reduced energy use through decreased congestion.

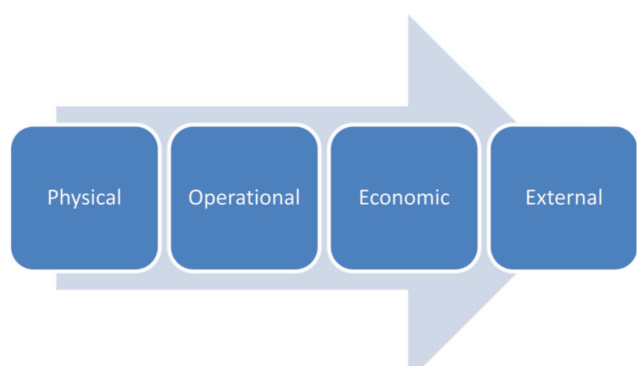


Figure 1.1 Four levels of return on investment.

1.2 Motivation for Present Study

Each year, the Indiana Department of Transportation (INDOT) makes a sizeable investment in the preservation and improvement of the state highway network through its Statewide Transportation Improvement Program (STIP). Careful assessment of the network-level outcomes of these investments is imperative to establish increased accountability of the program and to provide useful data for improving the program development process. At the present time there is not an established methodology to routinely monitor the actual impacts derived from highway investments at the system level.

In the past, there have been several impediments to ex-post facto program-level evaluation. First, quality data must be available for a sufficient period of time. The development of new technology has led to new and enhanced ways to collect and store data. As a result, some current performance measures have only been in use for a short period of time. Previous measurements of condition or operation may not be comparable to current measurements using new methods. By developing a monitoring plan for recurrent post-implementation evaluations, identified data can be collected to improve calibrated models over time. Second, some critical areas of performance may be difficult to measure. In these cases, proxy measures can be used to approximate the relationship between performance areas that are difficult to measure and associated expenditures. Finally, in the past, states did not have a compelling motivation to implement an ex-post facto analysis. The stimuli for adopting a post-implementation evaluation include the declining purchasing power of gas tax revenues and pressure from taxpayers to demonstrate efficient use of money (*8*). Additionally, passage of MAP-21 mandates that state DOTs begin to explicitly link measured performance with transportation expenditure. The current research will give INDOT a methodology for determining the impacts of past investments.

The present study initiates a recurring post-implementation evaluation of state highway investment programs for four specific reasons:

1. **Identification of successes:** Post-implementation evaluation demonstrates whether agencies are making real improvements to the statewide highway system over time. Implementing a monitoring plan allows decision makers to track cash flows, changes to the physical system, and changes in the operational performance of the system. Decision makers can identify progress toward goals.
2. **Quantitatively justifiable decision making:** Models developed during analysis quantify the impacts of expenditures. This information can be used to focus program dollars toward the areas that have the potential to increase the return. Decision makers can identify thresholds above which additional program allocations have marginally decreasing returns. This information can be used to maximize program return.
3. **Improved communications with legislative bodies:** The Government Performance Results Act (GPRA) of 1993 was designed to hold federal agencies, including USDOT, fiscally accountable for achieving goals. The GPRA Modernization Act of 2010 updates the original act to place more emphasis on the use of performance measurement to guide decision making. The emphasis on accountability trickles down from the federal level to state DOTs. MAP-21 specifically addresses accountability for transportation agencies with new performance measurement requirements. An existing post-implementation tool will allow a transportation agency to demonstrate achievement when requesting additional funding from legislative bodies.
4. **Improved communications with non-agency stakeholders:** As public entities, transportation agencies are responsible for using public funding in an efficient and equitable manner. The general public often does not make the connection between the fuel tax that is paid at the pump and the actual cost of constructing, preserving, and maintaining the highway system. Furthermore, the general public does not fully understand the link between the transportation system and the economic viability of a city, region or state. The National Environmental Policy Act (NEPA) requires that the general public be included in the transportation planning and programming processes, including project development, through public workshops and hearings. These meetings do not address the funding requirements for the overall system nor the real returns from the transportation investments. By providing means to demonstrate the effectiveness of the highway investment, ex-post facto evaluation will help transportation agencies garner public and legislative support for providing the needed levels of funding for these necessary programs.

1.3 Scope and Objectives of Research

The primary objective of the current study is to establish a systematic, comprehensive, and robust tool for INDOT to measure and monitor the physical and tangible returns from statewide highway investments. The relationship between expenditures and performance will be explored for the following types of assets:

- Pavements
- Bridges
- Safety
- Mobility (or congestion mitigation)

The models developed in this study define the relationship between achieved results and Indiana's investments over the study period, for most assets for the decade from 2000 to 2009. Similar models can be developed using the same process for other systems or over different time periods. On the basis of the present study, an easy-to-use software-based tool can be developed for subsequent evaluations that can be modified to fit an agency's needs.

The second objective of the present study is to quantify the economic development impacts of statewide highway investment in Indiana. Short-term and long-term impacts, in terms of jobs-added and earnings-added will be quantified using historical expenditure data and economic development models specific to the state of Indiana.

2. CURRENT PRACTICES IN PROGRAM EVALUATION

2.1 State of the Practice

Performance measurement has been widely accepted as an essential tool for public agencies at all levels to measure progress toward stated goals and objectives (*2*). Most states have minimum reporting requirements for all state agencies for major program areas, such as education, health, transportation, and criminal justice. Often the state's minimum reporting requirements do not include program-specific, goal-oriented outcomes, but focus mainly on cash flows. Furthermore, nearly all state DOTs use performance measures at some point in their planning and programming process. The choice of measures and the stage of the planning and programming process at which performance measures are used vary widely. Most often, performance measurements are used to estimate the costs and potential future benefits (typically related to safety and travel time savings) of specific projects during the planning phase (*7*). There is limited use of performance measurement at the statewide level to determine the costs and benefits of the entire program. Rather, transportation programmers add up the estimated project level costs and benefits. This method of determining the value of the investment program is inaccurate. The decision to commit funds in one area of the state on one particular project limits funds available to improve or even maintain transportation assets in other geographic areas. Also, the decision to commit funds to a particular asset category limits funds available for other asset categories. Simply monitoring physical performance alone is not sufficient to determine the effectiveness of transportation investments. State transportation agencies must be able to link expenditures with operational and tangible performances to determine the true value added from investments to the state economy. Performance measurement is an essential tool for ex post facto evaluation. Currently state DOTs do not perform ex post facto evaluations of their programs. At most, DOTs track the cash flows and physical measures of improvements.

A review of the national performance measurement practices was conducted to ascertain the state of the practice in each of the 50 states. This review of practice indicates that performance measurement is limited to extensive data collection with minimal use of the collected data to enhance program development. All states publish documentation, either in quarterly or annual reports, on the condition of various transportation assets. Popular methods of disseminating this information are dashboards and scorecards that include targets, previous values, current values, progress indicators, frequency of measurements, or some combination of these items. The Michigan Department of Transportation (MDOT), for example, recently announced a new infrastructure dashboard on their website (*9*). This online application is simply a new form of providing the previous and current values of 17 performance measures also available through MDOT's transportation scorecard. None of the reported measures, in either the dashboard or the scorecard, are linked to the transportation department's expenditures. Other states report similar content in publicly available reports and/or website applications.

In 2004, the Washington State Department of Transportation (WSDOT) conducted a survey to determine state performance measurement practices and the pressures that motivate changes in those practices (*10*). Using the results of the survey and updates for the American Recovery and Reinvestment Act (ARRA) of 2009, WSDOT maintains a performance measurement library on its website that links to current performance measurement documentation from the transportation agencies for all 50 states and Puerto Rico, as well as national-level performance measurement resources. The authors of the WSDOT survey found that, although there have been numerous research projects on the benefits and challenges of implementing a performance measurement system, there is minimal information available regarding how practitioners have developed and advanced existing systems.

In the generational concept developed by Bremmer et al. (*10*), states begin with a standard set of measures that are required by their individual state legislatures. Even though both expenditure and performance data are collected and made available to the public, the data are not used jointly for decision-making purposes. The next generation of performance measurement is to create a hierarchy of performance measures, including some that are more difficult to measure, such as meeting societal goals and customer expectations. Dashboards, trackers, scorecards, and quarterly reports are typically adopted at this phase for the reporting tool. Often the number of performance measures has grown substantially between the first and second generation. The reporting tool of second generation DOTs serves as an extensive list of many performance measures that are not tied to each other. The third, or most mature, generation of performance measurement practices includes agencies that continually adapt existing practices to meet new needs stemming from a new administration, shortfalls in funding, or new legislative requirements. In this phase, DOTs narrow their focus from hundreds of measures to select measures that are most relevant to specific goals. Third generation agencies are at the forefront of performance measurement practices, but these agencies still have not established the feedback loop to assess overall program performance. The present study aims to bridge the gap between third-generation performance measurement practices and a fully developed, ex-post facto program evaluation that completes the feedback loop between program implementation and an improved program development process.

In addition to individual state practices, the Federal Highway Administration (FHWA) of the USDOT requires all states to report annually on income, expenditures, and performance. The data are published annually in FHWA's *Highway Statistics* series (*11*). Finance summaries include the money that is collected by each state through the fuel tax and registration fees and the money that is expended through various capital, safety and maintenance programs. Performance data are submitted through the FHWA's Highway Performance Monitoring System (HPMS) (*12*). Ideally these two sets of information can be used to determine the relationships between changing highway conditions and varying expenditure levels on a program-wide basis. The reports mandated by FHWA are the only uniform reporting system for all states and have been fairly consistent over time. Even with FHWA's standard reporting system, states are given significant latitude in accounting methods and the time period covered for each submittal. Thus, even the "uniform" reporting varies widely from state to state.

Nilsson et al. (*13*) found that the costs of construction activities could not be tracked through the project life-cycle from the beginning—"the government's long term investment program"—through to the "cost realization" in an accounting system. The researchers attempted to follow the costs of various projects throughout the life cycle to compare preliminary costs with final costs. As a result, the researchers found that currently program expenditures are not consistently tracked through the system, but that a method to trace expenditures would be inexpensive to implement. The Nilsson et al. study demonstrated that there is a need for ex post facto assessments of when and where public agency investments are made. While the study considered the transportation expenditures made by the Swedish government, the procedure of an investment tracking system is transferable to state DOTs in the United States.

2.2 State of the Art

Since 1993, the Hartgen Group has released 19 annual reports aimed at evaluating the cost-effectiveness of state owned highway systems. The most recent report (19th Annual Report) contains data from 1984–2008 (*14*). States are ranked using four expenditure indicators:

1. Capital disbursements per mile
2. Maintenance disbursements per mile
3. Administrative disbursements per mile
4. Total disbursements per mile

Seven performance indicators are documented as follows:

1. Percentage of rural interstate pavement in poor condition (IRI > 170 inches per mile)
2. Percentage of rural other principal arterial pavement in poor condition (IRI > 220 inches per mile)
3. Percentage of urban interstate pavement in poor condition (IRI > 170 inches per mile)
4. Percentage of urban interstate miles with volume to service flow ratios (VSF) greater than 0.70
5. Percentage of rural other principal arterials with narrow lanes (width < 12 feet)
6. Fatalities per million vehicle miles traveled
7. Percentage of bridges that are structurally deficient of functionally obsolete

Each indicator is normalized by an average national performance indicator weighted by the number of miles on each state system. The four expenditure indicators are then multiplied by the ratio of the national average number of lanes per centerline mile (2.38 lanes per mile for 2008) to the individual state's number of lanes per centerline mile. For example, for the 2008 rankings, each of the four normalized expenditure indicators in Indiana was multiplied by the ratio 2.38/2.54 because Indiana had 2.54 lanes per centerline mile in 2008. The multiplier is intended to give states with more lanes per centerline mile "credit for extra per-centerline-mile costs" (*14*). The overall state performance rating is the sum of the normalized performance indicators and normalized expenditure indicators multiplied by the average number of lanes per centerline mile ratio. States are ranked by the value of the overall state performance rating, with the lowest sum ranked as the best.

The Hartgen report consistently finds that relatively small, rural states are the "best performers" because the methodology favors those states with lower total expenditures per mile. Smaller, rural states typically require lower total expenditures per mile than states with large urban areas, high traffic volumes, mountainous topography, or severe weather (*15*). The results of the Hartgen reports are biased because they ignore important differences between states. The results have been criticized by both FHWA and individual state DOTs for this flaw in the methodology (*16*). Another drawback of the Hartgen rankings is that the relationship between expenditures and results is not explicitly considered. The overall state performance rating combines the relative performance and relative expenditures for each state into a single measure. This does not provide information, for example, about how the capital disbursements per mile (an expenditure indicator) are related to the percentage of rural interstate pavement in poor condition (a performance indicator). The Hartgen reports miss the mark in program evaluation because state-to-state differences in programming needs are not accounted for and the relationship between investment and performance is muddled by combining inputs into a single measure.

In developing a multi-attribute utility methodology for asset management, Gharaibeh et al. (*17*) used regression models to establish the relationship between investment and network level performance for a case study in Champaign County, Illinois. They found that the functional form $y = \alpha X^{\beta}$ was the best fit for the relationship between performance and investment. The functions developed in their study related the percentage of pavement, bridge, intersection, culvert, and sign assets in adequate condition with funding for each year of a hypothetical five-year program. Although data from the network were used to develop the equations, Gharaibeh et al. (*17*) ignored time lags and the effects of other investments. The models were then used as a prediction tool to determine the benefits from investments as an input for asset management system methodology, where the information was used ex-ante rather than ex-post because decisions were based on anticipated outcomes. The current study improves upon the asset management system methodology because post-implementation evaluation can be used to compare the benefits actually achieved to those predicted in the optimization routine of an asset management system.

Hendren and Niemeier (*16*) characterized the relationship between eleven different expenditure categories and measures of safety and mobility performance. The expenditure categories came from Table SF-4C "Disbursements for State-Administered Highways" and Table SF-12A "State Highway Agency Capital Outlay" in FHWA's *Highway Statistics*. Similar to the data used in the Hartgen Group reports, safety was measured by the number of fatalities per 100 million VMT. Mobility was measured using the percentage of miles with a volume to service flow rate ratio (VSF) of less than 0.70. The authors used 17 years of FHWA's *Highway Statistics* data to estimate individual models for each state and Washington D.C. The authors noted that their developed models did not "provide a clear picture of the relationship between expenditure categories and performance" because coefficients of one expenditure group—major widening, for instance—were positive for some states and negative for others. The authors correctly chose to model each state separately, but the final results might not have fully accounted for differences in the traffic demand each state must accommodate. The results did indicate that expenditures in urban areas would not have the same performance effects as equal expenditures in rural areas. For some expenditure categories, such as traffic control devices and intelligent transportation systems, the greatest benefit is in urban areas. It makes sense that other expenditures, like widening and new construction, are more effective in rural areas because the costs of urban projects are higher due to right-of-way costs, but the benefits are similar. Hendren and Niemeier (*16*) also found that existing conditions impact the effectiveness of investments. Existing conditions are important because expenditure and performance are not proportional—when performance is above average, greater expenditures are necessary for additional improvement. Hendren and Niemeier also recommended explicit consideration of time lags in future research because the impacts or benefits of an improvement are not immediately available to motorists. The appropriate time lag is not always apparent because it will vary for different assets and between maintenance improvements and complex capacity improvements.

Oh and Sinha (*18*) used 10 years of *Highway Statistics* data from the 50 states and the District of Columbia to evaluate the effectiveness of expenditures. Two dependent variables were considered: (1) the percentage of road miles with IRI less than or equal to 95 inches per mile, and (2) the percentage of road miles with IRI less than or equal to 170 inches per mile. Linear regression was used to model each percentage as a function of previous conditions, per-mile capital expenditures, per-mile maintenance expenditures, and travel demand. Oh and Sinha explored different time lags by estimating models with expenditures over different periods of time. The results indicated that investments made in the previous year had the most significant effect. Their study used data from each state to describe, at a national level, the positive effects of investment and negative effects of demand.

Similarly, Anastasopoulos et al. (*19*) studied the relationship between pavement performance and preservation expenditures, dominant geology, and climate at the national level using state-level data. Rather than model each state individually, the data from each state in each year were treated as a single observation to create a national model. Therefore, for eight years of data on each of the 50 states and Washington D.C., there were 408 observations. The large dataset allowed the researchers to employ a mixed logit model to estimate the proportion of kilometers in each of four categories of IRI measurements. The authors corrected for surface geology and climate differences from state to state. Like related studies, the authors only normalized preservation expenditures by the number of lane-kilometers. This did not account for state-to-state investment need differences arising from differences in urbanization and traffic volumes. The use of random parameters allowed the models to capture the unobserved heterogeneity from different traffic volume levels, etc.; however, decision makers need state-specific parameter estimates to assess their own investment program. Although national models are useful as prediction tools, state-specific estimations are necessary for ex-post facto program analysis to complete the feedback loop for improved program development.

Overall, there is a lack of published research available to guide individual state DOTs to determine the ex-post facto impacts from investment at a system-wide level. This research attempts to close that knowledge gap.

3. STUDY METHODOLOGY AND DATA COLLECTION

3.1 Physical and Operational Impacts Evaluation Methodology

As discussed in Chapter 2, previous research in the area of program evaluation has been unsuccessful in one of three ways: (1) national studies have neglected state-to-state differences in programming goals, (2) cash flows and/or physical impacts have been monitored over time but the collected data have not been used together to evaluate the program, or (3) the analysis has been ex-ante rather than ex-post facto. The purpose of the current study is to address these issues by explicitly relating state-level expenditures with performance. State-specific analysis is necessary because the program is established and implemented by the state transportation agency. MPOs develop their own transportation improvement plans and programs, which are subsequently incorporated into the statewide plans and programs. Consequently, program evaluation can also be carried out at the MPO level using expenditure and performance indicators appropriate for a specific MPO. The current study used the INDOT program to demonstrate the developed post implementation methodology; therefore highway expenditure and performance measures related to INDOT's goals were used. The framework developed herein must be adapted before evaluating a different agency's program because stated goals and objectives are an integral part of the programmatic process. The only way to accurately evaluate the effectiveness of the program is through measurements that directly reflect the goals of the evaluated program.

Given the explicit emphasis on performance-based management in MAP-21, there is an obvious need for a performance-based program evaluation protocol. However, this type of study has not been undertaken to date. The primary reasons for a lack of focused research in program evaluation are the complexity of data collection and limitations in existing analytical evaluation methods. Although transportation agencies routinely monitor the condition of transportation infrastructure, the tools available for measuring condition and afterward storing the collected data have changed over time. New technology allows for improved monitoring, but cannot be applied to past condition assessments. As such, in selecting performance measures for use in the evaluation, researchers must strike a balance between those measures that best characterize performance and those measures for which sufficient historical data are available. The poor data availability limits the appropriate analytical approaches. Statistical and econometric techniques must be applied with careful consideration of the sample size.

The first, and most important, step in conducting an initial program evaluation for INDOT is selecting measures that accurately reflect the department's goals and objectives. If appropriate measures are not selected, the evaluation will not provide an accurate picture of the effectiveness of the program in achieving the desired end results. The implementation of ex-post facto program evaluation itself will serve to meet two of INDOT's five stated goals (*20*):

1. "Operate, maintain, and preserve INDOT's existing roadways and bridges. Actively manage cost-effective and innovative agency actions to ensure INDOT's pavement, bridge condition, and traffic safety ratings or are sustained.
2. Vigorously communicate INDOT's mission and values to employees, partners, and customers. Utilize innovative methods to create and sustain the awareness of INDOT's mission and values to engage employees and provide a positive work environment."

To meet these overall goals, INDOT has developed internal objectives that serve as benchmarks to indicate if a goal is being achieved. For example, objectives include the percent of bridges to maintain at a given condition or to reduce crashes by a certain percentage (*21*). These objectives are used in the planning and programming process. As such, the same performance measures that are used to evaluate potential projects and prioritize project selection were used in the program evaluation in the present study. After interviewing the directors of several INDOT divisions responsible for programming decisions to determine the appropriate measures, data were collected for those performance measures and expenditures for as many years as available.

Concurrent with the initial post-implementation evaluation conducted in this research, a methodology and corresponding software-based tool were developed for future evaluations. The collected data were used to characterize the relationship between actual expenditures and actual results over the study period. The estimated parameters of the models can be compared with the models used in estimating the costs and benefits of candidate projects. The findings will help INDOT identify differences between anticipated outcomes and those actually achieved in the past. This will improve decision making. The findings will also help INDOT demonstrate effectiveness of past investments when requesting future funds. As future data are collected, INDOT can perform subsequent evaluations to validate the relationship between resources and outcomes as well as determine if changes to programming procedures are more cost-effective than previous practices. The protocol for these future evaluations can be used, with appropriate modifications, by other transportation agencies.

3.2 Data Sources

The database compiled for this study includes expenditures in four asset groups and the values of selected performance measures to assess the physical condition or operation of those assets. The data were aggregated by calendar year because various performance measurements are made at different times throughout the calendar year and expenditures data were available by letting date. Thus, there is a measure of performance and a total amount of expenditures for each calendar year. Additionally, the data were classified using two road classification systems to account for differences in the significance of different road classes (and their analogous assets) in providing a safe, efficient, and economic transportation system.

In 1995, the U.S. Congress approved the National Highway System (NHS) which includes the roadways that are most vital to the nation's mobility, economy, and defense. First authorized under ISTEA, the NHS was designated so states could focus money on these most important routes. In addition to the Interstate system, key non-Interstate routes are designated part of the NHS. The NHS carries over 40% of the country's total highway traffic, including 75% of heavy truck traffic, while only representing approximately 4% of the centerline mileage (*22*). SAFETEA-LU specifically authorized funds to be spent on improving and maintaining the NHS. Even though the entire Interstate system is a part of the NHS, SAFETEA-LU also authorized additional funds specifically for preserving and improving the nation's Interstates. In the present study, the data were classified into Interstate, non-Interstate NHS, and non-NHS expenditures and performance because INDOT's program is influenced by the amount appropriated for each road classification.

Unfortunately, safety performance data were not available in accordance with the NHS/non-NHS designation. The safety data were available at the level of Interstates, U.S. Routes, and State Roads. Therefore, both expenditure and performance data for safety were considered using these route type classifications.

The following sections describe the sources of individual data as well as data collation efforts.

3.2.1 Expenditures

In the present study, for a given year the sum of the contract letting amounts over the calendar year represent the expenditures for that year. These data were provided from INDOT's Scheduling Project Management System (SPMS). This client-based server houses all of the data on INDOT's past, current, and future projects programmed to begin in the next year. The data used for this project were taken from a Microsoft Excel export of the SPMS on April 4, 2011. The exported data include the contract letting amount, the letting date, and other project-specific information. The letting date is the date on which a contract is awarded by INDOT. The actual construction does not begin until five (5) months to one (1) year after the letting date. Depending on the type of project, the construction is typically several months to two (2) years to completion. For the purposes of this study, expenditures were considered a part of the calendar year in which the contract letting date occurs. A moving average of annual expenditures is used to account for projects that do not begin construction during the calendar year of the letting date or for which construction spans multiple years. The contract letting amount is the amount obligated at the time of letting and does not reflect the final costs of projects. For purposes of this analysis, the cost overruns and underruns were assumed to be similar from year to year. The SPMS letting amounts were used as a representation of the actual expenditures in any given year.

The designation number assigned to each project was used to match each observation to a road classification—Interstate roadway, NHS roadway, or non-NHS roadway. Prior to 1993, the term NHS was not used for road classification; thus for records before 1993, the codes Primary, Secondary, and Urban were used to define the road classification. The road classifications prior to 1993 are not exactly analogous to current road classification designations. The current analysis does not include data for years prior to 1993; therefore, the different classifications used prior to 1993 do not impact the results. For this project, non-NHS expenditures include all expenditures on INDOT maintained roads that are not an Interstate or part of the NHS. These include routes on the Federal-Aid Highway System that are eligible for federal funding (but not the highest priority) and those that are not Federal-Aid highways. Projects that include work on multiple road classifications were classified as being non-NHS expenditures because they were not eligible for the same funding as those exclusively on the Interstate system or the NHS. Neither expenditures nor performance data pertaining to Interstate 80/90 (I-80/90), also called the Indiana Toll Road (ITR), were included in the database because the link between investment and performance is different for a public-private partnership tolled facility than for non-tolled publically owned and maintained roadways.

Several projects were removed from the SPMS snapshot for the present study. Railroad projects were removed because SAFETEA-LU separately apportions funds for the Railway-Highway Crossings program before apportioning funds for the Highway Safety Improvement Program (HSIP). Observations with the following "Work Type" entries were removed from the database:

- Railroad Crossing
- Railroad Crossing Removal
- Railroad Protection
- Railroad Protection and Surface
- Railroad Work

Projects on roads or parking lots within state parks, prisons, and other state-owned public facilities and not on state highways were also removed from the database. Expenditure observations with the following "Work Category" entries were removed from the database:

- Cooperative Recreational Access Road Project
- District Access Control Project (Roadside Fencing)
- DNR Properties Project (Bridge)
- DNR Properties Project (Road)
- Environmental Mitigation Project
- Indiana Toll Road Contracts
- Institutional Road Project
- Local Bridge Project
- Local Road Project
- Non-Highway CMAQ Project
- State Transportation Enhancement Project

Finally, direct payments to local governments to transfer jurisdiction of the roadway from INDOT to a local agency were also eliminated from the database.

For some projects, the "Work Type" field was not populated in SPMS and additional exploration of the contract was necessary to populate this field. The missing entries were added with the assistance of John

Weaver, Director of Financial Systems Integration at INDOT. The resulting list is shown in Appendix A.

Entries for "Work Type" were used to define an additional "Asset" field for each observation, using a lookup table provided with the original SPMS export. The asset lookup table, found in Appendix B, provided a systematic method to assign each expenditure to a single asset group. This information was used to determine the relative effects of expenditures in each asset group on the performance of each asset group. Projects that are classified for one asset group often affect the performance of other assets. For example, asphalt patching will improve the pavement condition and also can have a positive effect on mobility and safety performance. The developed models account for simultaneity of different expenditures by including the expenditures for each asset group as individual independent variables. Including each observation in multiple asset groups according to all assets that are affected by a given project would lead to double counting. Double counting would lead to an inaccurate tradeoff analysis.

In addition to missing information about projects that came in over- or under-budget compared to the contract letting amount, there are two additional reasons the SPMS snapshot is not a complete accounting of all expenditures. The snapshot taken of the SPMS database contains entries from 1983 to 2011. For the 1980s and early 1990s, there are very few projects in the database, likely because the data were not back-entered into SPMS, which did not exist when those projects were let. The SPMS was first launched in the late 1990s. Missing data from this early period do not affect the results of the current study because corresponding performance data are not available for those years. For some project entries with letting dates in the late 1990s and the 2000s, after SPMS was launched, incomplete information is available. In some cases, the contract letting amount is not recorded. The missing data from this later period likely are omitted because the original SPMS did not connect to all of INDOT's other systems and required duplicative data entry (*23*). Following an influx of money from leasing the ITR, INDOT began an upgrade of SPMS that was launched in 2010. The updated SPMS is integrated with other INDOT systems to eliminate duplicative data entry, ensuring more complete data in the future. As a result, subsequent program evaluations will not have specification errors caused by incomplete expenditure data. Missing information in the database for the current project reflects flaws of the original SPMS system that have since been corrected.

The percentage of project entries listed in the SPMS database that do not have a contract letting amount is shown in Table 3.1. For 2001, approximately one-third of all records do not contain a contract letting amount. The 2002 records are almost entirely complete. It can be assumed that the distribution of project expenditures does not change from year to year. If true, the samples of projects with contract letting amounts listed in SPMS from two consecutive years would not be significantly different.

TABLE 3.1
Percentage of Project Entries Missing Contract Letting Amount in SPMS

Year	Bridge	Pavement	Mobility	Safety
1995	0%	0%	0%	0%
1996	0%	0%	0%	0%
1997	0%	1%	0%	0%
1998	1%	5%	4%	1%
1999	6%	16%	5%	3%
2000	9%	27%	12%	9%
2001	31%	36%	30%	34%
2002	4%	8%	0%	8%
2003	4%	0%	4%	3%
2004	1%	0%	0%	4%
2005	1%	0%	0%	1%
2006	18%	0%	8%	2%
2007	0%	0%	12%	1%
2008	3%	1%	3%	0%

Hypothesis testing was used to test for significant differences between the distribution of projects listed in 2001, which had entries missing contract letting amounts, and the distribution of projects listed in 2002, which were nearly complete. If the hypothesis test indicates that the distributions of expenditures are significantly different between 2001 and 2002, the 2001 data should be excluded from the current study because the SPMS data are not representative of actual expenditures. If there is not a significant difference, the SPMS data can be used as a representation of actual expenditures.

The Wilcoxon Rank-Sum Test is a nonparametric method to test the null hypothesis that two populations have the same distribution (*24*). The nonparametric Wilcoxon Rank-Sum Test was used for this study, instead of a parametric method, because the distribution of project costs does not follow a normal (or other known) distribution. The Wilcoxon Rank-Sum Test was applied to each asset group separately to test whether the distributions of the 2001 and 2002 projects were the same. For each asset group, the records in both years were ranked by the contract letting amount, regardless of the year. In cases of a tie, the rank of each record was the arithmetic average of the ranks that the records would have had if there were not a tie. The sum of the ranks for each sample (w_i) could have been used to directly test the null hypothesis that the two populations have the same distribution. It was more convenient to transform the sum of each sample into the test statistic (U_i) using the following equation because critical values for the U distribution, which is symmetric, are easier to determine:

$$U_i = w_i - \frac{n_i(n_i+1)}{2}$$

when the size of both samples is greater than 8, the sampling distribution of U approaches the normal distribution with mean

$$\mu_{U_1} = \frac{n_1 n_2}{2}$$

and variance

$$\sigma^2_{U_1} = \frac{n_1 n_2 (n_1 + n_2 + 1)}{12}$$

Therefore, the test statistic

$$Z = \frac{U_1 - \mu_{U_1}}{\sigma_{U_1}}$$

can be compared with the critical region of the standard normal distribution. The number of project entries with contract letting amounts was greater than 8 for each asset group in both years; therefore the normal approximation was used. As shown in Table 3.2, for all asset groups, the null hypothesis that the distribution of projects in years 2001 and 2002 are the same cannot be rejected at the 95% confidence level. All of the Z-scores are less than 1.96, the critical value of the test statistic at the 95% confidence level. Therefore, even with a large percentage of incomplete records, the SPMS letting amounts can be used as a representation of actual expenditures in 2001.

Expenditure data were adjusted for inflation (base year 2003) using the Construction Price Index (CPI), also referred to as Bid Price Index (BPI), and the National Highway Construction Cost Index (NHCCI). Data for years prior to 2003 were adjusted with the composite index for Federal-Aid Highway Construction that was developed by FHWA with a 1987 base (*25*). In 2006, the NHCCI was established to replace the BPI with an index that is not tied to a 1987 base and better reflects the changing purchasing power of highway expenditures (*26*). The NHCCI was first developed using 2003 data. For the present study, the annual averages of the NHCCI quarterly indices were used to adjust expenditures after 2003.

3.2.2 Pavement Performance

INDOT uses the International Roughness Index (IRI) to measure pavement quality. IRI is a common measure of the vertical deviations (both up and down) of the surface of the pavement from a true planar surface, typically in units of inches per mile, along the traveled path. IRI measurements are collected in 0.1-mile increments in each wheel path of the outside lane in both directions of travel. The measurements for each wheel path can be averaged and the 0.1-mile increments can be aggregated into 1.0-mile segments, because IRI is independent of section length. Average IRI between the right and left wheel path for 1.0-mile road segments between 2000 and 2009 were used in this study. IRI measurements were collected on all miles of the Interstates annually during the study period. For the remaining INDOT roads, IRI data were only collected every other year between 2000 and 2005, then annually beginning in 2006. For the period between 2000 and 2005, most non-Interstate roads in Crawfordsville, Vincennes, and Seymour districts were surveyed in even numbered years while most non-Interstate roads in Fort Wayne, Greenfield, and LaPorte districts were surveyed in odd numbered years. The sample of roads in each of these years represents the same distribution of non-Interstate NHS roads and non-NHS roads from year to year. Because the southwest districts were surveyed in even numbered years and the northeast districts were surveyed in odd numbered years, some slight differences in the overall condition of the non-Interstate roads surveyed in each of these years may have occurred due to climate differences. The proportion of surveyed miles in five levels of performance were determined for each year and each road classification (Interstate, non-Interstate NHS, non-NHS) using INDOT's standard classification system as shown in Table 3.3.

IRI measurements from the ITR were not included in the database for the present study.

3.2.3 Bridge Performance

In accordance with National Bridge Inspection Standards (NBIS), INDOT inspects all state owned and maintained bridges on a two-year inspection cycle. Primary bridge elements—deck, superstructure, and substructure—are rated on a 0 to 9 scale, with 0 being failed condition and 9 being excellent condition. The condition ratings describe the current condition of the entire bridge element compared to the as-built condition. The structural evaluation of the bridge is calculated by the FHWA Edit/Update Program as the minimum of the substructure rating, superstructure rating, and the rating provided by comparing the average daily traffic (ADT) and the inventory rating, which is a measure of the maximum load that can be placed on a structure indefinitely (*27*). The structural evaluation from the National Bridge Inventory (NBI) for all inspected INDOT-maintained bridges in the

TABLE 3.2
Results of Wilcoxon Rank Sum Test for Differences between 2001 and 2002 Project Cost Distribution

Asset	n_1 (2001)	n_2 (2002)	μ_{U_1}	$\sigma^2_{U_1}$	U_1	Z
Bridge	140	158	11060	551156.7	10503	-0.750
Pavement	110	132	7260	294030.0	7343	0.153
Mobility	14	22	154	949.7	165	0.357
Safety	150	180	13500	744750.0	14619	1.297

TABLE 3.3
IRI Performance Level Definitions

	Excellent	Good	Satisfactory	Fair	Poor
IRI	< 80	< 115	< 150	< 170	≥ 170

years between 1992 and 2009 were used in this study. The proportion of inspected bridges with structural evaluations in five levels of performance were determined for each year and each road classification (Interstate, non-Interstate NHS, non-NHS) using INDOT's standard classification system as shown in Table 3.4.

Only bridges maintained by the State Highway Agency were included; those maintained by local agencies, private entities, or located at Camp Atterbury were omitted. Bridges on the ITR were also removed from the database. Data were omitted for each bridge in the years in which a given bridge was not inspected because the ratings do not change from the previous year if the bridge has not been inspected. Structures that carry or cross only a pedestrian walkway were removed from the database. Culverts were not included in the analysis.

3.2.4 Mobility Performance

Mobility data were obtained from INDOT's annual Highway Performance Monitoring System (HPMS) submittals to FHWA. FHWA requires only basic inventory information be reported on all segments of roadways that are open to traffic. More detailed information is required for a selected standard sample that is statistically chosen to represent all road classes except for rural minor collectors, rural local roads and urban local roads. The volume to service flow ratio (VSF) is used as a measure for peak hour congestion. VSF is only reported for the standard sample. VSF is calculated using the Highway Capacity Manual (HCM) 2000 methodology. The standard sample includes road segments that are not owned by INDOT. Only data from sample segments that are owned by INDOT were included in the database. Similar to the data for bridge and pavement performance, VSF data for segments that are on the ITR were omitted. Data for segments designated as in a rural area were omitted because congestion is less likely to occur in these areas. The proportion of sample miles that have a VSF greater than or equal to 0.70 is determined for each year and each road classification to measure the extent of congestion in the statewide network. The VSF value of 0.70 is consistent with previous research that identifies 070 as the lowest critical VSF for identifying congestion for a variety of facility types and area types (*28*).

TABLE 3.4
NBI Structural Evaluation Performance Level Definitions

	Excellent	Good	Satisfactory	Fair	Poor
NBI Rating	8 or 9	7	6	5	4 or below

3.2.5 Safety Performance

Counts of fatal and non-fatal injury crashes by year, road class, and urban or rural classification were provided by Jose E. Thomaz, Data Warehousing Administrator at the Center for Road Safety, as shown in Appendix C. The rural and urban counts were combined in the analysis because the expenditures were not divided by this classification. Only crash counts for Interstates, U.S. Routes, and State Roads were included because county, local/city, and other roads are maintained by local agencies. Fatal and non-fatal injury crash counts were summed for each system because the frequencies of fatal crashes are extremely low. The summation of all injury-only and fatality crashes is less variable than fatalities alone. Typically, project-level safety analysis is carried out using a three-year average crash rate because there are low frequencies of crashes at any one location. For this study, each year is an individual observation because there is a limited amount of data available and by using aggregate data at a statewide level, geographic differences around the state were assumed to account for low frequencies at any one location. Crash frequencies for each year and each route type were calculated using the crash counts shown in Appendix C and vehicle miles traveled (VMT) calculated from the section lengths and average annual daily traffic (AADT) provided in HPMS.

4. INDOT PROGRAM EVALUATION

4.1 Performance Trends

The initial program evaluation involved an analysis of the expenditures and performance over time. The first analysis step was to examine time series plots of performance in each of the asset groups for the analysis period. The time series data demonstrate whether the condition of the physical assets are improving, deteriorating, or remaining the same over the study period and whether the operational assets are functioning better, worse, or the same over time. As discussed in Chapter 2, state DOTs with second- and third-generation performance measurement practices regularly report the current and past condition of assets via the internet and print resources. Before assessing the relationship between investment and outcomes, the benefits derived from the investment should be published for agency and non-agency stakeholders to access. A condition assessment over the study period provides this information.

Currently, INDOT publishes the condition of selected assets in the Capital Program Report available on the INDOT website. The most recent report, *INDOT Capital Program Report, Fiscal Year 2011*, includes the condition of pavements and bridges for years 2006, 2011, and projections for 2016 (*29*). Aggregate performance data for years prior to 2006 and between 2006 and 2011 cannot be easily accessed by the public on INDOT's website. An important step in establishing accountability is to present the state of good repair of the infrastructure. Furthermore, after the 2016 performance data are collected, the actual condition should be compared to projections included in the 2011 Capital Program Report. The following sections describe the physical and operational performance of INDOT assets over the years for which data were available.

4.1.1 Pavement Performance, 2000 to 2009

The pavement performance was documented by the IRI data. As previously discussed in Chapter 3, the data were summarized by road classification as well as for the statewide system as a whole. The proportion of the total surveyed roadway miles, independent of road classification, in each of the five performance levels (as found in Table 3.3), for years 2000 to 2009 are shown in Figure 4.1. Between 2000 and 2002, there was a slight decrease in the proportion of pavements in excellent condition (IRI $<$ 80 inches/mile). After 2002, there was a steady increase in the proportion of pavements in excellent condition and a corresponding decrease in the proportion of pavements in either fair or poor condition (IRI $>$ 150 inches/mile). Time series plots of pavement performance for each road class—Interstates, non-Interstate NHS roadways, and non-NHS roadways, are included in Appendix D. Similar pavement performance trends held for each road class individually as for the statewide system.

4.1.2 Bridge Performance, 1992 to 2009

Bridge performance was measured by the NBI structural evaluation ratings. The proportion of all Indiana bridges inspected in a given year, independent of road classification, in each of the five performance levels (as found in Table 3.4), for years 1992 to 2009 are shown in Figure 4.2 Note that for 1992, the NHS designation did not exist; therefore, for 1992, the data represent the inspected Interstate bridges for that year. The proportion of bridges in each performance category fluctuated over time; however the proportion in fair and poor conditions (structural evaluation of 5 or less) has decreased steadily since 1993. Time series plots of bridge performance for each road class—Interstate bridges, non-Interstate NHS bridges, and non-NHS bridges—are included in Appendix E. Similar trends held for the bridge condition in each road class individually as for the statewide system.

4.1.3 Mobility Performance, 2000 to 2009

Mobility performance was represented by extent of network level congestion. Congestion is measured by the ratio of volume to service flow (VSF) during the peak hour as calculated by HPMS. For this study, network level congestion was defined as the proportion of sample miles with a peak VSF greater than or equal to 0.70. The VSF threshold is consistent with the congestion management system developed for INDOT (*28*). Figure 4.3 shows the proportion of the sample of roadway miles with a VSF ratio greater than or equal to 0.70 for years 2000 to 2009, by road class and for the system as a whole. For Interstates, congestion increased between 2000 and 2004, and then decreased over the remainder of the analysis period. For non-Interstate NHS facilities, for non-NHS facilities, and for the overall statewide sample with all road classes combined, the proportion of facilities that experience peak hour congestion decreased over the entire study period, 2000 to 2009, with a slight increase from 2001 to 2002. As expected, there was more congestion on non-Interstate NHS roads than on non-NHS roads for all years.

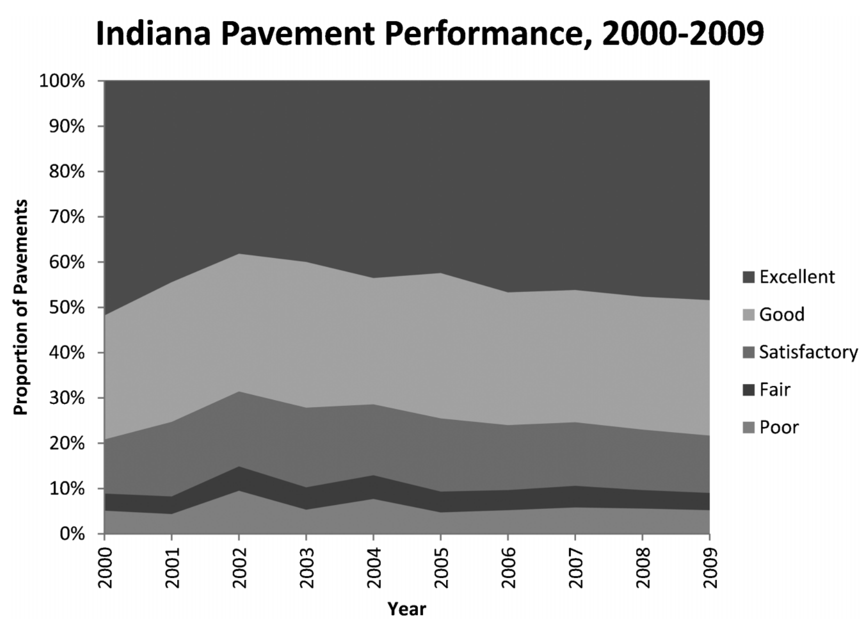


Figure 4.1 Time series of statewide pavement performance.

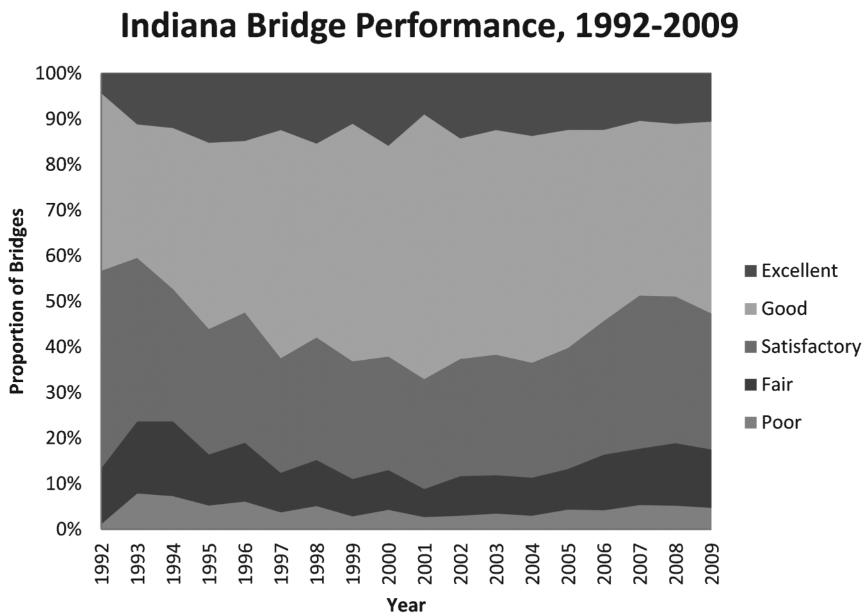


Figure 4.2 Time series of statewide bridge performance.

4.1.4 Safety Performance, 2003 to 2009

Safety performance was measured by the sum of non-fatal injury and fatality crashes per 100 million VMT. The crash rates are shown in Figure 4.4 for each route type—Interstates, U.S. Routes, and State Roads—and for the entire statewide system. As expected, the crash rate was much lower on the Interstate system than on other route types for all years. Similarly, the crash rate was lower on the U.S. Routes than on State Roads for all years analyzed. For all route types and the system as a whole, the crash rate has dropped slightly over the entire study period, with a larger decrease from 2006 to 2008 and slightly flatter change from 2008 to 2009.

4.2 Expenditure Trends

Reporting on the condition of transportation assets over time is only the first step in an ex post facto program evaluation. The post-implementation analysis herein seeks to determine what physical and operational benefits were achieved for the dollars expended through the transportation investment program. As described in Chapter 3, construction letting amounts were assigned to specific asset groups using the lookup table found in

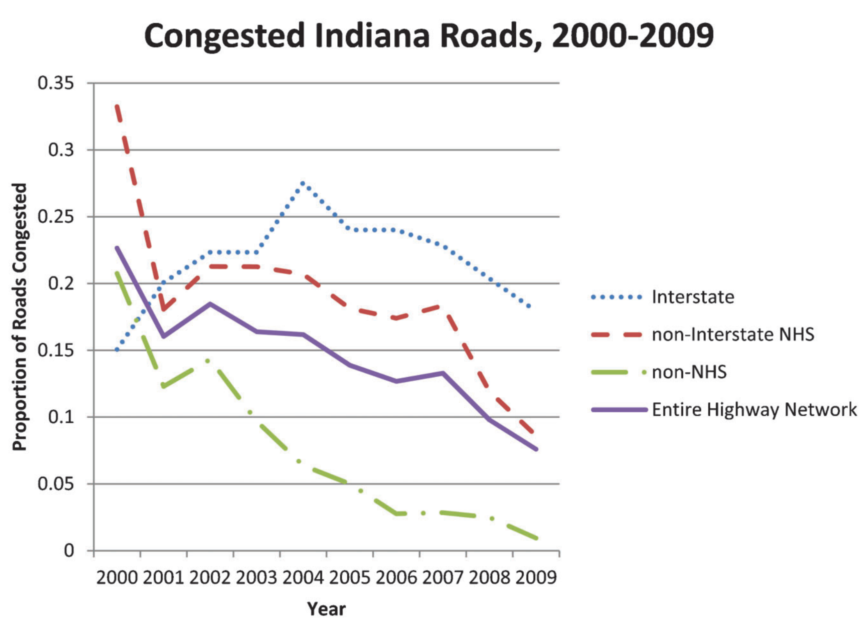


Figure 4.3 Time series of mobility performance.

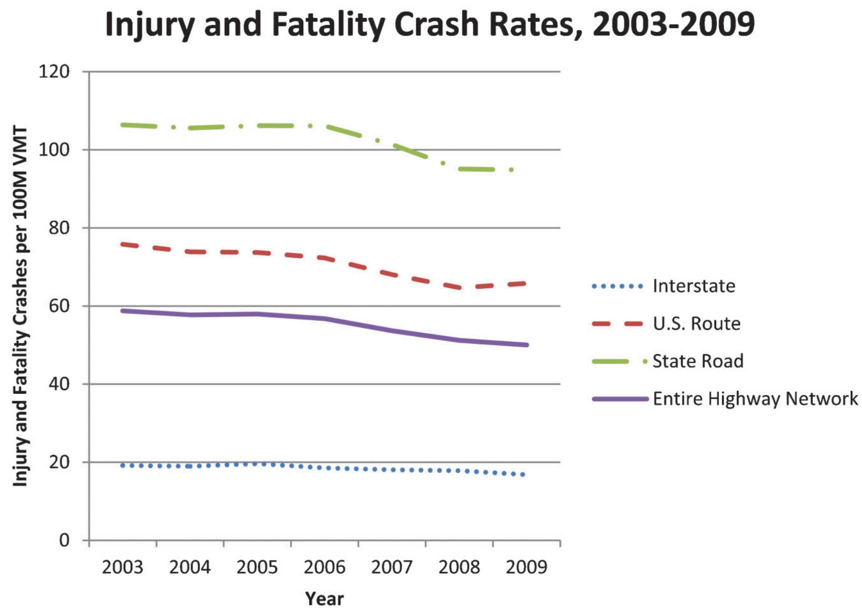


Figure 4.4 Time series of safety performance.

Appendix B. Figure 4.5 shows the total expenditures and the expenditures in each asset group, between 1995 and 2010. The expenditures were all adjusted for inflation and expressed in constant 2003 dollars. These expenditures, in adjusted 2003 dollars, fluctuated from year to year between 1995 and 2006. Between 1996 and 2006, there was no clear trend of increasing or decreasing expenditures, either in total or for any individual asset group. During this period, the fluctuations might have been the result of real fluctuations in the sum of contract letting amounts in each calendar year after adjusting for inflation or may reflect projects that were never entered into the SPMS database. In 2005, there was a decrease in INDOT expenditures. This coincided with a decrease in the federal appropriations to individual states. Prior to enactment of SAFETEA-LU in August 2005, surface transportation was funded through extensions of TEA-21. The fourth extension of TEA-21 adjusted the amount appropriated to each state based on the Revenue Aligned Budget Authority (RABA) (*30*). This also coincided with the transition from the Crossroads bond program to the Major Moves initiative that started in 2006 (*31*). Since 2006, there was a clear trend of increasing expenditures, especially on Mobility projects. The increase in expenditures reflects the impact of the Major Moves

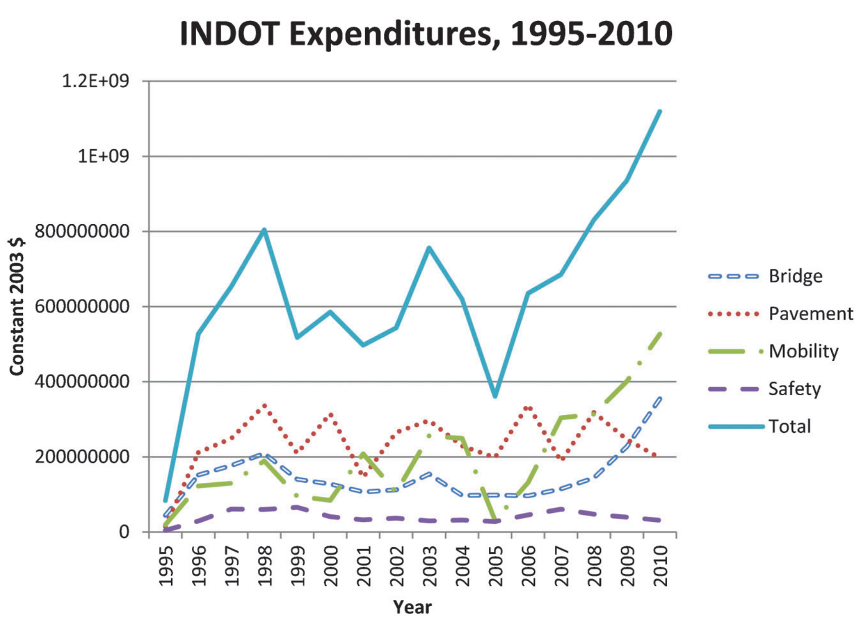


Figure 4.5 Time series of expenditures for each asset area and in total.

initiative which added to transportation investment after the state leveraged transportation funds by leasing the Indiana Toll Road to a private consortium in 2006.

5. PERFORMANCE-EXPENDITURE MODEL DEVELOPMENT

5.1 Model Specification

The evaluation of performance and expenditure trends in the previous chapter qualitatively demonstrated the improvements INDOT has made to the entire highway network and the cost of those improvements. The following sections demonstrate an analytical methodology to quantitatively evaluate the relationship between expenditures and improved condition of physical assets and improved operational performance. Quantitative results support future requests for continued investment in the transportation system.

Possible modeling approaches for this study are limited by the small number of observations available. Of the parameter estimation methods available, two of the most common methods are ordinary least squares (OLS) and maximum likelihood estimation (MLE). OLS estimation minimizes the squared differences between the observed and predicted values of the dependent variable. Linear regression has several assumptions: the dependent variable is continuous, the relationship between the dependent variable and independent variables is linear, the disturbance terms are identically and independently distributed with a mean of zero and constant variance, and the disturbance terms are not serial correlated (sometimes referred to as autocorrelated). The benefit of OLS estimation is that, if these assumptions are correct, the parameter estimates are unbiased, efficient, and consistent even for small datasets. When all of the linear regression assumptions are met, parameter estimates using OLS and MLE are identical. In cases when the linear regression assumptions are not met, MLE is preferred. MLE maximizes the log-likelihood of the probability that a given sample comes from a specified statistical distribution. MLE cannot be used on small datasets because the asymptotic property of efficiency is lost in small datasets (*32*). When an estimator is not efficient, the variance is large, which makes it difficult to reject the null hypothesis that variables are not significant. This can result in a Type II error where the independent variables are statistically significant predictors of the dependent variables in the population but the null hypothesis was not correctly rejected when analyzing the current sample. The dataset for this study is not sufficiently large to use MLE, therefore only OLS estimation was used to quantify the relationship between expenditures and performance.

Linear regression was used to evaluate the relationship between the performance in each asset group and the expenditures in all asset groups. Several model specifications were attempted with a combination of expenditures in each of the different asset groups. The selected models, chosen based on the significance of independent variables, model fit, and measures of autocorrelation, are included in this chapter. For bridge and pavement performance, we considered separately the proportion of assets in excellent condition and the proportion of assets in acceptable condition, defined as the proportion of assets in the top three performance levels of excellent, good, or satisfactory condition. Although there are combined effects in the performance of each asset group, there were not enough data to estimate a combined model or system of related models for all aspects of performance. Therefore, individual regression models were developed for each of the following dependent variables:

- Proportion of roads in excellent condition (IRI $<$ 80 inches/mile)
- Proportion of roads in acceptable condition (IRI $<$ 150 inches/mile)
- Proportion of bridges in excellent condition (structural evaluation 8 or 9)
- Proportion of bridges in acceptable condition (structural evaluation 6 or above)
- Proportion of sample miles with VSF ratio $\geq$ 0.70
- Non-fatal injury and fatality crashes per 100 million VMT

Several of the assumptions of linear regression were easily confirmed. The dependent and independent variables for this study were all continuous data. The linear relationship between the independent and dependent variables was not a strict requirement because transformation of the independent variables was used to linearize the relationship. The assumption that the mean of the error terms is zero was automatically met by minimizing the sum of the squared residuals.

Two characteristics of the data for this study posed challenges for using OLS. One issue with using OLS was that the predicted dependent variables were not bounded between 0 and 1, where in reality there cannot be a proportion less than 0 or greater than 1. One option would have been to use a logistic regression to bind the dependent variable between 0 and 1. Unfortunately, logistic regression uses MLE, which is not appropriate for the small dataset. Additionally, the data for this study were time series data. Therefore, we suspected that there may have been serial correlation in the disturbance terms because the terms are sequential by year. Typically, serial correlation is corrected by using MLE to estimate an autocorrelation parameter. Again, MLE is not appropriate for the small dataset. Even though the correction cannot be made due to the small sample size in this study, statistical tests of serial correlation were conducted for each model to determine if this regression assumption was violated.

The Durbin-Watson test was used to test for serial correlation (*33*). This test is only appropriate for models that do not include a lagged dependent variable as an independent variable, i.e., the value of the dependent variable in time period t-1 is used as an independent variable. When there is not serial correlation, the Durbin-Watson test statistic is approximately equal to 2. The critical values to determine if the test statistic is significantly different from 2 depend on whether there is a constant term and the number of independent variables. Durbin and Watson developed upper and lower limits, d_U and d_L, respectively, to define the bounds of the critical region when the model contains a constant. Farebrother (*34*) determined additional lower limits when the model does not contain a constant term. When the Durbin-Watson test statistic is between d_U and $(4-d_U)$, the null hypothesis is not rejected and we conclude that there is not serial correlation. When the test statistic is either less than d_L or greater than $(4-d_L)$, the null hypothesis is rejected and we conclude that there is serial correlation. When the test statistic is between d_U and d_L or between $(4-d_U)$ and $(4-d_L)$, the test is inconclusive. For the purpose of this study, if the test was inconclusive, we did not reject the null hypothesis because the test did not indicate with 95% confidence that there is serial correlation. Using MLE as an alternative analysis method to correct for autocorrelation was not an option due to the small dataset.

For models that include a lagged dependent variable, Durbin's h test is an alternative to test for serial correlation using the following statistic:

$$h=\left(1-\frac{d}{2}\right)\sqrt{\frac{T}{1-T\left[VAR\left(\tilde{\beta}\right)\right]}}$$

where d is the Durbin-Watson test statistic, T is the number of observations and $VAR\left(\widehat{B}\right)$ is the variance of the parameter of the lagged dependent variable (Washington et al., 2011)(*33*). Durbin's h test is only applicable when the term $T\left[VAR\left(\hat{B}\right)\right]<1$. Critical values for Durbin's h statistic can be taken from the standard normal distribution. As with the inconclusive Durbin-Watson statistics, the only correction if the null hypothesis is rejected using Durbin's h test includes MLE, which is not applicable for small datasets. Correction was not possible for this dataset; therefore, any OLS models for which serial correlation was suspected should be used with caution, particularly when extrapolating. The models developed in this study should be used for reporting and accountability purposes; therefore, there should be no need for extrapolation.

5.2 Model Specification Results for Entire Highway Network

Diagnostic plots of each dependent variable versus expenditures were developed to determine if a functional form is evident in the data, as shown in Appendix F. The network level performance data for the entire statewide highway network, including all road classifications, were plotted against both the expenditures in the asset group corresponding to the dependent variable and the total expenditures. For example, mobility performance was plotted against mobility expenditures and total expenditures but not bridge, pavement, or safety expenditures. It was assumed that the functional form of the relationship was the same for expenditures in different asset groups as evidenced in the plots versus total expenditures. For example, for the mobility performance model, the functional form was the same for bridge, pavement, and safety expenditures and it was the form indicated in the plot of mobility performance versus total expenditures. The relationships appeared to be non-linear. Previous research found that the form $y=\alpha X^{\beta}$ is the best fit for predictive models linking expenditure and performance (*17*). Estimation of this functional form is carried out by taking the natural logarithm of both the dependent and independent variables. A transformation on the dependent variable changes the distribution of the disturbance terms in the model. Therefore, we started with a transformation on the independent variables only—namely a logarithmic transformation. For this transformation, the functional form of the relationship was assumed to be $y=\alpha+\beta\ln X$.

The logarithmic trend also fit with the expectation that there were decreasing marginal returns for higher levels of expenditure. The transformation was essential for two reasons. First, the relationship appeared to be non-linear. If we had used a linear form for a non-linear relationship the resulting parameter estimates would have been biased and inconsistent. Second, without the transformation on the independent variables, there was not enough variation in the data and the models were highly sensitive to even small changes in the values of each variable. Without the transformation, commercially available software packages were used to calculate statistically significant parameter estimates. However, the reported statistical condition values, measures of the singularity of the matrices of independent variables, were extremely high. If the condition value is large, the matrix of independent variables is close to singular, the resulting parameter estimates are likely incorrect, and small changes in the value of the independent variables result in large changes in the solution (*35*). The transformation prevented large condition values in our model estimations.

The following sections detail the model specification results for the statewide relationships between performance and expenditure for each asset group. It must be noted that all of the models contained herein are predictive models based on observational studies. Statistically significant independent variables do not indicate that those variables necessarily caused performance to increase or decrease. With that in mind, the models do demonstrate the correlation between INDOT's program expenditures and statewide highway performance.

5.2.1 Pavement Models for Entire Highway Network

Model specification results for the proportion of pavements in excellent condition are outlined in Table 5.1. The proportion of pavements in excellent condition in the previous year is a marginally significant variable in predicting the proportion in the current year. The variable is included because it would likely be statistically significant for a larger sample. Assuming that the small sample estimate from the current model is representative of the population, if the sample size is increased, the resulting *t* statistic will be larger and likely higher than the critical value (*33*). Additionally, inclusion of the variable agrees with previous research that found the condition in the previous year is statistically significant (*18,19*). The natural logarithms of both pavement expenditures and bridge expenditures are also significant variables. The positive sign for the natural logarithm of pavement expenditures meets the expectation that higher pavement expenditures are associated with higher proportions of pavements in excellent condition, with a decreasing marginal increase. The negative sign for the natural logarithm of bridge expenditures does not meet expectations that higher expenditures in any asset group correlates with higher network performance in all areas. The negative sign for the parameter estimate likely captures the high costs of the collection of bridge projects each year relative to the small increases in the proportion of roads in excellent condition. Furthermore, there are minimum requirements for the funds obligated to each asset program. The negative sign likely captures the effect of a constrained budget because a portion of the budget is contracted each year to a collection of projects that do not directly affect the proportion of pavements in excellent condition.

In terms of model fit, the *F* statistic is 3.47 with a *p*-value of 0.10 and the adjusted R^2 is 0.38. The *F* statistic indicates that the model is marginally improved over a naïve model with a constant term only. In terms of variance explained, the adjusted R^2 of 0.38 is fairly low for the limited variation in the data.

Durbin's *h* statistic is -1.73; therefore, the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

Model specification results for the proportion of pavements in acceptable condition are outlined in Table 5.2. The proportion of pavements in acceptable condition in the previous year is a significant variable in predicting the proportion the current year. This finding corroborates the findings of previous research (*18,19*). The negative sign for the parameter estimate for the proportion of pavements in acceptable condition in the previous year does not correspond to previous estimations or meet the expectation that as the proportion of pavements in acceptable condition in year *t*-1 increases, the proportion of pavements in acceptable condition in year *t* also increases. It is possible that the negative parameter estimate captures the deterioration of pavements over time. For example, if limited or no investments were made to the system, the pavements would deteriorate due to loading and environmental stresses. Some of the pavements will deteriorate to the point that IRI measurements are classified as fair or poor condition. Similar to the proportion of pavements in excellent condition, the natural logarithm of pavement expenditures is a significant predictor of the proportion of pavements in acceptable condition. The parameter estimate is positive in sign, which meets the expectation that higher pavement expenditures are associated with a higher proportion of pavements in acceptable condition. Expenditures in other asset groups were not found to be statistically significant predictors of the proportion of pavements in acceptable condition.

In terms of model fit, the *F* statistic is 7.38 with a *p*-value of 0.02 and the adjusted R^2 is 0.62. The *F* statistic indicates that the model is improved over a naïve model with a constant term only. In terms of variance explained, the adjusted R^2 of 0.62 is reasonable for the amount of variation in the data.

Durbin's *h* statistic is -0.592; therefore, the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

TABLE 5.1
OLS Estimation of Proportion of Pavements in Excellent Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Proportion of roads in excellent condition in year *t*-1	0.314	0.243	1.29	0.245
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	0.162	0.072	2.24	0.066
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	-0.152	0.074	-2.04	0.087
Number of observations	9			
Sum of square errors	0.005			
Adjusted R^2	0.382			
F statistic (*p*-value)	3.47	(0.100)		
Durbin-Watson Statistic	2.789			
Durbin's *h* statistic (*p*-value)	-1.730	(0.084)		

TABLE 5.2
OLS Estimation of Proportion of Pavements in Acceptable Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Constant	−2.784	1.077	−2.59	0.042
Proportion of roads in acceptable condition in year *t*-1	−0.271	0.218	−1.24	0.261
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	0.203	0.055	3.68	0.010
Number of observations	9			
Sum of square errors	0.001			
Adjusted R^2	0.615			
F statistic (*p*-value)	7.38	(0.024)		
Durbin-Watson Statistic	2.298			
Durbin's *h* statistic (*p*-value)	−0.592	(0.554)		

5.2.2 Bridge Models for Entire Highway Network

Model specification results for the proportion of bridges in excellent condition are outlined in Table 5.3. The proportion of bridges in excellent condition in the previous year is a significant variable in predicting the proportion in the current year. This meets the expectation that the condition in the previous year is significant, as it is for statewide pavement condition models. The sign of the parameter estimate is negative, indicating that an increase in the proportion of bridges in excellent condition in year *t*-1 is correlated with a decrease in the proportion for the year *t*. It is possible that the negative parameter estimate captures the deterioration of bridges that occurs over time. For example, if limited or no investments were made to the system, the bridge elements would deteriorate due to loading and environmental stresses. The structural evaluations of some bridges would no longer be excellent, resulting in a lower proportion. The natural logarithms of bridge, pavement, and safety expenditures are all significant predictors of the proportion of bridges in excellent condition. The parameter estimate for the natural logarithm of bridge expenditures is positive in sign. This meets the expectation that higher bridge expenditures are associated with a higher proportion of bridges in excellent condition. The parameter estimates for the natural logarithm of pavement expenditures and the natural logarithm of safety expenditures are negative. The negative signs likely capture the effects of a constrained budget with minimum required expenditure amounts in each asset program. The negative signs account for the portion of expenditures each year that do not directly affect the proportion of bridges in excellent condition.

In terms of model fit, the *F* statistic is 7.38 with a *p*-value of 0.014 and the adjusted R^2 is 0.66. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of variance explained, the adjusted R^2 is reasonable for the amount of variation in the data.

Durbin's *h* statistic is -1.317; therefore, the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

Model specification results for the proportion of bridges in acceptable condition are outlined in Table 5.4. The proportion of bridges in acceptable condition in the previous year is a significant variable in predicting the condition in the current year. The parameter estimate is positive indicating that an increase in the proportion of bridges in acceptable

TABLE 5.3
OLS Estimation of Proportion of Bridges in Excellent Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Proportion of bridges in excellent condition in year *t*-1	−0.835	0.202	−4.142	0.004
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	0.105	0.027	3.891	0.006
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	−0.040	0.020	−1.992	0.087
Natural logarithm of the 3-year average of annual Safety expenditures for years *t*-1, *t*-2, and *t*-3	−0.055	0.023	−2.442	0.045
Number of observations	11			
Sum of square errors	0.001			
Adjusted R^2	0.657			
F statistic (*p*-value)	7.38	(0.014)		
Durbin-Watson Statistic	2.591			
Durbin's *h* statistic (*p*-value)	−1.317	(0.188)		

TABLE 5.4
OLS Estimation of Proportion of Bridges in Acceptable Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Proportion of bridges in acceptable condition in year *t*-1	0.338	0.253	1.34	0.212
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	0.087	0.034	2.59	0.027
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	−0.054	0.029	−1.86	0.093
Number of observations	13			
Sum of square errors	0.006			
Adjusted R^2	0.359			
F statistic (*p*-value)	4.36	(0.02)		
Durbin-Watson Statistic	2.450			
Durbin's *h* statistic (*p*-value)	−1.990	(0.047)		

condition year *t*-1 is associated with an increase in the proportion for year *t*. The positive sign meets expectations. The natural logarithms of bridge and pavement expenditures are significant predictors of the proportion of bridges in acceptable condition. The parameter estimate for the natural logarithm of bridge expenditures is positive in sign, which meets the expectation that higher bridge expenditures are correlated with a higher proportion of bridges in acceptable condition. The parameter estimate for the natural logarithm of pavement expenditures is negative in sign. The negative sign likely captures the effects of a constrained budget with minimum required expenditure amounts in each asset program. The negative sign accounts for the portion of expenditures each year that do not directly affect the proportion of bridges in acceptable condition.

In terms of model fit, the *F* statistic is 8.72 with a *p*-value of 0.01 and the adjusted R^2 is 0.61. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of variance explained, the adjusted R^2 is reasonable for the limited amount of variation in the data.

Durbin's *h* statistic is -1.931. This is greater than the critical value (at 95% confidence) of 1.645. Therefore, the null hypothesis is rejected and we conclude that serial correlation is present in this model. MLE estimation is the only recourse for models with serial correlation, but cannot be applied to the current dataset. The model does provide insight into the relationship between expenditures and the proportion of bridges in acceptable condition; however, it should not be used for extrapolation. Additional years of data are necessary to refine this model.

5.2.3 Mobility Model for Entire Highway Network

Model specification results for the proportion of state network sample miles with peak hour congestion, defined as a VSF ratio greater than or equal to 0.70, are outlined in Table 5.5. The natural logarithms of mobility and bridge expenditures are significant predictors of the proportion of sample miles with VSF ratios greater than or equal to 0.70. The parameter estimate for the natural logarithm of mobility expenditures is negative. This meets the expectation that higher mobility expenditures are associated with lower proportions of congestion. The parameter estimate for the natural logarithm of bridge expenditures is positive, which does not meet the expectation that higher expenditures in any asset group will be associated with

TABLE 5.5
OLS Estimation of Proportion of Sample Miles with VSF $\geq$ 0.70 in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	−0.103	0.026	−3.92	0.004
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	0.112	0.027	4.22	0.003
Number of observations	10			
Sum of square errors	0.005			
Adjusted R^2	0.632			
F statistic (*p*-value)	16.44	(0.004)		
Durbin-Watson Statistic	1.850			
d_L	0.539			
d_U	1.641			
4-d_U	2.359			
4-d_L	3.461			

better statewide performance, in this case lower proportions of congestion. The natural logarithm of bridge expenditures is likely significant because of the high costs per length of the collection of bridge projects relative to mobility projects. Additionally, the positive sign for the parameter estimate likely captures the effect of a constrained budget because a portion of the budget is contracted each year to a collection of projects that do not directly affect congestion. Unlike the pavement and bridge condition models, the extent of congestion in the previous year is not statistically significant for predicting congestion in the current year. This result fits intuition because pavements and bridges are physical assets which deteriorate due to loading and environmental factors over time. In contrast, mobility is an operational measure which does not have the same temporal relationship with environmental stresses.

In terms of model fit, the *F* statistic is 16.44 with a *p*-value of 0.004 and the adjusted R^2 is 0.63. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of variance explained, the adjusted R^2 is reasonable for the limited amount of variation in the data.

The Durbin-Watson test was used for this model because the lagged dependent variable is not statistically significant. The calculated Durbin-Watson statistic of 1.85 is between the bounds of d_U and $(4-d_U)$, therefore the null hypothesis is not rejected and we conclude that serial correlation is not present.

5.2.4 Safety Model for Entire Highway Network

Model specification results for the sum of non-fatal injury and fatality crashes per 100 million VMT are outlined in Table 5.6. The crash rate in the previous year was found to be a marginally significant variable in predicting the crash rate in the current year. In previous research this variable has not been found significant. Hendren and Niemeier (*16*) use a detrended dependent variable, $Y^{\$} = Y_{t-1} - Y_t$. The constant term in their model is equivalent to the parameter estimate for the lagged dependent variable in the current study. Hendren and Niemeier found that the constant was not significant at 90% for Indiana. The variable is included in the current models, with a *p*-value of 0.18, because with a larger sample, the variable would likely be statistically significant. The natural logarithms of both safety expenditures and bridge expenditures were also found to be significant. The negative sign for the natural logarithm of safety expenditures meets the expectation that, as safety expenditures increase, the crash rate decreases. The positive sign for the natural logarithm of bridge expenditures does not meet the expectation that higher expenditures in any project be associated with improved condition of the entire system. An increase in bridge expenditures would likely only decrease the crash rate if there were a prevalence of crashes on Indiana bridges. The parameter estimate is likely significant because of the high costs of the collection of bridge projects relative to small changes in the crash rate. The positive sign likely captures the effects of a constrained budget with minimum required expenditure amounts in each asset program. The positive sign accounts for the portion of expenditures each year that do not directly affect the number of fatality or injury crashes.

In terms of model fit, the *F* statistic is 50.73 with a *p*-value of 0.005 and the adjusted R^2 is 0.95. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of variance explained, the adjusted R^2 is favorable given the limited variation in the data.

Durbin's *h* statistic is -0.123; therefore, the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

5.3 Road Classification and Route Type Effects

As discussed in Chapter 2, the amount of money expended on assets in each road classification through INDOT's program is constrained by the funds appropriated for projects on the Interstate System and NHS. Additional models were developed for each asset group (using the same dependent variables as in the models for the entire highway network) for each road class (Interstate, non-Interstate NHS, non-NHS) or route

TABLE 5.6
OLS Estimation of non-fatal injury and fatality crashes per 100M VMT in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Non-fatal injury and fatality crashes per 100M VMT in year *t*-1	0.426	0.244	1.74	0.180
Natural logarithm of the 3-year average of annual Safety expenditures for years *t*-1, *t*-2, and *t*-3	−7.254	2.430	−2.99	0.058
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	8.442	2.942	2.87	0.064
Number of observations	6			
Sum of square errors	1.694			
Adjusted R^2	0.952			
F statistic (*p*-value)	50.73	(0.005)		
Durbin-Watson Statistic	2.080			
Durbin's *h* statistic (*p*-value)	−0.123	(0.902)		

type (Interstate, U.S. Route, State Road). Route types were used instead of the road classification for safety models because the road classification was not available with safety data.

Additional diagnostic plots of performance versus expenditure were developed for each asset group to visually investigate the relationships by road classification and route type. From these initial plots, as shown in Appendix G, the relationships appear to be different for the different road classifications and route types. The initial plots do not indicate that there is one single underlying relationship between expenditures and performance for each asset group with a different intercept for each of the different road classes (route types). If there is one single relationship, the different intercepts allow the values to be different for Interstates, non-Interstate NHS roadways, and non-NHS roadways, even while the underlying relationship between expenditures and performance is the same. The initial plots indicate that the relationship is different for each of the road classifications (route types).

The Chow test was used to test hierarchical stability for the different road classes (route types)—whether the relationship between expenditure and performance is different for each road classification (route type) or if the underlying relationship is the same with indicator variables to capture the different intercepts of each road classification (route type) (*33*). For each dependent variable, four models were estimated:

1. Model of all of the data with indicator variables for two of the three road classifications (route types)—called the full model
2. Three separate models using only the subset of data corresponding to each road classification (route type)—called models 1, 2, and 3

For the full model, i.e., the model of all of the data with indicator variables, at most two indicator variables can be used to represent the three road classes (route types). The third road class (route type) is captured by the intercept term. The Chow test compares the sum of the squared residuals for the full model with the sum of the sums of the squared residuals for the separate models. The test statistic is: where *SSE* is the sum of the squared error, *n* is the number of observations, *p* is the number of parameters and the subscripts indicate the full model (F) or the model for each road classification (route type). The null hypothesis for the Chow test is that the separate models do not explain more of the variance than the single model. The alternate hypothesis is that the separate models explain more of the variance in the data than one single model with indicator variables. The null hypothesis is rejected when the relationship between expenditure and performance is different for each road classification (route type).

The results of the Chow tests are outlined in Table 5.7. The null hypothesis is rejected for all performance measures except for the proportion of pavements in excellent condition. Therefore, the relationship between expenditure and performance is significantly different for each road classification (route type) for all of the dependent variables except the proportion of pavements in excellent condition. For pavements in excellent condition, the *p*-value is 0.24. Although we fail to reject the null hypothesis at the 95% confidence level, we can reject the null if the level of confidence were dropped to 75%. Although this is much lower than confidence typically used for engineering analysis, we have included the separate models for pavements in excellent condition to maintain consistency with the other dependent variables. It is possible that the difference between separate models and one single model with indicator variables would be statistically significant, for the proportion of roadways in excellent condition, with a larger sample, similar to the results in the current study for all of the other dependent variables.

The following sections detail the model specification results for the separate models for each asset group. For pavements in excellent condition, the full model, which assumes one underlying relationship with indicator variables for each road classification, is also included because the Chow Test statistic was not significant.

5.3.1 Pavement Models by Road Classification

Model specification results for the single model, with indicator variables, of the proportion of pavements in excellent condition are outlined in Table 5.8. The Chow test results indicate that the single model, with indicator variables for the Interstate System and the NHS, is not significantly better than separate models for each system. The parameter estimate for the interstate system is slightly higher than the parameter estimate for the NHS. Both estimates are positive. This meets the expectations that the proportion of Interstate pavements in excellent condition is slightly higher than

TABLE 5.7
Summary of Results for Chow Tests for Hierarchical Stability

Asset Category	*p*-value	Statistical Result	Interpretation
Pavements in Excellent Condition	0.241	Do not reject null	Underlying relationship is the same for all classifications
Pavements in Acceptable Condition	0.077	Reject null	Relationship is different for each classification
Bridges in Excellent Condition	0.000	Reject null	Relationship is different for each classification
Bridges in Acceptable Condition	0.011	Reject null	Relationship is different for each classification
Mobility	0.040	Reject null	Relationship is different for each classification
Safety	0.007	Reject null	Relationship is different for each classification

TABLE 5.8
OLS Estimation of Proportion of Pavements in Excellent Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Proportion of roads in excellent condition in year *t*-1	0.239	0.168	1.42	0.169
Interstate indicator variable (1 for Interstate roads, 0 otherwise)	0.146	0.045	3.26	0.004
NHS indicator variable (1 for non-Interstate NHS roads, 0 otherwise)	0.113	0.036	3.10	0.005
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	0.073	0.036	2.02	0.056
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	−0.060	0.039	−1.56	0.134
Number of observations	27			
Sum of square errors	0.081			
Adjusted R^2	0.556			
F statistic (*p*-value)	9.15	(0.0002)		
Durbin-Watson Statistic	2.260			
Durbin's *h* statistic (*p*-value)	−1.385	(0.166)		

the proportion of NHS pavements in excellent condition. This also meets the expectations that the proportions of both Interstate pavements and NHS pavements in excellent condition are higher than for non-NHS pavements. Similar to the model for the entire highway network, the proportion of pavements in excellent condition in the previous year, the natural logarithm of pavement expenditures and the natural logarithm of bridge expenditures are statistically significant variables in the single model with indicator variables for road classification. All of the parameter estimates have the same sign for the single model with indicator variables as for the previously estimated model for the entire highway network. No additional variables are significant in the single model with indicator variables.

In terms of model fit, the *F* statistic is 9.15 with a *p*-value of 0.0002 and the adjusted R^2 is 0.56. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of the variance explained, the R^2 is higher than the model for the entire highway network (0.56 compared to 0.38), but is still low given the limited variation in the data.

Durbin's *h* statistic is -1.385; therefore, the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

Separate model specification results for the proportion of pavements in excellent condition are included in Tables 5.9, 5.10, and 5.11 for Interstate roadways, non-Interstate NHS roadways, and non-NHS roadways, respectively. The model results for each road classification are included in the present discussion, even though the Chow test statistic was not significant for pavements in excellent condition, to maintain consistency with other performance measures.

For the proportion of Interstate pavements in excellent condition, as shown in Table 5.9, the natural logarithm of pavement expenditures and the natural logarithm of mobility expenditures are significant predictors of performance. The parameter estimate for the natural logarithm of pavements expenditures meets the expectation that, as pavement expenditures increase, the proportion of pavements in excellent condition increases. The negative sign for the natural logarithm of mobility expenditures does not meet with expectations that an increase in expenditures in any asset will correlate to higher performance in all asset areas. Similar to the models of the entire highway network, the negative parameter estimate likely

TABLE 5.9
OLS Estimation of Proportion of Interstate Pavements in Excellent Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	0.075	0.028	2.72	0.030
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	−0.044	0.027	−1.61	0.151
Number of observations	9			
Sum of square errors	0.031			
Adjusted R^2	0.310			
F statistic (*p*-value)	4.59	(0.069)		
Durbin-Watson Statistic	1.945			
dL	0.460			
dU	1.699			
4-dU	2.301			
4-dL	3.540			

TABLE 5.10
OLS Estimation of Proportion of Non-Interstate NHS Pavements in Excellent Condition

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Constant	1.809	1.875	0.97	0.367
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	−0.073	0.106	−0.69	0.514
Number of observations	9			
Sum of square errors	0.032			
Adjusted R^2	−0.071			
F statistic (*p*-value)	0.47	(0.514)		
Durbin-Watson Statistic	1.236			
dL	0.629			
dU	1.699			
4-dU	2.301			
4-dL	3.371			

captures the effects of a constrained budget with minimum required expenditure amounts in each asset program. The negative signs account for the portion of expenditures each year that do not directly affect the proportion of Interstate pavements in excellent condition.

In terms of model fit, the *F* statistic is 4.59 with a *p*-value of 0.07 and the adjusted R^2 is 0.31. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of the variance explained, the R^2 is lower than both the model for the entire highway network (0.38) and the single model with indicator variables for road classification (0.56).

The Durbin-Watson test is used for this model because the lagged dependent variable is not statistically significant. The calculated Durbin-Watson statistic of 1.945 is between the bounds of d_U and $(4-d_U)$, therefore the null hypothesis is not rejected and we conclude that serial correlation is not present.

For the proportion of non-Interstate NHS pavements in excellent condition, as shown in Table 5.10, the natural logarithm of pavement expenditures and a constant term were the only statistically significant variables. Furthermore, the expenditure parameter estimate is negative in sign, which does not meet the expectation that an increase in pavement expenditures is correlated with an increase in the proportion of pavements in excellent condition. This could occur because investments are being used to improve pavements in fair and poor condition. Improvements to pavements in fair and poor condition may increase the proportion of pavements in acceptable condition, but may have no impact on the proportion of pavements in excellent condition. Although the pavement expenditures are not positively associated with the proportion of pavements in excellent condition, we expect that the expenditures will be positively associated with the proportion of pavements in acceptable condition.

In terms of model fit, the *F* statistic is 0.49 with a *p*-value of 0.51, indicating that the model is not significantly improved over a naïve model with a constant term only. The adjusted R^2 is -0.07, which is extremely low.

The Durbin-Watson test was used for this model because the lagged dependent variable was not statistically significant. The calculated Durbin-Watson statistic of 1.236 is between the bounds of d_L and d_U, therefore the test is inconclusive. Typically, for an inconclusive test, corrections for serial correlation are

TABLE 5.11
OLS Estimation of Proportion of Non-NHS Pavements in Excellent Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Proportion of roads in excellent condition in year *t*-1	0.278	0.204	1.36	0.231
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	0.127	0.083	1.53	0.187
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	−0.183	0.056	−3.24	0.023
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	0.067	0.052	1.27	0.259
Number of observations	9			
Sum of square errors	0.003			
Adjusted R^2	0.763			
F statistic (*p*-value)	9.58	(0.016)		
Durbin-Watson Statistic	2.668			
Durbin's *h* statistic (*p*-value)	−1.267	(0.205)		

made using MLE and the results of the estimation with corrections for serial correlation is compared to the initial estimation. MLE is not an appropriate alternative analysis method for this study due to the small dataset. Therefore, the null hypothesis cannot be rejected at the 95% confidence level. We conclude that serial correlation is not present.

The *F* test and the R^2 values indicate that the estimated model is not a significant improvement over a naïve model. The Durbin-Watson statistic is inconclusive. However, model specifications that improve upon the naïve model could not be estimated with the limited data available in the current study. Future research using a larger database is necessary to determine if these relationships hold.

For the proportion of non-NHS pavements in excellent condition, as shown in Table 5.11, all of the variables in the model for the entire highway network are again significant—the proportion of pavements in excellent condition in the previous year, the natural logarithm of pavement expenditures, and the natural logarithm of bridge expenditures. The signs of the parameter estimates are the same as for the model for the entire highway network. The proportion of non-NHS pavements in excellent condition and the natural logarithm of pavement expenditures are marginally significant. These variables are included for two reasons: 1) the findings are consistent with the model for the entire highway network and, 2) with larger sample size, the significance of these variables will likely be higher. For non-NHS pavements, the natural logarithm of mobility expenditure is also a marginally significant predictor of the proportion of pavements in excellent condition. The parameter estimate is positive, which meets the expectation that, as expenditures increase, the pavement condition also increases.

In terms of model fit, the *F* statistic is 9.58 with a *p*-value of 0.02 and the adjusted R^2 is 0.76. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of the variance explained, the R^2 is much higher than both the model for the entire highway network (0.38) and the full model with indicator variables for road classification (0.56).

Durbin's *h* statistic is -1.267; therefore the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

Separate model specification results for the proportion of pavements in acceptable condition are included in Table 5.12, Table 5.13, and Table 5.14 for Interstate roadways, non-Interstate NHS roadways, and non-NHS roadways, respectively. The model results for each road classification are compared to the previously discussed model of the proportion of pavements in acceptable condition for the entire highway network.

For the proportion of Interstate pavements in acceptable condition, as shown in Table 5.12, two variables previously found significant in the model for the entire highway network are again significant—the proportion of pavements in acceptable condition in the previous year and the natural logarithm of pavement expenditures. The parameter estimate for the proportion of pavements in acceptable condition in the previous year is positive in the model specific to Interstates (unlike the model for the entire highway network). This likely occurs because the pavement quality standards for Interstates are much higher than for the statewide network as a whole. This also meets the expectation that, for a higher proportion of pavements in acceptable condition in year *t*-1, there is a corresponding higher proportion of pavements in acceptable condition in year *t*. For Interstate pavements, the natural logarithm of safety expenditures is also a significant predictor of the proportion of pavements in acceptable condition. The parameter estimate is negative, which does not meet expectation. The negative sign likely captures the effects of a constrained budget with minimum required expenditure amounts in each asset program. The negative sign accounts for the portion of expenditures each year that do not directly affect the proportion of pavements in acceptable condition. The natural logarithm of bridge expenditure is also a marginally significant predictor of

TABLE 5.12
OLS Estimation of Proportion of Interstate Pavements in Acceptable Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Proportion of roads in acceptable condition in year *t*-1	0.523	0.280	1.87	0.121
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	0.018	0.008	2.16	0.083
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	0.029	0.020	1.48	0.199
Natural logarithm of the 3-year average of annual Safety expenditures for years *t*-1, *t*-2, and *t*-3	−0.024	0.010	−2.51	0.054
Number of observations	9			
Sum of square errors	4.43E-04			
Adjusted R^2	−0.449			
F statistic (*p*-value)	0.17	(0.910)		
Durbin-Watson Statistic	2.182			
Durbin's *h* statistic (*p*-value)	−0.502	(0.615)		

TABLE 5.13
OLS Estimation of Proportion of Non-Interstate NHS Pavements in Acceptable Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	0.011	0.011	1.01	0.345
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	0.041	0.011	3.72	0.008
Number of observations	9			
Sum of square errors	0.002			
Adjusted R^2	0.429			
F statistic (*p*-value)	7.00	(0.033)		
Durbin-Watson Statistic	2.927			
Dl	0.460			
dU	1.699			
4-dU	2.301			
4-dL	3.540			

the proportion of pavements in acceptable condition. The parameter estimate is positive, which meets the expectation that as expenditures increase, the pavement condition also increases. The natural logarithm of bridge expenditures is included in the model because it is anticipated that the significance will increase with increasing sample size.

In terms of model fit, the *F* statistic is 0.17 with a *p*-value of 0.91 and the adjusted R^2 is 0.09. The *F* statistic indicates that the model is not significantly improved over a naïve model with a constant term only. In terms of the variance explained, the R^2 is extremely low and much lower than the R^2 of the model for the entire highway network (0.61). The goodness-of-fit measures indicate that the independent variables do not sufficiently account for the variation within the data. This likely occurs because there is too little data with too little variation. Although additional variables could explain more of the variation, there are too few observations to include additional parameters because the addition of parameters results in a loss of degrees of freedom. The number of observations for this subset of the data is 9; therefore, the degrees of freedom are limited to begin with. Additional parameters may be significant and yield a better fit if the dataset were larger.

Durbin's *h* statistic is -0.502; therefore the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

For the proportion of non-Interstate NHS pavements in acceptable condition, as shown in Table 5.13, the natural logarithm of pavement expenditures and the natural logarithm of mobility expenditures are included in model estimation. The natural logarithm of pavement expenditures is marginally significant. The variable is included in model estimation because the significance will likely be higher for a larger sample. Additionally, this variable is significant in other estimated models of pavement performance. Both parameter estimates are positive, which meets the expectation that as expenditure increases, the proportion of pavements in acceptable condition also increases. The proportion of pavements in acceptable condition in the previous year was not found significant for non-Interstate NHS pavements.

In terms of model fit, the *F* statistic is 7.00 with a *p*-value of 0.03 and the adjusted R^2 is 0.43. The *F* statistic indicates that the model is significantly improved over a

TABLE 5.14
OLS Estimation of Proportion of Non-NHS Pavements in Acceptable Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	−0.053	0.036	−1.45	0.192
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	0.106	0.039	2.74	0.029
Number of observations	9			
Sum of square errors	0.002			
Adjusted R^2	0.596			
F statistic (*p*-value)	12.81	(0.009)		
Durbin-Watson Statistic	2.118			
dL	0.460			
dU	1.699			
4-dU	2.301			
4-dL	3.540			

naïve model with a constant term only. In terms of the variance explained, the R^2 is less than the model for the entire highway network (0.61) and fairly low for the limited variation in the data.

The Durbin-Watson test is used for this model because the lagged dependent variable is not statistically significant. The calculated Durbin-Watson statistic of 2.927 is between the bounds of $(4-d_U)$ and $(4-d_L)$, therefore the test is inconclusive. Typically, for an inconclusive test, corrections for serial correlation are made using MLE and the results of the estimation with corrections for serial correlation are compared to the initial estimation results. MLE is not an appropriate alternative analysis method for this study due to the small dataset. Therefore, the null hypothesis that there is no serial correlation cannot be rejected at the 95% confidence level.

Similar to the model of the proportion of non-Interstate NHS pavements in acceptable condition, the natural logarithm of pavement expenditures and the natural logarithm of mobility expenditures are significant predictors of the proportion of non-NHS pavements in acceptable condition, as shown in Table 5.14. The natural logarithm of pavement expenditures is marginally significant. The variable is included in the current model estimation because the significance will likely be higher for a larger sample. The parameter estimate for the natural logarithm of pavement expenditures is negative, which does not meet expectation. This could occur because there was a large investment in a few large projects that only improved the pavement condition in a localized area rather than the entire state. The estimation of additional parameters poses a problem with this data due to the small sample size (9 observations) and the loss of degrees of freedom. The estimated parameter for the natural logarithm of mobility expenditures meets the expectation that an increase in expenditures corresponds to an increase in the proportion of roads in acceptable condition. The proportion of pavements in acceptable condition in the previous year is not significant for non- NHS pavements.

In terms of model fit, the *F* statistic is 12.81 with a *p*-value of 0.009 and the adjusted R^2 is 0.60. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of the variance explained, the R^2 is slightly less than the model of the entire highway network—0.60 compared to 0.61.

The Durbin-Watson test is used for this model because the lagged dependent variable is not statistically significant. The calculated Durbin-Watson statistic of 2.118 is between the bounds of d_U and $(4-d_U)$, therefore the null hypothesis is not rejected and we conclude that serial correlation is not present.

5.3.2 Bridge Models by Road Classification

Separate model specification results for the proportion of bridges in excellent condition are included in Table 5.15, Table 5.16, and Table 5.17 for Interstate roadways, non-Interstate NHS roadways, and non-NHS roadways, respectively. The model results for each road classification are compared to the previously discussed model for the entire highway network for bridges in excellent condition.

For the proportion of Interstate bridges in excellent condition, as shown in Table 5.15, three variables previously found significant in the model for the entire highway network are again significant—the proportion of bridges in excellent condition in the previous year, the natural logarithm of bridge expenditures, and the natural logarithm of safety expenditures. The signs of the parameter estimates are the same as for the model for the entire highway network. For Interstate bridges, the natural logarithm of mobility expenditures is also a significant predictor of the proportion of bridges in excellent condition. The parameter estimate is negative, which does not meet expectations. The negative sign likely captures the effects of a constrained budget with

TABLE 5.15
OLS Estimation of Proportion of Interstate Bridges in Excellent Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Proportion of bridges in excellent condition in year *t*-1	−0.989	0.148	−6.70	0.000
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	0.060	0.025	2.43	0.046
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	−0.016	0.009	−1.73	0.127
Natural logarithm of the 3-year average of annual Safety expenditures for years *t*-1, *t*-2, and *t*-3	−0.036	0.018	−1.96	0.091
Number of observations	11			
Sum of square errors	0.002			
Adjusted R^2	0.822			
F statistic (*p*-value)	16.41	(0.002)		
Durbin-Watson Statistic	2.010			
Durbin's *h* statistic (*p*-value)	−0.019	(0.985)		

TABLE 5.16
OLS Estimation of Proportion of Non-Interstate NHS Bridges in Excellent Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	0.096	0.019	5.14	0.001
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	−0.035	0.010	−3.47	0.008
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	−0.049	0.014	−3.46	0.009
Number of observations	11			
Sum of square errors	0.002			
Adjusted R^2	0.715			
F statistic (*p*-value)	13.56	(0.003)		
Durbin-Watson Statistic	1.781			
Dl	0.460			
dU	1.928			
4-dU	2.072			
4-dL	3.540			

minimum required expenditure amounts in each asset program. The negative sign accounts for the portion of expenditures each year that do not directly affect the proportion of bridges in excellent condition.

In terms of model fit, the *F* statistic is 16.41 with a *p*-value of 0.002 and the adjusted R^2 is 0.82. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of the variance explained, the R^2 is higher than the R^2 for the model for the entire highway network (0.65) and reasonable for the limited variation in the data.

Durbin's *h* statistic is -0.019; therefore the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

For the proportion of non-Interstate NHS bridges in excellent condition, as shown in Table 5.16, two variables previously found significant in the model for the entire highway network are again significant—the natural logarithm of bridge expenditures and the natural logarithm of safety expenditures. The signs of the parameter estimates are the same as for the model for the entire highway network. For non-Interstate NHS bridges, the natural logarithm of mobility expenditures is also a significant predictor of the proportion of bridges in excellent condition. The parameter estimate is negative, which does not meet expectations. The negative sign likely captures the effects of a constrained budget with minimum required expenditure amounts in each asset program. The negative sign accounts for the portion of expenditures each year that do not directly affect the proportion of bridges in excellent condition. The proportion of bridges in excellent condition in the previous year was not found significant.

In terms of model fit, the *F* statistic is 13.56 with a *p*-value of 0.003 and the adjusted R^2 is 0.72. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of the variance explained, the R^2 is

TABLE 5.17
OLS Estimation of Proportion of Non-NHS Bridges in Excellent Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Constant	4.909	1.964	2.50	0.055
Proportion of bridges in excellent condition in year *t*-1	−0.893	0.352	−2.54	0.052
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	−0.135	0.084	−1.60	0.170
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	−0.133	0.046	−2.92	0.033
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	0.105	0.045	2.35	0.066
Natural logarithm of the 3-year average of annual Safety expenditures for years *t*-1, *t*-2, and *t*-3	−0.096	0.034	−2.83	0.037
Number of observations	11			
Sum of square errors	0.001			
Adjusted R^2	0.396			
F statistic (*p*-value)	2.31	(0.190)		
Durbin-Watson Statistic	2.003			

higher than the R^2 for the model for the entire highway network (0.65) and reasonable for the limited variation in the data.

The Durbin-Watson test is used for this model because the lagged dependent variable is not statistically significant. The calculated Durbin-Watson statistic of 1.781 is between the bounds of d_L and d_U, therefore the test is inconclusive. Typically, for an inconclusive test, corrections for serial correlation are made using MLE and the results of the estimation with corrections for serial correlation is compared to the initial estimation. MLE is not an appropriate alternative analysis method for this study due to the small dataset. Therefore, the null hypothesis that there is no serial correlation cannot be rejected at the 95% confidence level.

For the proportion of non-NHS bridges in excellent condition, as shown in Table 5.17, all of variables previously found significant in the model for the entire highway network are again significant—the proportion of bridges in excellent condition in the previous year, the natural logarithm of bridge expenditures, the natural logarithm of pavement expenditures, and the natural logarithm of safety expenditures. For the proportion of bridges in excellent condition in the previous year, the natural logarithm of pavement expenditures, and the natural logarithm of safety expenditures, the signs of the parameter estimates are the same as for the model for the entire highway network. Unlike the model for the entire highway network, the parameter estimate for the natural logarithm of bridge expenditures is negative, which does not meet expectations. This could occur because investments are being used to improve bridges in fair and poor condition. Improvements to bridges in fair and poor condition may increase the proportion of bridges in acceptable condition but have no impact on the proportion of bridges in excellent condition. Although the bridge expenditures are not positively associated with the proportion of bridges in excellent condition, we expect that the expenditures will be positively associated with the proportion of bridges in acceptable condition. In addition to a constant, the natural logarithm of mobility expenditures is also a significant predictor of the proportion of bridges in excellent condition for non-NHS bridges. The parameter estimate is positive, which meets the expectation that an increase in expenditures corresponds to an increase in statewide performance.

In terms of model fit the F statistic is 2.31 with a p-value of 0.19, indicating that the model is marginally improved over a naïve model with a constant term only. The adjusted R^2 is 0.40 which is less than the R^2 of the model for the entire highway network (0.65) and fairly low for the limited variation in the data.

Durbin's h statistic could not be calculated for this model because the term $T\left[VAR\left(\hat{B}\right)\right] > 1$. The regular Durbin-Watson test cannot be used due to the lagged dependent variable. Although the h statistic could not be computed, the calculated Durbin-Watson statistic is 2.003, which is extremely close to 2, which indicates that serial correlation likely is not present.

Separate model specification results for the proportion of bridges in acceptable condition are included in Table 5.18, Table 5.19, and Table 5.20 for Interstate roadways, non-Interstate NHS roadways, and non-NHS roadways, respectively. The model results for each road classification are compared to the previously discussed model for the entire highway network for bridges in acceptable condition.

For the proportion of Interstate bridges in acceptable condition, as shown in Table 5.18, two variables previously found significant in the model for the entire highway network are again significant—the proportion of bridges in acceptable condition in the previous year and the natural logarithm of bridge expenditures. The signs of the parameter estimates are the same as for the model for the entire highway network. The natural logarithm of mobility expenditures is also a significant predictor of the proportion of bridges in acceptable condition for Interstate bridges. The parameter estimate is negative, which does not meet expectations. The negative sign likely captures the effects of a constrained budget with minimum required expenditure amounts in each asset program. The negative sign accounts for the portion of expenditures each year that do not directly affect the proportion of bridges in acceptable condition.

In terms of model fit the F statistic is 22.69 with a p-value of 0.001, indicating that the model is significantly

TABLE 5.18
OLS Estimation of Proportion of Interstate Bridges in Acceptable Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Proportion of bridges in acceptable condition in year *t*-1	0.705	0.180	3.91	0.005
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	0.020	0.011	1.89	0.096
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	−0.005	0.005	−1.07	0.317
Number of observations	11			
Sum of square errors	0.001			
Adjusted R^2	0.813			
F statistic (*p*-value)	22.69	(0.001)		
Durbin-Watson Statistic	1.608			
Durbin's *h* statistic (*p*-value)	0.811	(0.417)		

TABLE 5.19
OLS Estimation of Proportion of Non-Interstate NHS Bridges in Acceptable Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	0.115	0.026	4.44	0.002
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	−0.062	0.025	−2.46	0.036
Number of observations	11			
Sum of square errors	0.007			
Adjusted R^2	0.476			
F statistic (*p*-value)	10.08	(0.011)		
Durbin-Watson Statistic	2.805			
dL	0.610			
dU	1.604			
4-dU	2.396			
4-dL	3.390			

improved over a naïve model with a constant term only. The adjusted R^2 is 0.81 which is much higher than the R^2 of the model for the entire highway network (0.36) and reasonable for the limited variation in the data.

Durbin's *h* statistic is 0.811; therefore the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

Similar to the model for the entire highway network, the natural logarithm of bridge expenditures is a significant predictor of the proportion of non-Interstate NHS bridges in acceptable condition, as shown in Table 5.19. The parameter estimate for the natural logarithm of bridge expenditures is positive, which meets the expectation that an increase in bridge expenditures is correlated with an increase in the proportion of bridges in acceptable condition. The natural logarithm of mobility expenditures is also significant. The parameter estimate is negative, which does not meet expectations. The negative sign likely captures the effects of a constrained budget with minimum required expenditure amounts in each asset program. The negative sign accounts for the portion of expenditures each year that do not directly affect the proportion of bridges in acceptable condition. The proportion of bridges in acceptable condition in the previous year is not a statistically significant predictor of the proportion of bridges in acceptable condition for non-Interstate NHS bridges.

In terms of model fit the *F* statistic is 10.08 with a *p*-value of 0.01, indicating that the model is significantly improved over a naïve model with a constant term only. The adjusted R^2 is 0.48 which is higher than the R^2 of the model for the entire highway network (0.36) but low for the limited variation in the data.

The Durbin-Watson test is used for this model because the lagged dependent variable is not statistically significant. The calculated Durbin-Watson statistic of 2.805 is between the bounds of $(4-d_U)$ and $(4-d_L)$, therefore the test is inconclusive. Typically, for an inconclusive test, corrections for serial correlation are made using MLE and the estimation with corrections for serial correlation is compared to the initial estimation. MLE is not an appropriate alternative analysis method for this study due to the small dataset. Therefore, the null hypothesis that there is no serial correlation cannot be rejected at the 95% confidence level.

For the proportion of non-NHS bridges in acceptable condition, as shown in Table 5.20, all of the variables in the model for the entire highway network are again significant—the proportion of bridges in

TABLE 5.20
OLS Estimation of Proportion of Non-NHS Bridges in Acceptable Condition in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Proportion of bridges in acceptable condition in year *t*-1	0.486	0.238	2.04	0.076
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	0.084	0.034	2.43	0.041
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	−0.057	0.028	-2.03	0.077
Number of observations	11			
Sum of square errors	0.004			
Adjusted R^2	0.541			
F statistic (*p*-value)	6.89	(0.018)		
Durbin-Watson Statistic	2.465			
Durbin's *h* statistic (*p*-value)	−1.261	(0.207)		

acceptable condition in the previous year, the natural logarithm of bridge expenditures, and the natural logarithm of pavement expenditures. The signs of the parameter estimates are the same as in the model for the entire highway network.

In terms of model fit, the *F* statistic is 6.89 with a *p*-value of 0.018 and the adjusted R^2 is 0.54. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. The adjusted R^2 is higher than the R^2 of the model for the entire highway network (0.36) but low for the limited variation in the data.

Durbin's *h* statistic is -1.269; therefore the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

5.3.3 Mobility Models by Road Classification

Separate model specification results for the proportion of sample roads that are congested (defined as a VSF ratio greater than or equal to 0.70) are included in Table 5.21, Table 5.22, and Table 5.23 for Interstate roadways, non-Interstate NHS roadways, and non-NHS roadways, respectively. The model results for each road classification are compared to the previously discussed model for the entire highway network for mobility.

For the proportion of Interstate roadways with a VSF ratio greater than or equal to 0.70, as shown in Table 5.21, the natural logarithm of mobility expenditures and the natural logarithm of pavement expenditures are the only statistically significant variables. The natural logarithm of pavement expenditures is only marginally significant. The variable is included because it is the most significant variable of all of the transformed expenditures, the proportion of congested roads in the previous year, and a constant. Without the addition of this variable, the *t*-statistic for the natural logarithm of mobility expenditures becomes very high because there are missing variables. The parameter estimate for the natural logarithm of mobility expenditures is positive, which does not meet the expectation that higher mobility expenditures are associated with lower levels of congestion. This could occur because there was a large investment in a few large projects that only addressed congestion in a localized area rather than the entire state. The number of observations for this subset of the data is 9; therefore, the addition of parameters has a large impact on the degrees of freedom. Additional parameters may be significant and yield a better fit if the dataset were larger.

In terms of model fit the *F* statistic is 1.60 with a *p*-value of 0.24, indicating that the model is not significantly improved over a naïve model with a constant term only. The adjusted R^2 is 0.07, which is much lower than the R^2 equal to 0.63 for the model for the entire highway network.

The Durbin-Watson test is used for this model because the lagged dependent variable is not statistically significant. The calculated Durbin-Watson statistic of 0.979 is between the bounds of d_L and d_U, therefore the test is inconclusive. Typically, for an inconclusive test, corrections for serial correlation are made using MLE and the results of the estimation with corrections for serial correlation is compared to the initial estimation. MLE is not an appropriate alternative analysis method for this study due to the small dataset. Therefore, the null hypothesis that there is no serial correlation cannot be rejected at the 95% confidence level.

The *F* test and the R^2 values indicate that the estimated model is not a significant improvement over a naïve model. The Durbin-Watson statistic is inconclusive. However, model specifications that improve upon the naïve model could not be estimated with the limited data available in the current study. Future research using a larger database is necessary to determine if these relationships hold or if additional variables are significant.

Model specification results for the proportion of non-Interstate NHS roadways with a VSF ratio greater than or equal to 0.70 are outlined in Table 5.22. Unlike

TABLE 5.21
OLS Estimation of Proportion of Interstate Sample Miles with VSF $\geq$ 0.70 in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	0.022	0.011	2.00	0.086
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	−0.010	0.011	−0.88	0.407
Number of observations	9			
Sum of square errors	0.005			
Adjusted R^2	0.070			
F statistic (*p*-value)	1.6	(0.246)		
Durbin-Watson Statistic	0.979			
dL	0.460			
dU	1.699			
4-dU	2.301			
4-dL	3.540			

TABLE 5.22
OLS Estimation of Proportion of Non-Interstate NHS Sample Miles with VSF ≥ 0.70 in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Proportion of sample miles with VSF ≥ 0.7 in year *t*-1	0.326	0.178	1.83	0.117
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	−0.054	0.019	−2.84	0.029
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	0.059	0.019	3.15	0.020
Number of observations	9			
Sum of square errors	0.005			
Adjusted R^2	0.561			
F statistic (*p*-value)	6.10	(0.036)		
Durbin-Watson Statistic	2.151			
Durbin's *h* statistic (*p*-value)	−0.268	(0.788)		

the model for the entire highway network, the proportion of roads with peak hour congestion in the previous year is a marginally significant variable. The variable is included in the model because it is anticipated that the significance will increase with a larger sample size. The natural logarithm of mobility expenditures and the natural logarithm of pavement expenditures are also statistically significant. The negative parameter estimate for the natural logarithm of mobility expenditures meets the expectation that an increase in expenditures correlates with a decrease in congestion. The positive parameter estimate for the natural logarithm of pavement expenditures does not meet expectations. The positive sign likely captures the effects of a constrained budget with minimum required expenditure amounts in each asset program. The positive sign accounts for the portion of expenditures each year that do not directly affect congestion.

In terms of model fit, the *F* statistic is 6.10 with a *p*-value of 0.04 and the adjusted R^2 is 0.56. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. The adjusted R^2 is slightly less than the R^2 of the model for the entire highway network (0.63) and low for the limited variation in the data.

Durbin's *h* statistic is -0.268; therefore the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

Model specification results for the proportion of non-NHS roadways with a VSF ratio greater than or equal to 0.70 are outlined in Table 5.23. Similar to the model for non-Interstate NHS roadways, the proportion of roads with peak hour congestion in the previous year is a significant variable. The natural logarithm of mobility expenditures and a constant are also significant. The negative parameter estimate for the natural logarithm of mobility expenditures meets the expectation that an increase in mobility expenditures correlates with a decrease in congestion.

In terms of model fit, the *F* statistic is 62.68 with a *p*-value of 0.0001 and the adjusted R^2 is 0.94. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. The adjusted R^2 is much higher than the R^2 of the model for the entire highway network (0.63) and favorable for the limited variation in the data.

Durbin's *h* statistic is -0.609; therefore the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

5.3.4 Safety Models by Route Type

Separate model specification results for the sum of non-fatality injury and fatality crashes per 100 million VMT are included in Table 5.24, Table 5.25, and Table 5.26 for Interstate, U.S. Routes, and State

TABLE 5.23
OLS Estimation of Proportion of Non-NHS Sample Miles with VSF ≥ 0.70 in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Constant	1.425	0.301	4.74	0.003
Proportion of sample miles with VSF ≥ 0.7 in year *t*-1	0.470	0.078	6.00	0.001
Natural logarithm of the 3-year average of annual Mobility expenditures for years *t*-1, *t*-2, and *t*-3	−0.080	0.017	−4.72	0.003
Number of observations	9			
Sum of square errors	0.001			
Adjusted R^2	0.939			
F statistic (*p*-value)	62.68	(0.0001)		
Durbin-Watson Statistic	2.395			
Durbin's *h* statistic (*p*-value)	−0.609	(0.542)		

TABLE 5.24
OLS Estimation of Non-Fatality Injury and Fatality Crashes per 100M VMT on Interstates in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Natural logarithm of the 3-year average of annual Safety expenditures for years *t*-1, *t*-2, and *t*-3	2.448	1.026	2.39	0.076
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	−1.093	0.888	−1.23	0.286
Number of observations	6			
Sum of square errors	3.241			
Adjusted R^2	0.144			
F statistic (*p*-value)	1.84	(0.247)		
Durbin-Watson Statistic	1.982			
dL	0.180			
dU	1.896			
4-dU	2.104			
4-dL	3.820			

Roads, respectively. The model results for each route type are compared to the previously discussed model for the entire highway network for safety.

For the model estimation of the Interstate crash rate, as shown in Table 5.24, the natural logarithm of safety expenditures and the natural logarithm of pavement expenditures are the only statistically significant variables. The natural logarithm of pavement expenditures is marginally significant. The variable is included because it is the most significant variable of all of the transformed expenditures, the previous year's crash rate, and a constant. Without the addition of this variable in the model, the *t*-statistic for the natural logarithm of safety expenditures becomes very high because there are missing variables. The parameter estimate for the natural logarithm of safety expenditures is positive, which does not meet the expectation that higher expenditures are associated with lower non-fatal injury and fatality crash rates. This could occur because there was a large investment in a few large projects that only addressed safety in a localized area rather than the entire state. The number of observations for this subset of the data is 6; therefore, the addition of parameters has a large impact on the degrees of freedom. Additional parameters may be significant and yield a better fit if the dataset were larger. The negative parameter estimate for the natural logarithm of pavements does meet expectation.

In terms of model fit the F statistic is 1.84 with a p-value of 0.25, indicating that the model is marginally improved over a naïve model with a constant term only. The adjusted R^2 is 0.14 which is much less than the R^2 of the model for the entire highway network (0.95) and low for the limited variation in the data. Additional parameters may be significant and yield a better fit if the dataset were larger.

The Durbin-Watson test is used for this model because the lagged dependent variable is not statistically significant. The calculated Durbin-Watson statistic of 1.982 is between the bounds of d_U and $(4-d_U)$, therefore the null hypothesis is not rejected and we conclude that serial correlation is not present.

Model specification results for the non-fatal injury and fatality crashes on U.S. Routes are outlined in Table 5.25. The constant term is marginally significant. The constant is included because the significance will likely be higher for a larger dataset. The parameter estimate for the natural logarithm of safety expendi-

TABLE 5.25
OLS Estimation of Non-Fatality Injury and Fatality Crashes per 100M VMT on U.S. Routes in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Constant	−103.047	64.234	−1.60	0.207
Natural logarithm of the 3-year average of annual Safety expenditures for years *t*-1, *t*-2, and *t*-3	−10.451	2.310	−4.52	0.020
Natural logarithm of the 3-year average of annual Bridge expenditures for years *t*-1, *t*-2, and *t*-3	19.915	3.813	5.22	0.014
Number of observations	6			
Sum of square errors	6.328			
Adjusted R^2	0.874			
F statistic (*p*-value)	18.30	(0.021)		
Durbin-Watson Statistic	3.329			
dL	0.467			
dU	1.896			
4-dU	2.104			
4-dL	3.533			

tures is negative. This meets the expectation that higher safety expenditures are correlated with lower crash rates. The positive parameter estimate for the natural logarithm of bridge expenditures does not meet expectations. The positive sign for the parameter estimate likely captures the high costs of the collection of bridge projects each year relative to the small decreases in the crash rate. Additionally, the positive sign likely captures the effect of a constrained budget because a portion of the budget is contracted each year to a collection of projects that do not directly affect safety.

In terms of model fit, the *F* statistic is 18.30 with a *p*-value of 0.02 and the adjusted R^2 is 0.87. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of variance explained, the adjusted R^2 is slightly less than the R^2 for the model for the entire highway network (0.95). The R^2 is reasonable given the limited variation in the data.

The Durbin-Watson test is used for this model because the lagged dependent variable is not statistically significant. The calculated Durbin-Watson statistic of 3.329 is between the bounds of $(4-d_U)$ and $(4-d_L)$, therefore the test is inconclusive. Typically, for an inconclusive test, corrections for serial correlation are made using MLE and the results of the estimation with corrections for serial correlation is compared to the initial estimation. MLE is not an appropriate alternative analysis method for this study due to the small dataset. Therefore, the null hypothesis that there is no serial correlation cannot be rejected at the 95% confidence level.

For the sum of non-fatality injury and fatality crashes per 100 million VMT on State Roads, as shown in Table 5.26, two variables previously found significant in the model for the entire highway network are again significant—the previous year's crash rate and the natural logarithm of safety expenditures. The signs of the parameter estimates are the same as for the model for the entire highway network. On State Roads, the natural logarithm of pavement expenditures is also a significant predictor of the sum of non-fatality injury and fatality crashes per 100 million VMT. The parameter estimate is positive, which does not meet the expectation that an increase in any type of expenditures is associated with a decrease in the number of crashes per 100 million VMT. The positive sign likely captures the effects of a constrained budget with minimum required expenditure amounts in each asset program. The negative sign accounts for the portion of expenditures each year that do not directly affect safety.

In terms of model fit, the *F* statistic is 113.37 with a *p*-value of 0.002 and the adjusted R^2 is 0.98. The *F* statistic indicates that the model is significantly improved over a naïve model with a constant term only. In terms of variance explained, the adjusted R^2 is slightly higher than the R^2 for the model for the entire highway network (0.95). The R^2 is favorable given the limited variation in the data.

Durbin's *h* statistic is -0.930; therefore the null hypothesis cannot be rejected at the 95% confidence level, and we conclude that serial correlation is not present.

5.4 Discussion

The primary objective of the present study is to define the relationship between INDOT's program expenditures and the resulting performance in four areas: pavements, bridges, mobility, and safety. Models were developed using ex-post facto data for the relationship between expenditures and performance at the system (or statewide) level. After developing models for the entire highway network, additional models were estimated to explore the effects of road classification on the relationship between expenditures and performance. This analysis seeks to answer the question—is the relationship between actual performance and expenditures different for different road classes? Several overarching themes were prevalent in the model estimation results.

First, estimation efforts are significantly limited by the small number of observations. OLS estimators are unbiased only when the linear regression assumptions are met. The assumption that the disturbances are not serially correlated is validated for some but not all of

TABLE 5.26
OLS Estimation of Non-Fatality Injury and Fatality Crashes per 100M VMT on State Roads in Year *t*

Variable Description	Estimated Parameter	Standard Error	*t* Statistic	P[|T|>t]
Non-fatal injury and fatality crashes per 100M VMT in year *t*-1	0.220	0.126	1.75	0.178
Natural logarithm of the 3-year average of annual Safety expenditures for years *t*-1, *t*-2, and *t*-3	−11.279	1.441	−7.83	0.004
Natural logarithm of the 3-year average of annual Pavement expenditures for years *t*-1, *t*-2, and *t*-3	14.292	1.873	7.63	0.005
Number of observations	6			
Sum of square errors	1.899			
Adjusted R^2	0.978			
F statistic (*p*-value)	113.37	(0.002)		
Durbin-Watson Statistic	2.722			
Durbin's *h* statistic (*p*-value)	−0.930	(0.353)		

the models. For the model of bridges in acceptable condition for the entire highway network, the null hypothesis is rejected and we conclude that serial correlation is present. The parameter estimates for this model may be biased. Although the signs of the parameters likely would not change with correction, the magnitude of the impact (and potentially the significance of some or all variables) likely would. Unfortunately, the only correction for serial correlation involves MLE estimation, which is not possible due to the limited data available. For the proportion of non-NHS bridges in excellent condition, a formal test for serial correlation could not be conducted. The Durbin-Watson test is inconclusive for all of the following dependent variables:

- Proportion of non-Interstate NHS pavements in excellent condition
- Proportion of non-Interstate NHS pavements in acceptable condition
- Proportion of non-NHS pavements in acceptable condition
- Proportion of non-Interstate NHS bridges in excellent condition
- Proportion of non-Interstate NHS bridges in acceptable condition
- Proportion of Interstate sample miles with VSF ratio greater than or equal to 0.70
- Sum of fatality and non-fatality injury crashes per 100 million VMT on U.S. routes

A practical approach for inconclusive tests would have been to correct for serial correlation and compare the parameter estimates of the corrected model to the original estimates. Unfortunately, the only correction for serial correlation involves MLE estimation.

In addition to potentially biased estimates, with a small dataset several independent variables that may be true predictors of performance in the population are only marginally significant in the current analysis. A larger database is necessary to determine if these variables are truly significant.

The number of observations has a large effect on the *F* statistic used to measure goodness-of-fit. The degrees of freedom for the *F* statistic are equal to the difference between the number of observations and the number of estimated parameters, for both the estimated and naïve models. For a sample of a given size, the addition of parameters decreases the available degrees of freedom and a larger difference between the estimated and naïve model is necessary for a statistically significant results. For a small dataset, fewer parameters can be estimated without a restrictive loss of degrees of freedom. The model estimations for the proportion of non-Interstate NHS pavements in acceptable condition, the proportion of Interstate pavements in acceptable condition, and the proportion of Interstates with peak hour congestion were not significantly improved over naïve models. The model estimations for the statewide proportion of pavements in excellent condition, the proportion of non-Interstate NHS bridges in excellent condition and the crash rate on Interstates were marginally improved over naïve models. If the database contained more observations, potentially significant parameters could be estimated without a loss of degrees of freedom.

The limited number of observations is compounded by too little variance. The amount of variance affects the adjusted R^2 values. In the statewide safety model estimation and the models of the proportion of non-NHS roads with peak hour congestion and the crash rate on State Roads, the R^2 values are above 0.90. Although these values are very high, they may be inflated due to the small variation in the independent variables.

Second, parameter estimates are not consistent in sign. In the case of the proportion of pavements in excellent condition or the proportion of bridges in excellent condition, parameter estimates may be capturing the deterioration that occurs over time due to loading and environmental stresses. The estimates may also have signs opposite to expectations because the proportion of pavements or bridges in acceptable condition is increasing but the proportions in excellent condition are not.

As previously noted, the number of projects could potentially influence the relationship between expenditures and performance. A large sum of funds spent on a few large projects could have a very small impact over the entire state; whereas if that same sum were spent on a collection of many smaller projects throughout the state, the net impact statewide could be much more substantial. For example, a few large projects for pavement reconstruction in an urban area might have a large cost for a very small length of the entire statewide network that does not drastically change the proportion of pavements in excellent or acceptable condition. In contrast, several smaller projects such as pavement overlays across the state may drastically change the proportion of pavements in excellent or acceptable condition. This hypothesis is difficult to test because there are not enough data in the current dataset. As additional variables are introduced, the degrees of freedom decrease and the likelihood of a Type II error increases. Several model estimations were attempted that included the number of projects as an independent variable. Unfortunately there are not enough degrees of freedom to include both the amount of money spent and the number of projects. Attempts were made to correct for this by looking at the sum of three years of expenditures per the sum of the number of projects over those three years. The effects of this variable are much more difficult to interpret and may be potentially confusing. Estimations with this class of variables were abandoned because accountability and the potential for reporting are two of the main purposes for undertaking a post-implementation evaluation.

Additionally, the model estimation results are heavily dependent on the quality of input data. For example, expenditures were classified using the very specific asset lookup table, as found in Appendix B. The asset lookup table was provided by INDOT; however, several work types could potentially be identified with an alternative asset group. The provided table was used to consistently group expenditures. Changes to the asset group composition could alter the magnitude or significance of different expenditures.

The parameter estimates could also be influenced by missing variables. For example, the economic conditions in a given year could potentially influence the impact of investments. The correction for inflation is not the same as a variable to reflect the economic outlook in a given year. Even if additional variables to measure this effect (or others) were available, the limited size of the dataset makes the estimation of additional parameters infeasible.

Third, the relationship between performance and expenditures is different for each road classification (route type), with the exception of the models for the proportion of pavements in excellent condition. For the proportion of pavements in excellent condition, it is likely that with a larger database, the trend would be similar to all of the other dependent variables. This finding intuitively makes sense because program funds are appropriated based on designation as either on the Interstate System or the NHS. The Interstate System and the NHS must be maintained in better condition than non-NHS roads because the majority of the travel occurs on the NHS. To maintain these systems in better condition than non-NHS routes naturally requires additional funding. Future data collection should include the road classification. Safety measures were not available with the NHS designation for the current study. In the future, models of the relationship between expenditures and safety performance should be developed using the road classification of Interstate roadways, non-Interstate NHS roadways, and non-NHS roadways.

6. ECONOMIC DEVELOPMENT IMPACT EVALUATION

6.1 Introduction

Since Aschauer's (*36*) pioneering findings that public capital investment can be a powerful engine to prompt economic growth, the impacts of transportation investment on regional economic growth have been recognized by numerous other studies (*37–41*). Economic development impact is used as a means to assess the value of transportation system investment, which may prompt regional economic growth by generating job opportunities and increasing income. Extensive project-level and program-level economic impact evaluation studies have been carried out by State DOTs to evaluate future and on-going transportation expenditures before project selection and investment decisions (*42–47*). Our study had a different focus: to assess the statewide economic impacts of past fifteen years INDOT transportation investment and verify if the anticipated benefits have been achieved based on post-implementation data.

As seen in Figure 6.1, there is no clear trend of increasing or decreasing expenditures over the years for 1995 to 2010. When a 10-year Major Moves program began in 2005, the expenditures, especially those for Interstate and National Highway System highways start to rise significantly. In order to understand how changing transportation investment and accessibility generate direct, indirect and induced economic impacts to the Indiana economy, we use input-output (I-O) analysis as the basic tool.

6.2 Methodology

6.2.1 Input-Output Analysis

Input-output (I-O) analysis forms the basis for economic impact models. An input-output model describes how many units of input from various industrial sectors are required to produce one unit of output in the state's highway construction sector. The job (employment) and earning multipliers that are derived from I-O analysis play a fundamental role in economic impact analysis.

As a key component in multiplier analysis, an I-O table is able to provide data on industry demands from all other industries (depicted in the columns of the table for each industry) and suppliers to all other industries (depicted across the rows of the table for each industry). Final demands and total output for the economy are

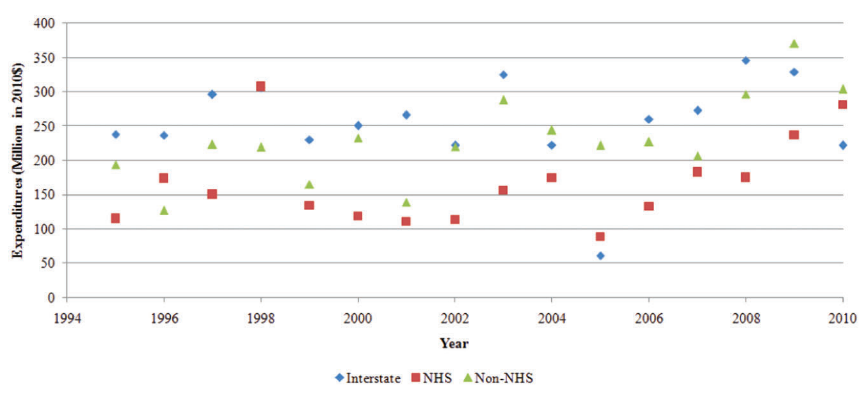


Figure 6.1 Time series of INDOT investment by state highway systems (2010$).

also included in the table (*48*). In order to quantify the total economic impacts of a new transportation project in an economy, changes in all demands from other industries (the upstream linkages) should be determined. For instance, a $2.07 million bridge replacement project constructed on I-465 over Monon Trail in Hamilton County could have provided an initial and direct impact of $2.07 million on the local economy. Moreover, this construction project called for raw materials like concrete and asphalt, and labor like construction workers and supervisors. The expenditures on these materials and services comprise the indirect impacts. Furthermore, the businesses experiencing direct and indirect impacts will hire more workers or raise wages. When additional income is spent at local retail and service businesses, it generates induced impacts. The mechanism used to measure total indirect and induced impacts associated with direct impacts is the (I-O) table. The data from an I-O table can also offer quantitative measures of upstream and downstream linkages. An upstream linkage shows the relationship between the construction sector and its suppliers, and measures the strength of the supplier relationship, while a downstream linkage denotes the relationship between the construction sector and its consumers and measures the strength of the market for selling the product as an input (*48*).

For the United States, the Bureau of Economic Analysis (BEA) collects and publishes benchmark input-output data every five years. And the Bureau of Labor Statistics (BLS) develops BEA benchmark-year input-output table based on this data. Usually, regional multipliers are generated from regional purchase coefficients (RPCs) and the national I-O table. RPCs denote the percentage of local demand that is satisfied by local suppliers. High RPCs are an indication of higher multiplier effects because money spent on input requirements is being retained locally. I-O models generally use the national I-O table in some way, but each has different methods of calculating RPCs (*49*).

Widely used I-O models include the Regional Input-Output Modeling System (RIMS II) and IMPLAN. RIMS II is a sophisticated regional input-output model provided by the BEA. It uses location quotients to regionalize the national technical coefficients and assumes that local demand is satisfied first before the remainder of any production is exported (*50*). However, the location quotient does not deal with cross-hauling (regional demand being satisfied by some combination of regionally produced and imported products/services) very well and tends to overstate the multiplier. The IMPLAN model is a classic I-O economic impact model produced by Minnesota IMPLAN Group, Inc.. It assumes a uniform national production technology and uses the RPC approach to regionalize the technical coefficients. The software uses interstate trade flow matrices of the uncorrected Miro's model from the U.S. Department of Health and Human Services and estimated regional demand (*50*). The calculated supply-demand pool ratios give an upper bound on the RPCs, which can create problems on a regional scale if additional industries are added to the region, thereby reducing the level of inter-regional trade flow (*49*). These models contains all the necessary information on sectoral linkages to estimate the total economic impact of a specified change in the final demand for the output of any given industry. But it may be difficult to develop a localized input-output matrix, because the inter-industry relationship from a national forecast is seldom applicable to smaller analysis levels. (*51,52*).

6.2.2 Economic Impact Model

To capture more precise inter-industry linkages of state economy, we chose the Strategic Advantage package from Economic Modeling Specialists Inc. (EMSI) as the analysis tool (the EMSI model). It is a web-based regional I-O tool and has an economic impact analysis module built on the Indiana I-O matrix. By using a localized I-O table, we are able to better establish the demand side of the local economy.

The economic impact model in EMSI incorporates a sophisticated variation of the Stevens method of calculating the RPCs (*49*), which is expected to relax the artificial upper bound restricted by IMPLAN and solve the issues of inter-regional trade and cross-hauling that are ignored by RIMS II. Besides, our analysis is performed at the most refined industry level, which is up to six-digit North American Industry Classification System (NAICS) code, as opposed to three or four digits employed by popular commercial models like REMI and IMPLAN and two digits by the Regional Input-Output Modeling System (RIMS II). Construction is one of the large business sectors at two-digit level. As shown in the tree graph of Figure 6.2, this sector contains subsectors or industry groups like Oil and Gas Pipeline and Related Structures Construction (237120) and Land Subdivision (237210) etc. If we restrict our investment just in an aggregate level like two-digit Construction (23) sector or a three-digit Heavy and Civil Engineering Construction (237) industry, the direction of fund flow cannot be exactly revealed. In our case, we specify the expenditures in the industry of Highway, Street, and Bridge Construction (NAICS code: 237310) to ensure more accurate inputs to I/O model.

Other distinct features of the EMSI model compared to other commercial models are its cost and user-friendly interface. According to a comparison list from the EMSI Strategic Advantage 2007 User's Manual (*53*) (see Table 6.1), the EMSI model appears more affordable because it is operated in a web-based environment, lower license costs and operational cost are possible.

Because regions are economically diverse and transportation costs increase with region size, multipliers often depend on the size of the region and can get out of date. Usually, the national I-O accounts are released in a "benchmark" format every five years, while regional data depend primarily on the BEA's State and Local Personal Income reports, the BLS's Quarterly Census

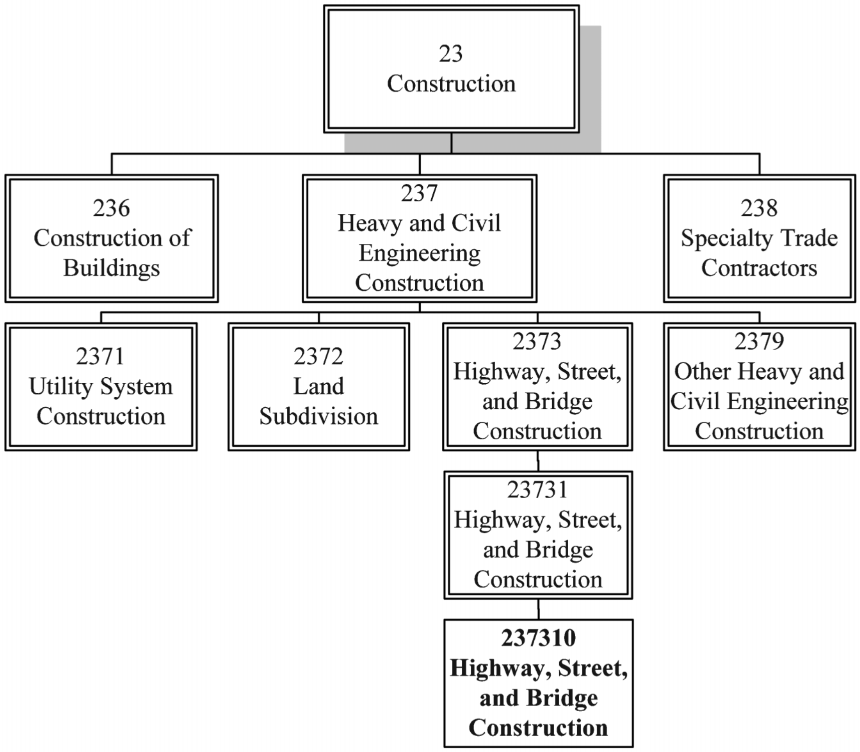


Figure 6.2 Tree graph of construction sector in North American Industry Classification System (NAICS).

of Employment and Wages, and the Census Bureau's County Business Patterns. These data sources have lots of industry and geographic detail, but with a lag time of six months to two years. Other current data sources (like the Current Employment Survey) have a lag of only about one month, but with significantly less detail. The EMSI model is built on federal and state data sources and creates an integrated data set that balances accuracy with up-to-date relevance. New annual-average data is released on a quarterly schedule, keeping the model updated with new information (*54*).

6.3 Short-Term Economic Impacts Analysis

The short-term economic impacts include direct, indirect and induced impacts in response to highway construction activities. Usually, they are viewed as not contributing to sustainable economic growth and cover little more years of construction period. Direct impacts consist of capital and operations spending on labors and construction operators. Indirect effects are generated by additional orders to raw materials and services from supplier industries. Included impacts are consumer spending generated by the additional income of direct and indirect labors. The short-term construction-related impacts are estimated using EMSI model.

As illustrated in Figure 6.3, we simulate construction-related short-term economic impacts from highway system expenditures on all assets (bridge, roadway, safety and mobility) for the last 16 years. Since there is little information available about past I-O tables, we used an index (consumer price index/construction cost index) to bring the expenditures arising from INDOT's expenditures in support of its bridge, roadway, safety and mobility assets to their 2010 values, year-by-year. Then we use the 2010 Indiana I-O table in EMSI to assess the impacts based on the assumption that the Indiana I-O table changes little across years. Economic

TABLE 6.1
Comparison of Economic Impact Models (*53*)

	RIMS II	IMPLAN	REMI	EMSI Model
Zip code data	No	Yes	No	Yes
Software /Interface	Installed software	Installed software	Installed software	Web-based exportable reports
RPC estimation	1990s methods	More recent	More recent	More recent
Interregional modeling	No	In development	Yes	In development
GIS feature	No	No	No	In development
Model type	Comparative static	Comparative static	Limited dynamic	Comparative static
Cost of model for 10-county region (10 users)	\$275 per region (regardless of region size)	\$475~\$22K	\$80K - \$100K+	\$3.5K first year with half-price renewal option

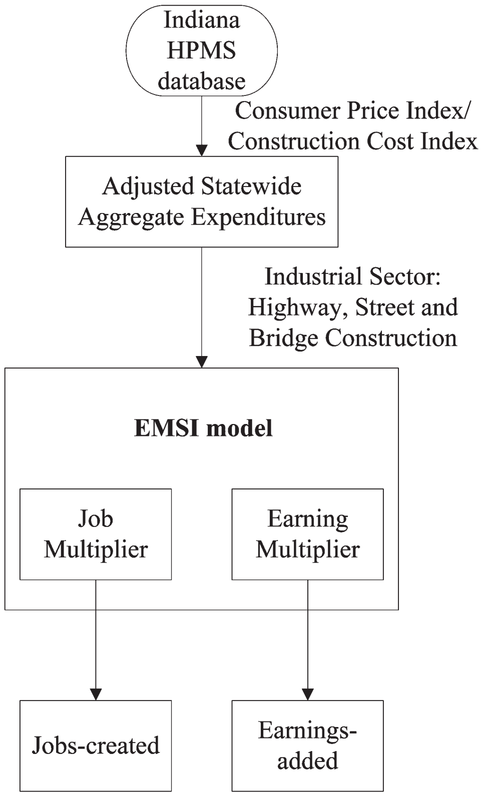


Figure 6.3 Flow chart of input-output analysis process.

impacts from such a model are measured in terms of total employment change and total earnings change. Total employment includes full- and part-time employment, consistent with the U.S. Bureau of Economic Analysis (BEA). Total earnings are defined as total employee compensation such as labor income, wages, salaries, and benefits.

The estimation results are presented in Table 6.2. It shows that $10.4147 billion (in 2010 $) investment in highway construction during 1995-2010 would have created 179,905 jobs and would have increased total earnings by $9.5314 billion (in 2010 $) in the state of Indiana. As presented in Figure 6.4 and Figure 6.5, the time series trends of total jobs-created and total earnings-added are consistent with that of total INDOT statewide expenditures on all highway assets. This confirms that the input-output model is fundamentally linear in nature. We use jobs (employment) multipliers and earnings multipliers to indicate how important the role of transportation system construction is in jobs creation and earnings increases. A jobs multiplier of 2.93 means that, for every new "direct" job in highway, street and bridge construction industry, 1.93 more jobs would be created in other industries. Similarly, a 1.97 earnings multiplier denotes that for every dollar of compensation entered as a "direct effect" in the industry, an additional $0.97 is paid out in wages, salaries, and other compensation throughout the Indiana economy.

To display direct impacts and secondary (indirect and induced) impacts in addition to initial impacts, we present pie charts (Figure 6.6) showing the effect on jobs and total earnings from investment in Highway, Street, and Bridge Construction (NAICS code: 237310).

The pie charts in Figure 6.7 summarize the top 10 impacted 2-digit level industrial sectors by INDOT investment in the past 16 years in terms of earnings-added and jobs-created. The construction sector plays the largest role because the employment of labors and compensation are directly created through transportation construction activity. Based on detailed industry linkage, a given direct impact on the construction sector can be traced backward to their suppliers, second-tier

TABLE 6.2
Short-Term Statewide Economic Impacts of Indiana State Highway Investment

Year	Investment (Million 2010$)	Jobs-created	Earnings-added (Million 2010$)	Per Capita Earnings-added (2010$/person)
1995	546.3640	9,438	500.0252	85.4531
1996	537.7453	9,289	492.1375	83.3282
1997	669.2757	11,561	612.5124	102.8522
1998	832.7895	14,386	762.1581	127.0501
1999	529.8597	9,153	484.9207	80.2189
2000	601.3609	10,388	550.3577	90.3463
2001	515.8942	8,912	472.1396	77.0844
2002	555.3041	9,592	508.2071	82.6486
2003	769.6224	13,294	704.3484	113.9392
2004	640.7756	11,069	586.4295	94.3654
2005	371.4763	6,417	339.9703	54.3681
2006	619.3055	10,698	566.7804	89.9409
2007	662.3061	11,441	606.1339	95.5127
2008	817.8534	14,128	748.4888	117.1654
2009	937.6263	16,197	858.1034	133.7633
2010	807.1195	13,942	738.6653	114.4886
Total	**10,414.6785**	**179,905**	**9,531.3783**	—

NOTE: Jobs multiplier: 2.93; earnings multiplier: 1.97.

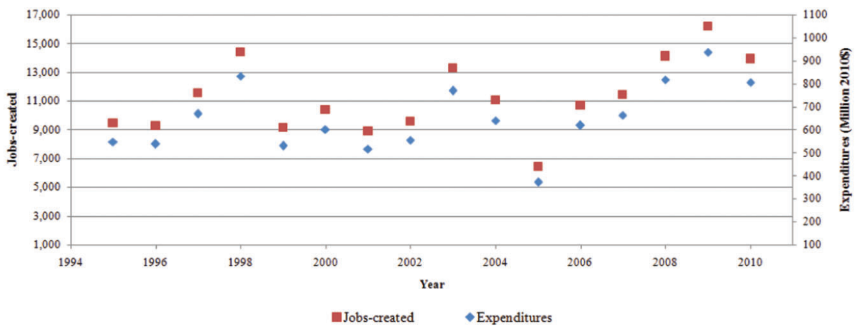


Figure 6.4 Time series of total expenditures and short-term statewide jobs-created.

suppliers, and so on. Health care, manufacturing, services, retail trade and government sectors benefit the most among the indirect and induced impacts of INDOT's highway expenditures.

6.4 Long-Term Economic Impacts Analysis of Adding Capacity Projects and New Construction Related Projects

Long-term economic development impacts include not only construction-related direct, indirect and induced impacts, but also business expansion effects, business attraction effects, property values and regional competitiveness growth effects. A general process for evaluating the long-term impacts of investment in transportation projects would involve estimating user benefits from the projects, translating these benefits into economic consequences, allocating benefits to specific economic sectors, and finally estimating the additional impact due to changes in logistics and product markets, over and above short-term impacts (*55*).

Even though there are a few recognized commercial packages (e.g., REMI, TREDIS, etc.) developed for long-term economic impacts assessment and prediction, they could not be used to meet the needs of our ex-post facto assessment of the impacts of historical highway projects. This is because we need to specify statewide econometric models based on information for only the past 16 years. Therefore, we adopted a simultaneous equation system developed by Gkritza et al. (*56*) to estimate the benefit measures of long-term economic development based on attributes of project types. Only two project types could be considered (adding travel lane projects and new construction-related projects), accounting for almost 34% of all expenditures in total. Nevertheless, the approach would indicate a measure of long-term economic development impacts of highway expenditures.

"Adding travel lane" category is one of the more common highway project categories. "Adding travel lane" projects are primarily implemented to improve the capacity of roadway segments, which are mobility assets in the SPMS database. "New construction-related" projects are new road, new median and new interchange construction projects. New road construction investments are aimed at providing better access to designated areas, and are always categorized as mobility assets. New median construction projects are usually built on highway segments for safety considerations and generally belong to roadway or safety assets. Interchange construction projects also enhance mobility assets. They include new interchange construction on interstate facilities and upgrades from at-grade signalized intersections to grade-separated interchanges on non-interstate facilities. Interstate highway interchanges with a high degree of accessibility to employment have been found to generate more economic

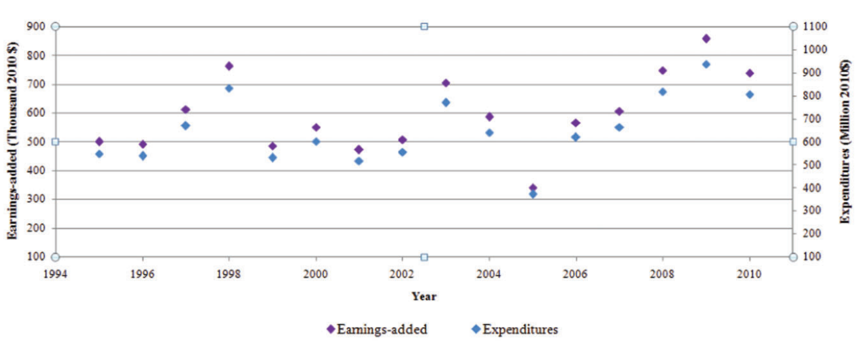
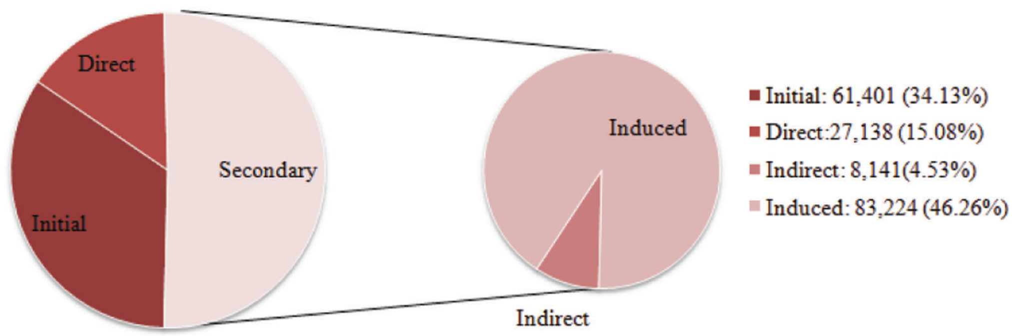
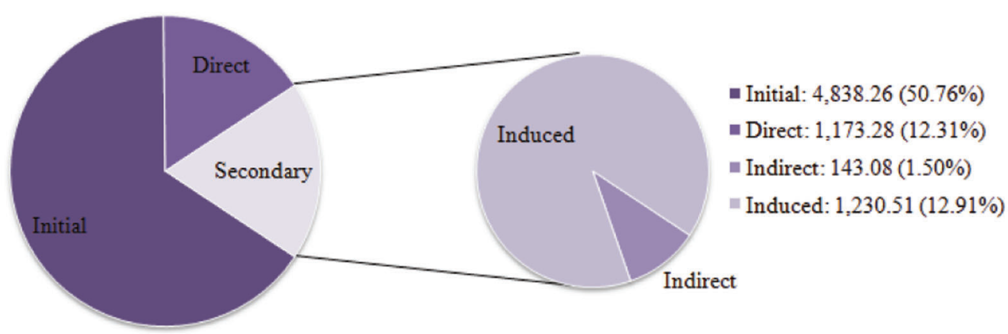


Figure 6.5 Time series of total expenditures and short-term statewide earnings-created.



(a)



(b)

Figure 6.6 Effect on (a) jobs and (b) earnings from INDOT expenditures in highway, street, and bridge construction (NAICS Code 237310).

development benefits than median construction projects or new road construction projects on state roads in North or Central Indiana (*56*).

In the SPMS database, 9,055 out of 9,826 INDOT transportation improvement projects for the years 1995-2010 have non-missing values for "letting amount". Capacity expansion projects accounted for \$2713.9 million (1996 \$), or 34.3 percent, out of the \$7895.9 million (1996 \$) spent. Within "capacity expansion", \$1,628.6 million (1996 \$) were spent on "adding travel lane" projects and \$1,085.3 million (1996 \$) were spent on "new construction-related" projects. In terms of number of projects, 734 (8.1%) out of the 9,055 total projects are "Added Travel Lanes" projects and 446 (4.9%) are "new construction-related" projects. The data summary by year is shown in Table 6.3. To understanding the effects of INDOT investment on long-term statewide economic development impacts, it is necessary to study the long-term economic impacts of these projects. The expenditures were adjusted to 1996 dollars to facilitate use of the calibrated econometric models developed by Gkritza et al. (*56*).

The equation developed by Gkritza et al. (*56*) allows for contemporaneous (cross-equation) correlation of errors. This is because the dependent variables are indicators of the same underlying process (i.e., change in economic activity) resulting from a specific highway project. Four measures (Net Change in Employment, Net Change in Income, Net Change in Output, Net Change in GRP) are used as dependent variables, because these variables are typically used as measures of economic development by state/local agencies when evaluating competing projects (*57*). Project-specific attributes like project size/length/costs/geographic location/area type are chosen as explanatory variables. The employment estimates are based on different assumptions that feed the business attraction estimation module. For this reason, Gkritza et al. (*56*) developed a set of equations that produce lower bound estimates of employment impacts and another set for upper bound estimates.

The simultaneous equation system for lower bound estimates of highway investment impacts involving added-capacity projects is:

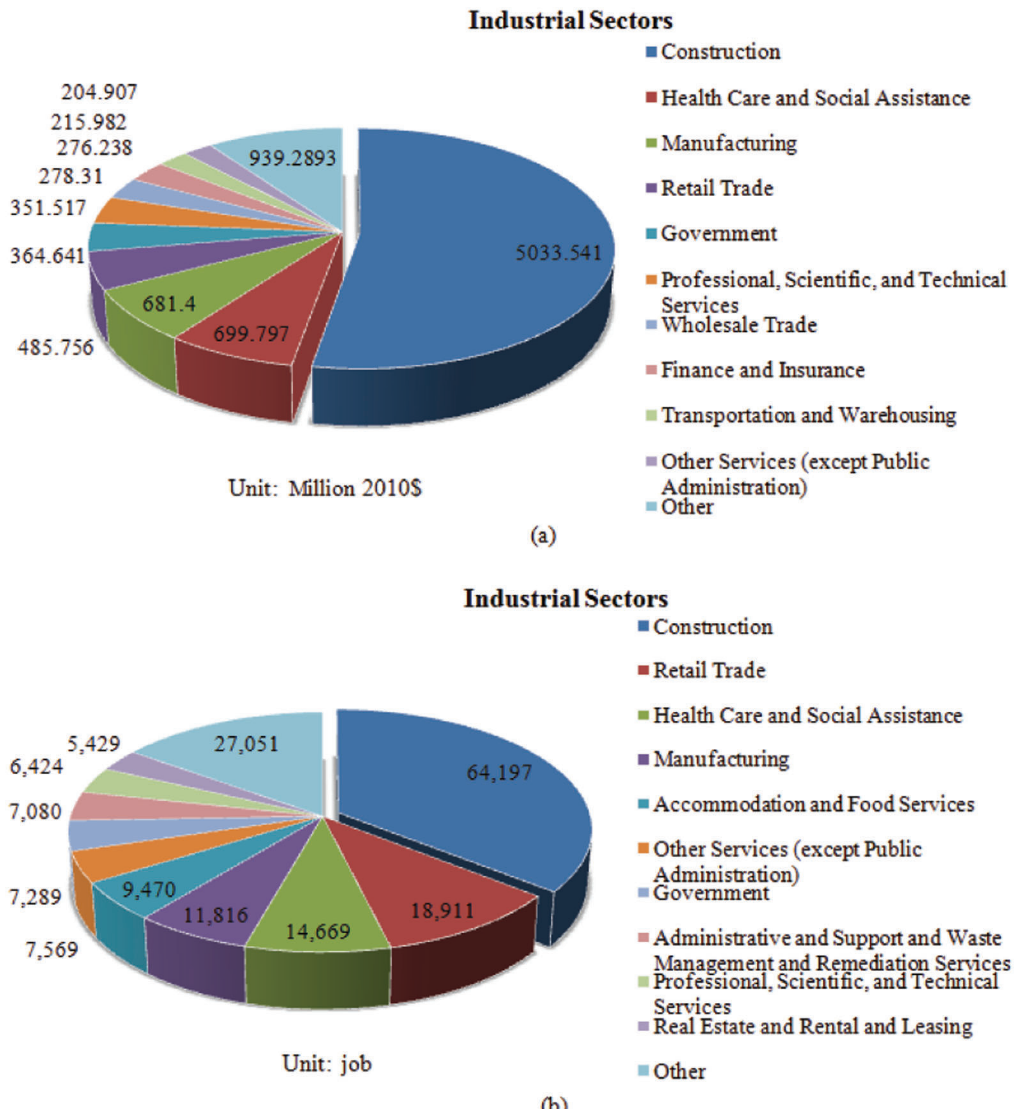


Figure 6.7 Rankings of most impacted industrial sectors in (a) earnings-added and (b) jobs-created.

TABLE 6.3
Percentage of 1995-2010 INDOT Investments Classified as "Added-Capacity" Projects and "New Construction-Related" Projects

Year	Expenditures (Million 1996$)	Expenditures in "Added-Capacity" Projects (Million 1996$)	% of "Added-Capacity" Projects in Total	Expenditures in "New Construction-Related" Projects (Million 1996$)	% of "New Construction-Related" Projects in Total
1995	414.2	7.4	1.8%	0.0	0.0%
1996	407.7	21.8	5.4%	8.8	2.2%
1997	507.4	58.8	11.6%	32.8	6.5%
1998	631.4	77.4	12.3%	98.2	15.6%
1999	401.7	31.9	7.9%	34.7	8.6%
2000	455.9	67.4	14.8%	24.4	5.4%
2001	391.1	83.3	21.3%	17.0	4.3%
2002	421.0	92.0	21.9%	4.0	0.9%
2003	583.5	187.7	32.2%	58.1	10.0%
2004	485.8	177.8	36.6%	54.2	11.2%
2005	281.6	16.5	5.9%	10.9	3.9%
2006	469.5	52.9	11.3%	60.6	12.9%
2007	502.1	181.5	36.2%	42.0	8.4%
2008	620.1	154.1	24.9%	79.8	12.9%
2009	710.9	272.6	38.4%	148.9	20.9%
2010	611.9	145.3	23.7%	411.0	67.2%
Total	**7,895.9**	**1,628.6**	**20.6%**	**1,085.3**	**13.7%**

$$\begin{cases} REMIEMP = -205.57 + 6.92NEWLNMI \\ \qquad -36.04URBAN + 150.43I \\ \qquad +33.83ACCAIRP - 21.90CENTRAL \\ REMINCMI = -10.87 + 0.31NEWLNMI \\ \qquad +2.16URBCENTR + 8.20I \\ \qquad +2.10ACCAIRP + 0.44ACUNIVS \\ REMIOUTMI = -67.35 + 1.97NEWLNMI \\ \qquad +40.98I + 11.41ACCAIRP \\ REMIGRPMI = -29.14 + 0.93NEWLNMI \\ \qquad -2.03RESTURBAN + 22.04I \\ \qquad -5.15ACCAIRP - 3.26CENTRAL \end{cases}$$

The simultaneous equation system for upper bound estimates of highway investment impacts involving added-capacity projects is:

$$\begin{cases} REMIEMP = -156.00 + 10.56NEWLNMI \\ \qquad -168.40URBAN + 347.21I \\ \qquad +43.75ACCAIRP - 90.86CENTRAL, \\ REMINCMI = -8.71 + 0.51NEWLNMI \\ \qquad -4.51RESTURBAN + 14.08I \\ \qquad +2.04ACCAIRP - 3.78ACENTRL \\ \qquad +0.022PRCOSTMI, \\ REMIOUTMI = -77.01 + 3.01NEWLNMI \\ \qquad -17.93URBAN + 65.85I \\ \qquad +15.97ACCAIRP, \\ REMIGRPMI = -27.21 + 2.18NEWLNMI \\ \qquad -16.16RESTURBAN + 21.43I \\ \qquad -19.25ST + 8.13ACCAIRP \\ \qquad -22.44CENTRAL. \end{cases}$$

The simultaneous equation system for lower bound estimates of highway investment impacts involving new construction-related projects is:

$$\begin{cases} REMIEMP = 16.59 + 1.40PRLENNRC \\ \qquad +172.84I + ACEMPI45 \\ REMINCMI = 3.08 + 14.25I + 11.35ACEMPI45 \\ \qquad +0.66URBU - 1.32MC \\ REMIOUTMI = 8.26 + 0.27PRLENNRC \\ \qquad +82.18I + 50.60ACEMPI45 \\ \qquad -2.12URBAN \\ REMIGRPMI = 3.25 + 37.14I + 25.60ACEMPI45 \end{cases}$$

The simultaneous equation system for upper bound estimates of highway investment impacts involving new construction-related projects is:

$$\begin{cases} REMIEMP = 10.42 + 4.02PRLENNRC + 225.24I \\ \qquad +175.44ACEMPI45 \\ \qquad +18.41SOUTHNRC \\ REMINCMI = 2.14 + 0.28PRLENNRC + 19.37I \\ \qquad +19.34ACEMPI45 + 0.65URBU \\ \qquad -0.60MC - 0.67STNRC \\ REMIOUTMI = 4.96 + 1.35PRLENNRC \\ \qquad +106.62I + 80.68ACEMPI45 \\ REMIGRPMI = 2.32 + 0.64PRLENNRC \\ \qquad +48.48I - 40.32ACEMPI45 \end{cases}$$

where the variable notation is given in Table 6.4.

Low and high estimates of the long-term jobs created from investment in adding travel lane projects along with the total expenditures, are presented for each year, 1995 to 2010, in Figure 6.8. A similar display for new construction-related projects is presented in Figure 6.9.

Overall, as a proportion of the total long-term employment impacts from all 1995-2010 highway projects, the estimated long-term statewide jobs created from 3.580 billion 2010$ investment in adding capacity projects and new construction-related projects (34.3% of total investment) ranges from 28,887 to 86,339.

6.5 Discussion

Our short-term estimates indicated that 17,274 construction-related jobs would have been created and \$0.9152 billion (2010 \$) total earnings would have been added for each \$1 billion (2010 \$) investment spent on highway construction in Indiana. In order to verify the short-term values, we compared those of past state/national transportation investment practices in terms of analysis period and analysis level (shown in Table 6.5). With respect to analysis period, short-term jobs and earnings are supported each year by capital spending and ongoing operations and maintenance spending, while long-term jobs and income are generated as a result of improvements in the transportation system and last for a longer period—15 to 20 years. Aggregate impacts are the combined impacts of all highway projects within the state.

From the studies reviewed above, we can summarize that:

- Short-term impacts expressed as new jobs per \$1 billion tend to be larger than long-term impacts because construction related jobs do not last beyond the life of the project. Long-term impacts of transportation investments on economic growth depend on the availability of land, labor and capital. If these factors are present, they contribute to sustainable economic growth, which may take many years to realize. The available methodology for long term impact analysis could account for only about one-third of highway expenditures and thus the

TABLE 6.4
Variable Notation Description for Gkritza et al. (*56*) Simultaneous Equation System

Dependent Variables	
REMIEMP	net change in employment (jobs)
REMINCMI	net change in real disposable income (million 1996 dollars)
REMIOUTMI	net change in output (million 1996 dollars)
REMIGRPMI	net change in gross regional product (million 1996 dollars)
Independent Variables	
ACCAIRP	degree of accessibility to major airports (1-low to 5-high)
ACUNIVNS	degree of accessibility to universities in North and South Indiana (1 to 5)
ACEMPI45	high degree of accessibility of interchange construction projects to employment (4 to 5)
CENTRAL	1, if project located in Central Indiana; 0, otherwise
I	1, for interstate highway improvements; 0, otherwise
MC	1, for median construction projects; 0, otherwise
NEWLNMI	new (added) lane-miles
PRCOSTMI	project costs (million 1996 dollars)
PRLENNRC	project length in miles for new road construction projects
RESTURBAN	1, if project located in urban areas excluding Marion county; 0, otherwise
SOUTHNRC	1, for new road construction projects in South Indiana, 0 otherwise
ST	1, for state highway improvements; 0, otherwise
STNRC	1, for new road construction projects on state highways; 0, otherwise
URBAN	1, if project located in urban areas; 0, for rural projects
URBCENTR	1, if project located in urban areas in Central Indiana; 0, for rural projects
URBU	1, if project located on urban US highway; 0, otherwise

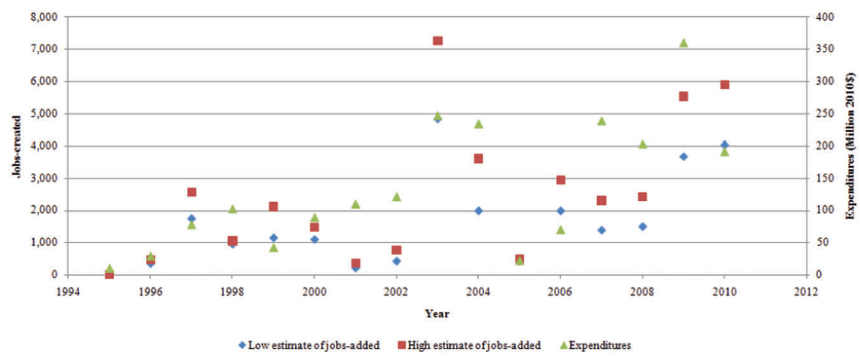


Figure 6.8 Time series of total expenditures in “added new capacity” projects and corresponding long-term statewide jobs-created impacts.

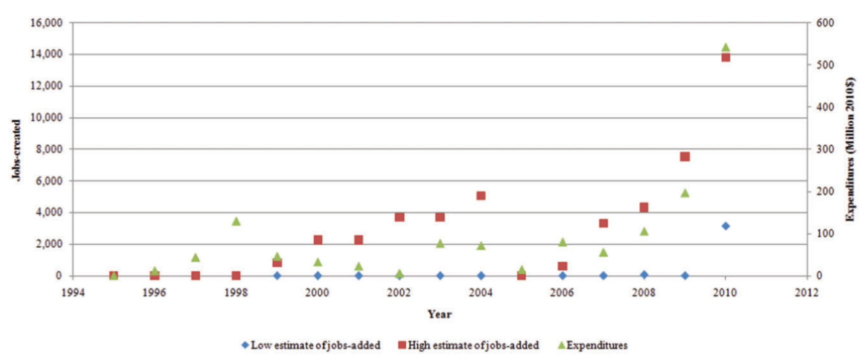


Figure 6.9 Time series of total expenditures in “new construction-related” projects and corresponding long-term statewide jobs-created impacts.

TABLE 6.5
Comparison of Economic Development Impact Estimates

Economic Impact Type	Multipliers	Investment Objects	Estimation Tools	Reference
Short-term Project-specific Statewide	22,805 jobs / $1 billion investment in 2010 dollars	1999-2002 South Carolina Department of Transportation (SCDOT) expenditures on construction and maintenance, other operations and employee payroll.	IMPLAN	University of South Carolina (*48*)
Long-term Project-specific Statewide	1,325 jobs / $1 billion investment in 2010 dollars	All the projects from 2003-2028 Indiana Long-Range Transportation Plan (roadway, bridge, safety, mobility assets included)	REMI within Major Corridor Investment-Benefit Analysis System (MCIBAS)	BLA & Cambridge Systematics, Inc., 2004 (*58*)
Short-term Aggregate Nationwide	33,775 jobs / $1 billion investment in 2010 dollars	Federal-Aid Programs and Projects (roadway, bridge, safety, mobility assets included)	N/A	U.S. DOT, FHWA, 2007 (*59*)
Short-term Project-specific Statewide	18,265–21,005 jobs / $1 billion investment in 2010 dollars	117 representative sample highway improvement projects from the 2003-2028 Indiana Long-Range Transportation Plan (roadway, bridge, safety, mobility assets included)	RIMS II/ IMPLAN	Gkritza, K., Labi, S. and Sinha, K (*56*)
Long-term Project-specific Statewide	1,228–3,677 jobs / $1 billion investment in 2010 dollars	Capacity expansion/ New road construction projects from the 2003–2028 Indiana Long-Range Transportation Plan	REMI within self-developed economic impacts analysis system	
Short-term Aggregate Nationwide	For highway repair and maintenance investments: 24,684 jobs /$ 1 billion in 2010 dollars For new highway construction investment: 21,227 jobs /$ 1 billion investment in 2010 dollars	National job-creation program linked to the need to revitalize the nation's crumbling infrastructure since Nov.,2008. (roadway, bridge, safety, mobility assets included)	IMPLAN	Heintz, J., Pollin, R. and Garrett-Peltier, H., 2009 (*60*)

figures generated represented the low-end of possible long term economic impacts.

- Compared to similar nationwide aggregate analyses, Indiana statewide short-term estimates of economic impacts of highway expenditures are lower. Indiana might be importing quite a few items (e.g. raw materials) from other states, and hence investment dollars leak out of the economy without creating an impact. For example, a high percentage of Indiana's income is from the manufacturing industry, including automobile, medical devices, rubber and so on, which may consume a large amount of electric power. Indiana spent the 9th most on total net imports of coal: $1.14 billion per year in the nation for generating electricity (*61*). In that case, some economic impacts created by the manufacturing industry leak out because of Indiana's dependence on imported coal. In comparison, at a national level, the states are importing much less from other countries, so the same value of investment circulates more within the domestic economy, creating much larger impacts.
- Compared to similar statewide project-specific analyses, aggregate estimates are close, but a little bit lower. Gkritza (*56*) estimated that 18,265 short-term jobs would be created per $1 billion (in 2010 $) investment of Indiana Long-Range Transportation Plan projects, which is comparable to our short-term estimates. Generally, multipliers of statewide economic impacts are smaller than those of aggregate project-specific economic impacts, because the interregional employment shifts within the state are not being counted at the state level. Meanwhile, our study is conducted on 6-digit NAICS code level, which is more conservative, but realistic. To this end, expenditures can be input to the highway and bridge construction sector directly, instead of taking input from other sectors like utility system construction and land subdivision.

The estimation results from this I-O approach are based on the following assumptions:

- NAICS codes were first released in 1997, followed by substantial revisions in 2002 and 2007. Prior to 1997, Standard Industrial Classification (SIC) system codes were used. SIC and NAICS are very different systems, with SIC going up to only 4 digits whereas NAICS had 6-digit industry codes. The number of industries identified by NAICS and the extent to which a larger system is subdivided has been increasing with every release. The structure of the national I-O table followed definitions of SIC and NAICS, hence older I-O tables would have been aggregated and had fewer industries. The current EMSI I-O table uses the 2007 NAICS definitions and a proprietary methodology to develop an annual 6-digit I-O table. Various public sources of data include the benchmark 2002 national I-O table and annual summarized national I-O tables from BEA; annual national I-O tables developed by BLS (which uses the original BEA I-O tables) and proprietary methods to calculate the regional purchase coefficients.

- The I-O approach is static with no specific time dimension; it is assumed that impacts occur in one year. These effects include construction jobs and the secondary impacts of construction that are short-term in nature. As such, they are viewed as not contributing to sustainable economic growth. In the long-run, when the construction stimulus is removed, the magnitude of these effects will depend on the availability of land, labor and capital (*62*).
- The process of data collection for the input-output accounts is necessarily labor and computer-intensive. It always takes five to seven years before the publication of an I-O table. In addition, the economic "snapshot" that is the benchmark version of the tables is typically taken only once every few years. Because the past I-O matrix is not available to us, our analysis is based on the 2010 Indiana I-O table. However, the recent recession effects from December 2007 to June 2009 (*63*) are not completely enumerated by the current I-O tables. On the one hand, disruptions in financial markets further resulted in significant declines in business investment as well as industry supply-demand relationship. Gross Domestic Product (GDP) has fallen sharply along with consumption during the depression. On the other hand, crude oil prices rose from $51 per barrel in January 2007 to a peak of $129 per barrel in July 2008, and then dropped by half in 2009. These fluctuations, as well as its effects on transportation costs in the past years, cannot be captured well by the 2010 I-O relationship. Hence the estimated multipliers could have been higher.

In addition to the construction-related direct, indirect and induced economic benefits originated from INDOT highway expenditures, there are long-term economic impacts that include business expansion effects, business attraction effects, property values effects, and regional competitiveness growth (*56*). Short-term impacts are viewed as not contributing to sustainable economic growth, as opposed to the long-term effects that depend on the availability of land, labor and capital. These impacts are necessary components of overall economic activities (*64*). However, they are inherently much more difficult to estimate quantitatively and call for a more complicated and expensive dynamic economic impact analysis model.

7. CONCLUSIONS

7.1 Implications of Study Findings

The current study has demonstrated that, in general, the condition of INDOT's physical assets, and the performance of INDOT's operational assets, have improved over the study period. The pavement condition has steadily improved between 2002 and 2009, with higher proportions of pavements in excellent and acceptable condition. The overall bridge condition, on the other hand, has not changed much during the analysis period. The proportion of roads with congestion, measured as a volume to service flow ratio (VSF) greater than or equal to 0.70, has steadily decreased since 2002. The number of fatality and non-fatality injury crashes per 100 million VMT has decreased since 2003. The investments made by INDOT over the study period have been effective because the goal of ensuring that INDOT's pavement, bridge condition, and safety performance has been sustained was realized. In the case of pavement condition and safety, the performance has improved.

The quantitative models developed herein demonstrate that there are relationships between the physical condition and operational performance of INDOTs assets and expenditures. Generally, increases in expenditures are correlated with improvements to the overall highway network. Due to the limited dataset available for the present study, additional elements such as travel demand, climate, and vehicle mix which have been previously shown to impact condition and operational performance were not explicitly accounted for. The quantitative results of this evaluation provide a basis for continued post-implementation program evaluations.

The evaluation of short-term construction-related economic impact indicates that INDOT investment in transportation assets (roadway, bridge, safety and mobility) during 1995-2010 would have created 179,900 jobs and increased total earnings by $9.53 billion (in 2010 $) to the state economy. Industrial sectors like health care, manufacturing, services, retail trade, and government sectors etc. benefit the most from the transportation expenditures.

7.2 Implementation Steps for INDOT

7.2.1 INDOT Website

The first implementation step is for INDOT to publish performance measurement information on the INDOT website so that it is easily accessible to the public. As discussed in Chapter 4, the 2011 Capital Program contains charts with the proportion of pavements and bridges in each performance level for only years 2006 and 2011. The performance measures for the intervening years can easily be displayed on graphs similar to those for 2006 and 2011. As discussed in Chapter 2, many other state DOTs post dashboards, scorecards, or report cards so that the public can track performance over time. INDOT may establish a dashboard or report that contains the target, current value, previous value, indication of progress toward achieving the target, and the frequency of measurement for each of the performance measures used during the program development process. At a minimum, the performance measures used as dependent variables in the present study can be included.

7.2.2 Indiana Transparency Portal

The Indiana Transparency Portal is an existing web-based tool for the general public to look up performance information for different state agencies, including INDOT (*65*). From the Indiana Transparency Portal, the public can access the Performance Measurement Dashboard and customize queries for each state agency. The Agency Summary page for INDOT's Dashboard contains graphical displays of the following information:

- Annual amount appropriated for fiscal years 2007 through 2011
- Number of indicators that are unsatisfactory, satisfactory, or superior for each quarter of years 2009 to 2011
- Proportion of construction contracts completed within 105% of award amount for each quarter years 2008 to 2011
- Percent change of construction contract cost for each quarter of years 2008 to 2011
- Number of traffic fatalities on state controlled roads for each quarter of years 2009 to 2011

The public can download the data used to create each graph. The number of indicators that are unsatisfactory, satisfactory, or superior is of interest for the current study, as shown in Figure 7.1. The indicators are listed in Table 7.1. With additional queries through the "Performance by Program" and "Performance by Fund" tabs on INDOT's Dashboard, the public can locate the values of each indicator and the values that correspond to unsatisfactory, satisfactory, or superior measurements. The number of years for which data are available depends on the performance indicator, but ranges between two years and five years in the past. The data used for the current study include data for years prior to those provided through the Dashboard. The Dashboard does not include INDOT's target value for any indicator. Both target values and the period of time in which INDOT seeks to achieve the target can be listed. The information available through the query process is also limited to the indicators listed in Table 7.1. Other measures, such as the proportion of bridges or pavements in other performance levels, the number of non-fatal injury crashes on state controlled roads, and measures of mobility are not included.

In addition to limited information available, it can be extremely difficult to gather the data of interest with the current Dashboard query process. For example, the actual performance values for "% of Roads with Acceptable International Roughness Index (IRI) Quality," can only be found by using the "Performance by Program" or "Performance by Fund" tabs and selecting the appropriate program (fund), in this case the "Maintenance Work Program." There are two methods to determine the program that corresponds to a given indicator. One method is to go through each individual program to see the data that is not located on the Agency Summary tab. The other method is to download the data for the number of indicators that are unsatisfactory, satisfactory, or superior for each quarter because this data contains the name of each indicator and the corresponding program. Both of these options require a large amount of work for the public to gather very limited information.

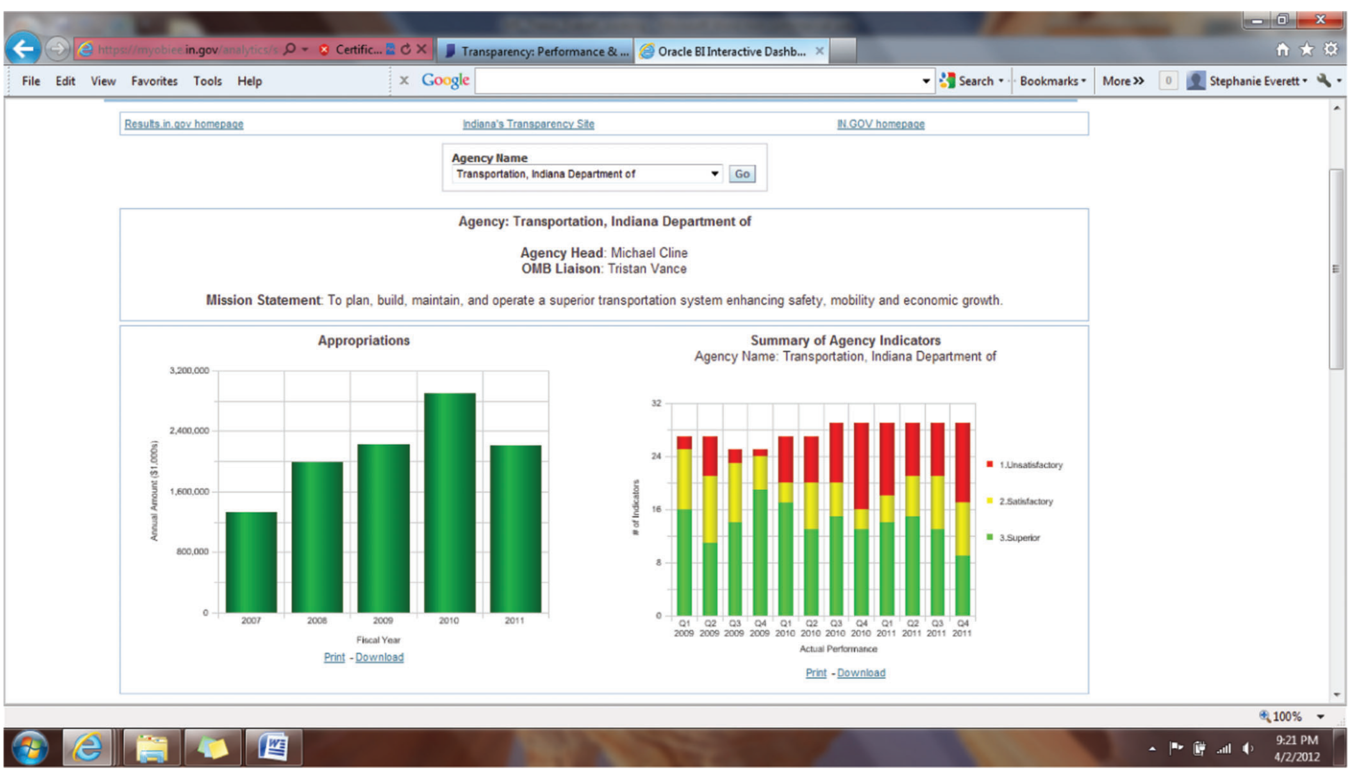


Figure 7.1 View of INDOT Dashboard from Indiana Transparency Portal.

TABLE 7.1
List of Agency Indicators as Reported to Indiana Transparency Portal

Indicator Name
% of available pool vehicles used per month
% of bridges with an acceptable evaluation
% of research projects which result in an implementation
% of roads with acceptable International Roughness Index (IRI) quality
% of state match for federal state construction plan contracts awarded on-schedule
% of state match for federal state construction plan dollars awarded on schedule
% total INDOT budget spent on consulting, row, construction and preservation
Construction contracts completed within 105% of award amount
Duration from selection of professional consultant to notice-to-proceed (in days)
Local planning agencies contract letting—percent let (advertised) on-time vs. annual plan, year-to-date (state fiscal year)
Local planning agencies contract letting—percent of planned estimated cost of contracts let (advertised) on-time vs. annual plan, year-to-date (state fiscal year)
Net change of construction contract cost
Percentage of condemnations
QA of contract packages from production to assure 100% complete
Real estate schedule attainment
Traffic fatalities on state controlled roads

7.2.3 Web-Based Reporting Tool

In terms of providing information to the public about the current state of the system, INDOT is lagging behind other states that currently provide dashboards, scorecards, or report cards that are easily accessible, easily navigable, and contain an appropriate amount of detail. A web-based reporting tool can demonstrate to the public that the condition of INDOT assets is generally improving. The web-based tool may be similar to those of other states such as the Michigan DOT's Infrastructure Dashboard, the Minnesota DOT's Tracker, or Washington State DOT's Gray Notebook. Indiana's web-based tool can expand on those presented by other states to include relevant expenditure data.

7.2.4 Comparison of Predicted and Realized Outcomes

The next step in implementing a recurrent ex-post facto program evaluation is to compare the predicted benefits of the investment program with actual investments and benefits. As discussed in Chapter 4, the 2011 Capital Program Report, available on INDOT's website, contains predictions of the proportions of pavements and the proportions of bridges in each level of performance for year 2016. In 2016, the actual values can be compared to these predicted values. A similar effort could not be carried out for the present study because the predicted performance values were not available for the time period analyzed. Both performance and expenditures should be compared with predicted values. The actual performance measures should be compared to those published in the Capital Report. The actual amounts obligated should be compared with the Statewide Transportation Improvement Program (STIP).

In addition to a before-and-after comparison of both the performance and expenditures, linear regression or other econometric modeling techniques can be used to routinely determine the relationship between actual performance and actual expenditure. Future models can be compared to the ex-post facto models developed in the current study to determine if the relationship is changing.

7.2.5 Anticipated Costs and Benefits of Implementation

As discussed in Chapter 1, INDOT will benefit from recurring ex-post facto evaluations in four primary ways:

1. Identification of successes
2. Quantitatively justifiable decision making
3. Improved communication with legislative bodies
4. Improved communications with non-agency stakeholders

INDOT is responsible for crafting messages that demonstrate achievements and can be used to solicit funding. Performance measurement alone is not enough. INDOT must determine the effectiveness of past expenditures to inform decision making in the future to best use limited resources. This first, of potentially many, ex-post facto evaluations indicates that over the study period, the state of the transportation system has improved. Future post-implementation program evaluations can determine if this remains the case.

The cost of future ex-post facto evaluations is likely to be small in comparison to the anticipated benefits. The data used for the present evaluation are already routinely collected by INDOT. The only anticipated costs are the time for statistical modeling and the cost of software. Although the models contained herein were estimated using a commercially available econometric software, Microsoft Excel is capable of the same analysis. The cost of Microsoft Excel is negligible as it is typically acquired as a part of the Microsoft Office suite necessary for daily activities. The software used to estimate the economic impacts of the highway investment program can be costly; however, INDOT likely has licenses of the necessary software for other department activities.

7.3 Contributions of the Present Study to National Conversations about the Enactment of MAP-21

As FHWA transitions into fully enacting MAP-21, it is imperative that any performance-based funding structure be capable of accounting for state-to-state differences in program goals and objectives. States cannot be ranked absolutely based on the values of various performance measures or even the absolute performance for given levels of expenditure. A performance-based funding structure that allows states to define appropriate targets will increase accountability without favoring any group of states based on urbanization, climate, or the extent of the existing transportation system.

7.4 Recommendations for Future Research

The following sections outline improvements and extensions that can be made in the area of post-implementation evaluation.

7.4.1 Improvements to Current Models

Future work is necessary to refine the models developed in the present study for future application. Due to the limited number of observations, only OLS evaluations could be conducted. As more data become available, more appropriate models can be developed using MLE. The options for achieving the large sample size necessary to use MLE are to either have enough years of data, which is not practical, or to use information from multiple states. The disadvantage of having data from multiple states is that states do not have the same transportation program goals. Program goals are influenced by the extent of urbanization, traffic volumes, topography, and climate. These differences must be accounted for if data from multiple states are included. Random parameters models, which are based on MLE, can be used to account for heterogeneity among the individual states in a panel dataset (*33*).

For the multiple state modeling to be successful, the same data must be collected from all of the states over the same time period (e.g., the data for a single year must cover the same time period for Indiana as for Idaho). Additional variables to characterize the states in terms of urbanization, system size, terrain, and climate, are also necessary. These variables are intended capture the different transportation program goals as well as the varying existing transportation systems in each state. The results of this study indicate that the road classification has an effect on the relationship between expenditures and performance. As such, all of the data collected from other states must be categorized for the Interstate System, NHS, and other state-controlled, non-NHS assets. Some of the data available in FHWA's *Highway Statistics Series* is already available with this classification system. Although the HPMS submittals include the NHS designation as a field, some of the information provided in FHWA's *Highway Statistics* is only published in tables using a separate functional classification that is not analogous to the NHS designation. The road classification was chosen for this study to reflect the different funds appropriated for each road classification. Future research should use the data as submitted by state DOTs with this designation so that relationships between investment and outcomes can be defined for each class.

After all of this information is collected, we can estimate a random parameters model that allows the effect of any variable to be random or fixed. Fixed effects are the same for all states while random parameters can vary for each observation. Simulation can be used to determine the marginal effects of each estimated random parameter for each individual state (*66*). The state-specific marginal effects can then be used to determine the state-specific relationship between performance and expenditure while accounting for differences in the state's goals and objectives.

There are several benefits to using a large dataset that contains information from all states over several years. First, there may be more appropriate functional forms which can only be estimated using MLE. For example, logistic regression can be used to confine the proportions between 0 and 1 for the pavement, bridge, and mobility performance measures. This is not accomplished with the current OLS estimations. Random parameters can be estimated for a number of model specifications, not only linear regression. Therefore, other functional forms can be used while retaining the benefits of parameters that vary by state. Finally, MLE can be used to account for any serial correlation effects.

In addition to different functional forms, a larger dataset can include additional variables that may be significant predictors of performance. Although traffic demand is indirectly accounted for in the current estimations for congestion and safety, it is not accounted for at all for the condition of physical assets. Potential independent variables to include in future model estimations include AADT, the percentage of trucks, or equivalent single axle loads (ESALs). In addition to measure of demand, variables that account for urbanization, climate, or topography can also be added.

7.4.2 Ex-Post Facto Evaluation of Higher-Level Returns

The ex-post facto analysis contained in this study considered the physical and operational improvements to Indiana's statewide highway system as well as economic impacts. The highest level returns on investment are externalities such as air quality impacts and energy use impacts. Future research can explore the relationship between expenditure and performance for these externalities. These impacts will be even more difficult to accurately quantify because there are many other factors that affect air quality and climate change. Additionally, the impacts are not geographically confined to Indiana; therefore, regional studies may be more appropriate than individual state analyses.

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APPENDIX A. WORK TYPE ENTRIES ADDED FOR PROJECT DESIGNATIONS

TABLE A.1
Work Type Entries Added for Project Designations

Designation	Work Type Added
760242E	Added Travel Lanes
9230445	Bridge Rehabilitation or Repair
9300620	Bridge Rehabilitation or Repair
9303200	Bridge Rehabilitation or Repair
0002060	Bridge Rehabilitation or Repair
9767227	Roadside Maintenance, Mowing
9767301	Bridge Painting
9767303	Bridge Painting
9767304	Bridge Painting
976752X	Bridge Painting
976752Y	Bridge Painting
9612410	Erosion Control
9620227	Interchange Modification
9102333	Landscaping
9667113	Bridge Rehabilitation or Repair
9667213	Asphalt Patching
9767101	Asphalt Patching
9767110	Bridge Painting
9767112	Pavement Repair or Rehabilitation
9767230	Roadside Maintenance, Mowing
9767406	Pavement Repair or Rehabilitation
9767530	Bridge Rehabilitation or Repair
9767605	Bridge Painting
9767606	Bridge Painting
9867209	Pavement Repair or Rehabilitation
9867213	Pavement Repair or Rehabilitation
9867605	Pavement Repair or Rehabilitation
966760V	Bridge Painting
976760A	Bridge Rehabilitation or Repair

APPENDIX B. ASSET GROUP BY WORK TYPE

TABLE B.1
Asset Group by Work Type

Work Type	Asset	Work Type	Asset
Access Control	Mobility	Its Program Contracted Services	Mobility
Added Travel Lanes	Mobility	Its Program Equipment	Mobility
Added Travel Lanes, Composite	Mobility	Its Traffic Management Systems	Mobility
Added Travel Lanes, Construct Turn Lanes	Mobility	Its Traffic Monitoring Systems	Mobility
Added Travel Lanes, HMA	Mobility	Its Traveler Information Systems	Mobility
Added Travel Lanes, PCC	Mobility	Landscaping	Other
Arch Reconstruction or Repair	Bridge	Lighting	Safety
Asphalt Patching	Pavement	Lighting Installation / Maintenance	Safety
Auxiliary Lanes, Accel & Decel or Turn Lanes	Mobility	Lighting Maintenance	Safety
Auxiliary Lanes, Passing	Mobility	Line, Paint	Other
Auxiliary Lane Construction	Mobility	Median Construction	Pavement
Auxiliary Lanes	Mobility	Modernize Continuous Lighting	Safety
Barrier Wall	Safety	Modernized Communications Towers	Other
Beautification / Wildflowers	Other	New Barrier Wall	Safety
Bike/Pedestrian Facilities	Other	New Br, Comp. Cont. Conc. Constr.	Bridge
Box Culvert Replacement	Bridge	New Br, Comp. Cont.Stl.Grdr (Wld.Plate)	Bridge
Br Repl, Cast In Place Box Culvert	Bridge	New Br, Comp.Cont.Precast Conc.Beam	Bridge
Br Repl, Comp. Cont. Conc. Construction	Bridge	New Br, Comp.Cont.Pres.Conc Box Beam	Bridge
Br Repl, Comp.Cont.Precast Conc. Beam	Bridge	New Br, Comp.Cont.Pres.Conc.Bulb T-Beam	Bridge
Br Repl, Comp. Cont. Pres. Conc. I-Beam	Bridge	New Br, Comp.Cont.Pres.Conc.I-Beam	Bridge
Br Repl, Comp. Cont. Pres. Conc. Box Beam	Bridge	New Br, Comp.Cont.Steel Beam	Bridge
Br Repl, Comp. Cont. Pres. Conc. Bulb T-Beam	Bridge	New Br, Comp.Steel Beam-Simple Span	Bridge
Br Repl, Comp. Cont. Steel Beam	Bridge	New Br, Conc Beam Construction	Bridge
Br Repl, Comp. Cont. Stl. Grdr (Wld Plate)	Bridge	New Br, Cont. Rc Slab	Bridge
Br Repl, Comp. Steel Beam (Simple Span)	Bridge	New Br, Cont.Pres.Conc.Box Beam	Bridge
Br Repl, Comp. Stl. Gdr. (Wld Plt, Smpl. Spn)	Bridge	New Br, P.T.Comp.Cont.Pres.Conc.Bulb T	Bridge
Br Repl, Conc. Beam Construction	Bridge	New Br, Pipe Arch or Culvert	Bridge
Br Repl, Cont. Pres. Conc. Box Beam	Bridge	New Br, Precast 3 Sided Culvert	Bridge
Br Repl, Cont. Rc Slab	Bridge	New Br, Precast Box Culvert	Bridge
Br Repl, P.T. Comp. Cont. Pres. Conc. I-Beam	Bridge	New Br, Pres.Conc. I-Beam (Simple Span)	Bridge
Br Repl, P.T. Comp. Cont. Pres. Conc. T-Bulb	Bridge	New Br, Rc Box - Under Fill	Bridge
Br Repl, Pipe Arch	Bridge	New Br, Rc Slab (Simple Span)	Bridge
Br Repl, Post Tension Conc. Construction	Bridge	New Br, Special	Bridge
Br Repl, Precast 3 Sided Culvert	Bridge	New Br, Steel Girder	Bridge
Br Repl, Precast Box Culvert	Bridge	New Br, Steel Thru Truss	Bridge
Br Repl, Pres. Conc. Box Beam (Smpl. Span)	Bridge	New Br, Welded Steel Thru Girder	Bridge
Br Repl, Pres. Conc. I-Beam(Simple Span)	Bridge	New Bridge Construction	Bridge
Br Repl, Rc Box - Under Fill	Bridge	New Bridge Special Construction	Bridge
Br Repl, Rc Slab - Under Fill	Bridge	New Bridge, Concrete Construction	Bridge
Br Repl, Rc Slab (Simple Span)	Bridge	New Bridge, Other	Bridge
Br Repl, Reinforced Conc. Construction	Bridge	New Bridge, Other Construction	Bridge
Br Repl, Steel Girder	Bridge	New Bridge, Steel Construction	Bridge
Br Repl, Welded Steel Thru Girder	Bridge	New Flasher Installation	Safety
Bridge Channel Correction	Bridge	New Interchange Construction	Mobility
Bridge Deck Barrier Wall	Bridge	New Road Construction	Mobility
Bridge Deck Overlay	Bridge	New Road Construction, HMA	Mobility
Bridge Deck Patching	Bridge	New Road Construction, PCC	Mobility
Bridge Deck Reconstruction	Bridge	New Road, Grading Only	Mobility
Bridge Deck Reconstruction & Widening	Bridge	New Road, HMA Paving Only	Mobility
Bridge Deck Replacement	Bridge	New Road, Paving Only	Mobility
Bridge Deck Replacement & Widening	Bridge	New Sign Installation	Safety
Bridge Inspections	Bridge	New Signal Installation	Safety
Bridge Maintenance and Repair	Bridge	Noise Abatement	Mobility
Bridge Painting	Bridge	Other Intersection Improvement	Safety
Bridge Rehabilitation or Repair	Bridge	Other Project Type	Other
Bridge Removal	Bridge	Other Roadside Maintenance	Other
Bridge Replacement	Bridge	Other Sewer/Curb/Gutter Construction	Other
Bridge Replacement, Concrete	Bridge	Other Type Project (Miscellaneous)	Other

TABLE B.1
(Continued)

Work Type	Asset	Work Type	Asset
Bridge Replacement, Other Construction	Bridge	Overhead Sign Install	Safety
Bridge Replacement, Pipe Arch or Culvert	Bridge	Overhead Sign Repair	Safety
Bridge Replacement, Special	Bridge	Parking Area Reconstruction	Other
Bridge Widening	Bridge	Partial 3-R	Pavement
Br Repl, Cast In Place Box Culvert	Bridge	Patch and Rehab Bituminous Pavement	Pavement
Br Repl, Comp. Cont. Conc. Construction	Bridge	Patch and Rehab Pavement	Pavement
Br Repl, Comp.Cont.Precast Conc. Beam	Bridge	Patch and Rehab PCC Pavement	Pavement
Br Repl, Comp. Cont. Pres. Conc. I-Beam	Bridge	Pavement Markings	Safety
Br Repl, Comp. Cont. Pres. Conc. Box Beam	Bridge	Pavement Repair or Rehabilitation	Pavement
Br Repl, Comp. Cont. Pres. Conc. Bulb T-Beam	Bridge	Pavement Replacement	Pavement
Br Repl, Comp. Cont. Steel Beam	Bridge	Pavement Replacement, Concrete	Pavement
Br Repl, Comp. Cont. Stl. Grdr (Wld Plate)	Bridge	Pavement Replacement, HMA	Pavement
Br Repl, Comp. Steel Beam (Simple Span)	Bridge	Pavement Replacement, New PCC	Pavement
Br Repl, Comp. Stl. Gdr.(Wld Plt, Smpl.S pn)	Bridge	Pavement Replacement, Small Town	Pavement
Br Repl, Conc. Beam Construction	Bridge	Pavement Replacement, Small Town, HMA	Pavement
Br Repl, Cont. Pres. Conc. Box Beam	Bridge	Pavement, Other	Pavement
Br Repl, Cont. Rc Slab	Bridge	PCCP Cleaning and Sealing Joints	Pavement
Br Repl, P.T. Comp. Cont. Pres. Conc. I-Beam	Bridge	PCCP on PCC Pavement	Pavement
Br Repl, P.T. Comp. Cont. Pres. Conc. T-Bulb	Bridge	PCCP Patching	Pavement
Br Repl, Pipe Arch	Bridge	Pipe Lining	Bridge
Br Repl, Post Tension Conc. Construction	Bridge	Profiling, PCCP	Pavement
Br Repl, Precast 3 Sided Culvert	Bridge	Protective Buying	Mobility
Br Repl, Precast Box Culvert	Bridge	Pumping / Lift Stations	Other
Br Repl, Pres. Conc. Box Beam (Smpl. Span)	Bridge	Radii Improvement	Mobility
Br Repl, Pres. Conc. I-Beam (Simple Span)	Bridge	Railing Replace or Repair	Safety
Br Repl, Rc Box - Under Fill	Bridge	Railroad Crossing	Safety
Br Repl, Rc Slab (Simple Span)	Bridge	Railroad Crossing Removal	Safety
Br Repl, Rc Slab - Under Fill	Bridge	Railroad Protection	Safety
Br Repl, Reinforced Conc. Construction	Bridge	Railroad Protection & Surface	Safety
Br Repl, Steel Girder	Bridge	Railroad Work	Safety
Br Repl, Welded Steel Thru Girder	Bridge	Raised Pavement Markings, New	Safety
Bridge Channel Correction	Bridge	Raised Pavement Markings, Refurbished	Safety
Bridge Deck Barrier Wall	Bridge	Reconstruct Weigh Station	Other
Bridge Deck Overlay	Bridge	Relinquishments/Road Transfer	Other
Bridge Deck Patching	Bridge	Remove & Replace Beam	Bridge
Bridge Deck Reconstruction	Bridge	Remove Bridge Abutments	Bridge
Bridge Deck Reconstruction & Widening	Bridge	Repair Guard Rail	Safety
Bridge Deck Replacement	Bridge	Repair or Replace Barrier Wall	Safety
Bridge Deck Replacement & Widening	Bridge	Repair or Replace Joints	Bridge
Bridge Inspections	Bridge	Repair or Replace Lighting	Safety
Bridge Maintenance and Repair	Bridge	Repair PCCP & HMA Overlay	Pavement
Bridge Painting	Bridge	Repairs To Approach Slab	Bridge
Bridge Rehabilitation or Repair	Bridge	Replace Guard Rail	Safety
Bridge Removal	Bridge	Replace Superstructure	Bridge
Bridge Replacement	Bridge	Rest Area & Parking Area Constr/Reconstr	Other
Bridge Replacement, Concrete	Bridge	Rest Area Modernization	Other
Bridge Replacement, Other Construction	Bridge	Resurface over Asphalt Pavement	Pavement
Bridge Replacement, Pipe Arch or Culvert	Bridge	Resurface PCC Pavement (Partial 3/R Standards)	Pavement
Bridge Replacement, Special	Bridge	Retrofit Joint Load Transfer	Pavement
Bridge Widening	Bridge	Road Construction	Pavement
Buildings	Other	Road Reconstruction (3R/4R Standards)	Pavement
Channel Clearing and Protection	Other	Road Rehabilitation (3R/4R Standards)	Pavement
Closed Loop Interconnect System	Mobility	Roadside Facilities	Other
Concrete Pavement Restoration (CPR)	Pavement	Roadside Maintenance	Other
Construct ADA Approved Sidewalk Ramps	Pavement	Roadside Maintenance, Herbicide Treatmnt	Other
Construct Weigh Station	Other	Roadside Maintenance, Mech.Sweeping	Other
Covered Bridge Rehabilitation	Bridge	Roadside Maintenance, Mowing	Other
Crack & Seat Composite Pavement & HMA Overlay	Pavement	Roadside Maintenance, Tree Remov/Trimmng	Other
Crack & Seat PCCP & HMA Overlay	Pavement	Roadside Work	Other
Crack Sealing	Pavement	Roadside Work, Other	Other
Culvert Clean and Repair	Bridge	Rubblize Composit & HMA Overlay	Pavement
Curve Correction	Safety	Rubblize PCCP & HMA Overlay	Pavement

TABLE B.1
(Continued)

Work Type	Asset	Work Type	Asset
Debris Removal From Channel	Other	Safety Revisions	Safety
Demolition	Other	Scour Protection (Erosion)	Bridge
Demolition, Remove Buildings, Foundations	Other	Sewer / Curb / Gutter Const/Reconstr	Other
District Wide Bridge Maintenance	Bridge	Sewer / Curb / Gutter Construction	Other
Ditch Relocation	Other	Shoulder Rehabilitation and Repair	Pavement
Drainage Ditch Correction	Other	Sight Distance Improvement	Safety
Enhancement	Other	Sign Modernization (Series Of Units)	Safety
Environmental Mitigation	Other	Signing	Safety
Erosion Control	Other	Signing Installation / Repair	Safety
Fence Replacement or Repair	Other	Signs, Lighting, Signals and Markings	Safety
Flashers, Modernize	Safety	Slide Correction	Pavement
Guard Rail Attenuators, New or Modernize	Safety	Small Structure Replacement	Bridge
Guard Rail Work	Safety	Small Structure, Replacement	Bridge
Guardrail, Maintenance	Safety	Small Structures & Drains Construction	Bridge
Guardrail, Maintenance or Repair	Safety	Storm Sewer Repair or Replacement	Other
Historical Site Preservation	Other	Straighten Beam	Bridge
HMA Functional Overlay on PCCP	Pavement	Substructure Repair and Rehabilitation	Bridge
HMA Overlay, Functional	Pavement	Surface Treatment, Chip Seal	Pavement
HMA Overlay, Preventive Maintenance	Pavement	Surface Treatment, Microsurface	Pavement
HMA Overlay, Structural	Pavement	Surface Treatment, PM	Pavement
Horizontal Sight Correction	Safety	Surface Treatment, Thin HMA Overlay	Pavement
Install Lighting	Safety	Surface Treatment, Ultrathin Bonded Wearing Course	Pavement
Install Loop Detector	Mobility	Tower Lighting	Safety
Install New Continuous Lighting	Safety	Traffic Hardware Modernization	Safety
Install New Guard Rail	Safety	Traffic Signal Maintenance	Safety
Install New Small Structure	Bridge	Traffic Signal Repair	Safety
Institution & Park Road Maintenance	Other	Traffic Signals	Safety
Intelligent Transportation Systems (Its)	Mobility	Traffic Signals Modernization	Safety
Interchange Modification	Mobility	Traffic Signals, New or Modernized	Safety
Interchange Work	Mobility	Traffic, Other	Safety
Intersect. Improv. W/ Added Turn Lanes	Safety	Truss Reconstruction or Repair	Bridge
Intersect. Improv. W/ New Signals	Safety	Utility Relocation	Other
Intersection Improvement	Safety	Vertical Sight Correction	Safety
Its Communications Systems	Mobility	Wedge and Level	Pavement
Its Devices Maintenance Contracts	Mobility	Weigh Stations Constr./Reconstr.	Other
Its Operations and Maintenance Contracts	Mobility		

APPENDIX C. FATALITY AND NON-FATALITY CRASH COUNTS IN INDIANA

TABLE C.1
Fatality Crash Counts in Indiana by Route Type and Year

Route Type	Rural/Urban	2003	2004	2005	2006	2007	2008	2009	2010
Interstate	Rural	66	61	79	70	86	62	54	43
	Urban	19	36	34	26	23	21	23	18
US Route	Rural	114	129	119	92	116	101	82	93
	Urban	30	36	28	39	25	34	26	33
State Road	Rural	179	188	197	216	201	156	140	155
	Urban	33	36	47	49	38	37	28	43
State System Total		**441**	**486**	**504**	**492**	**489**	**411**	**353**	**385**

TABLE C.2
Non-Fatality Injury Crash Counts in Indiana by Route Type and Year

Route Type	Rural/Urban	2003	2004	2005	2006	2007	2008	2009	2010
Interstate	Rural	1492	1437	1600	1544	1543	1565	1407	1514
	Urban	1508	1546	1484	1428	1410	1321	1328	1541
US Route	Rural	3097	3064	3119	2921	2766	2645	2597	2608
	Urban	4109	4036	3962	3826	3559	3300	3227	3163
State Road	Rural	6015	5941	5828	5960	5586	5052	4859	5104
	Urban	4320	4233	4263	4201	4112	4023	3735	3901
State System Total		**20541**	**20257**	**20256**	**19880**	**18976**	**17906**	**17153**	**17831**

APPENDIX D. PAVEMENT PERFORMANCE TIME SERIES PLOTS BY ROUTE TYPE

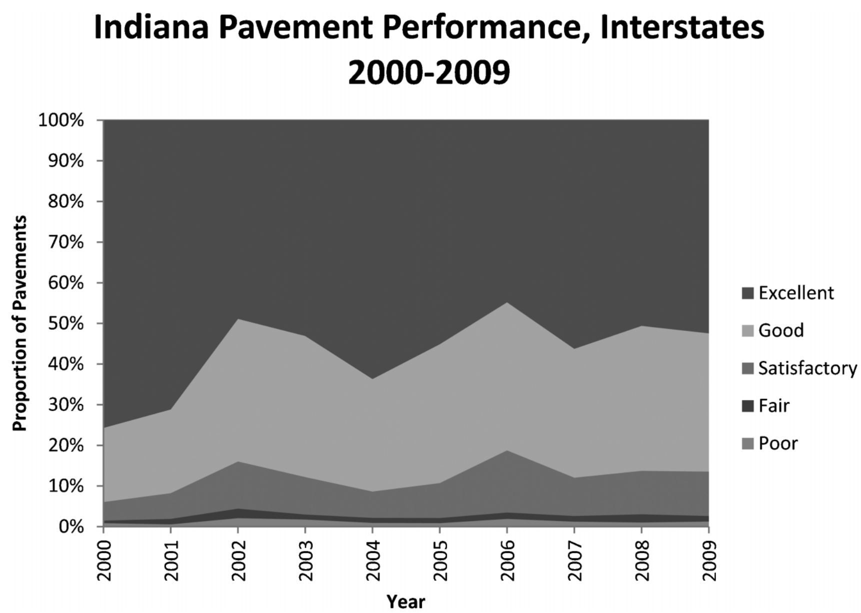

Figure D.1 Time series of Interstate pavement performance.

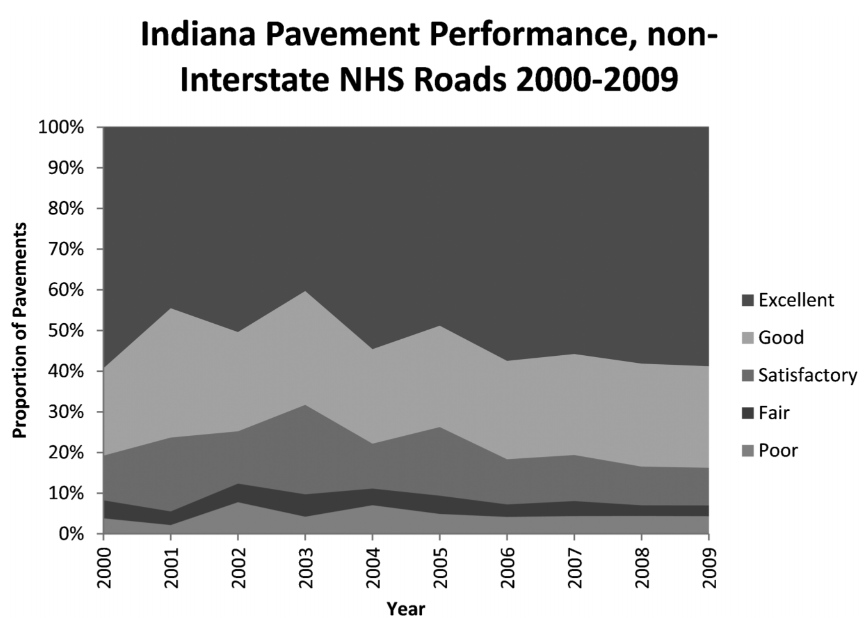

Figure D.2 Time series of non-Interstate NHS pavement performance.

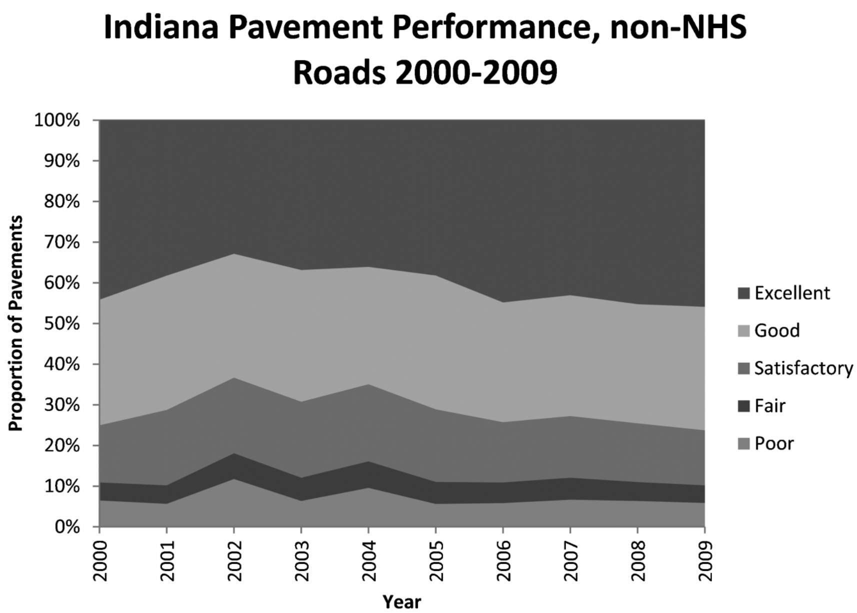

Figure D.3 Time series of non-NHS pavement performance.

APPENDIX E. BRIDGE PERFORMANCE TIME SERIES PLOTS BY ROUTE TYPE

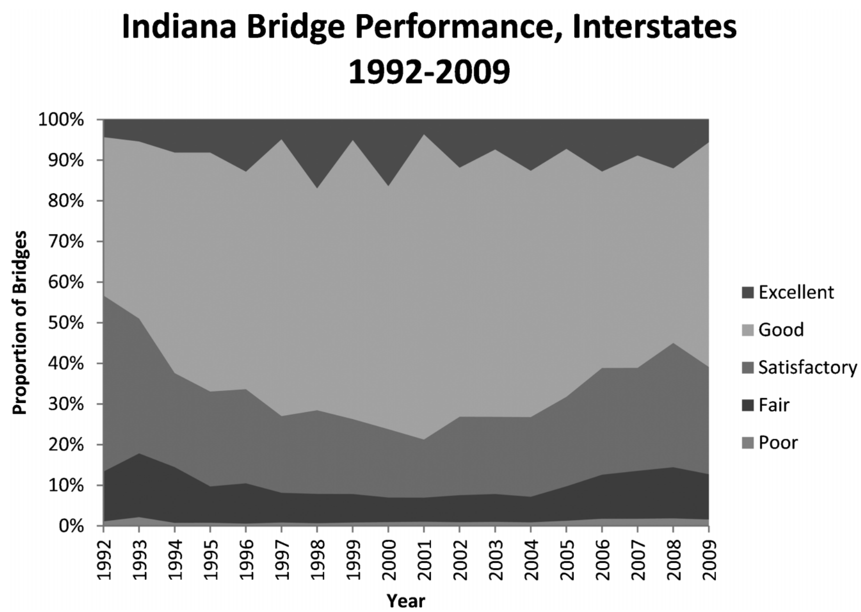

Figure E.1 Time series of Interstate bridge performance.

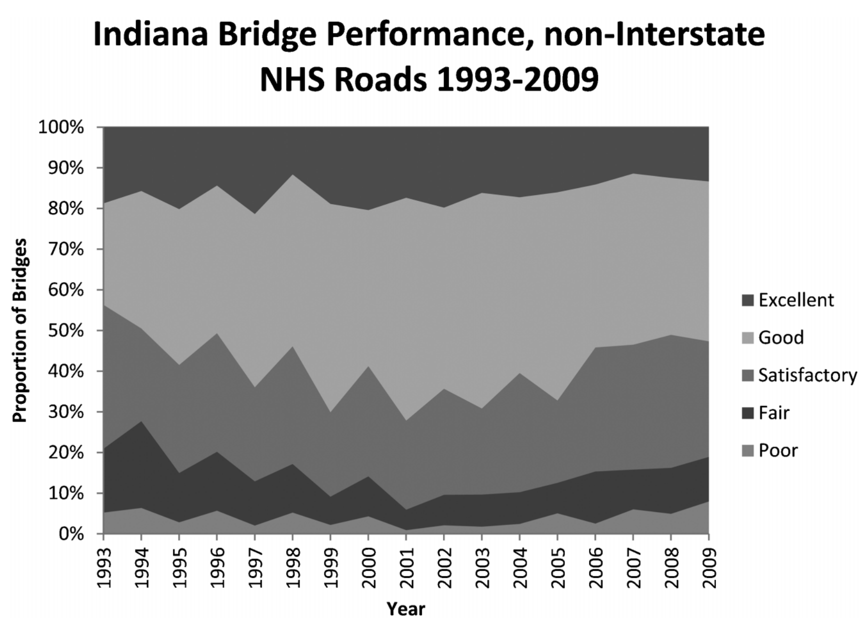

Figure E.2 Time series of non-Interstate NHS bridge performance.

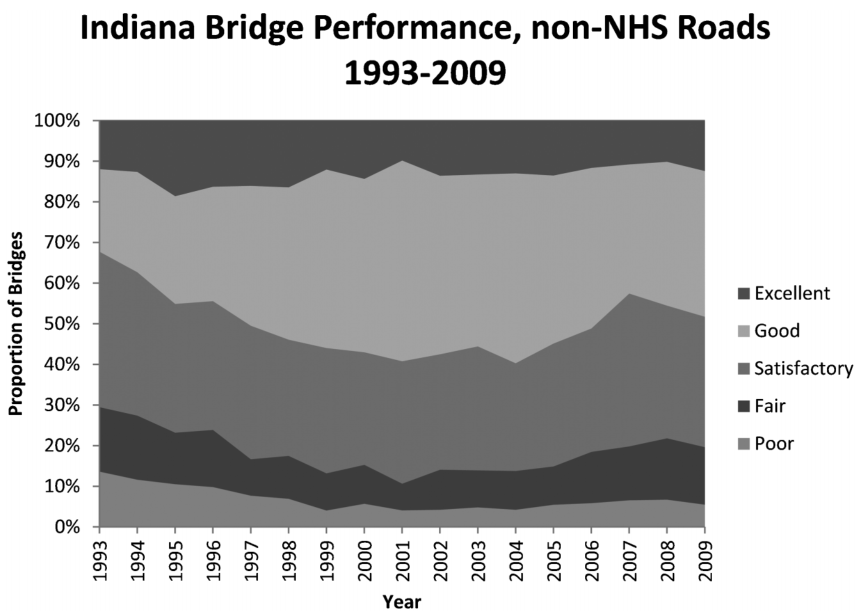

Figure E.3 Time series of non-NHS bridge performance.

APPENDIX F. DIAGNOSTIC PERFORMANCE VS. EXPENDITURE PLOTS

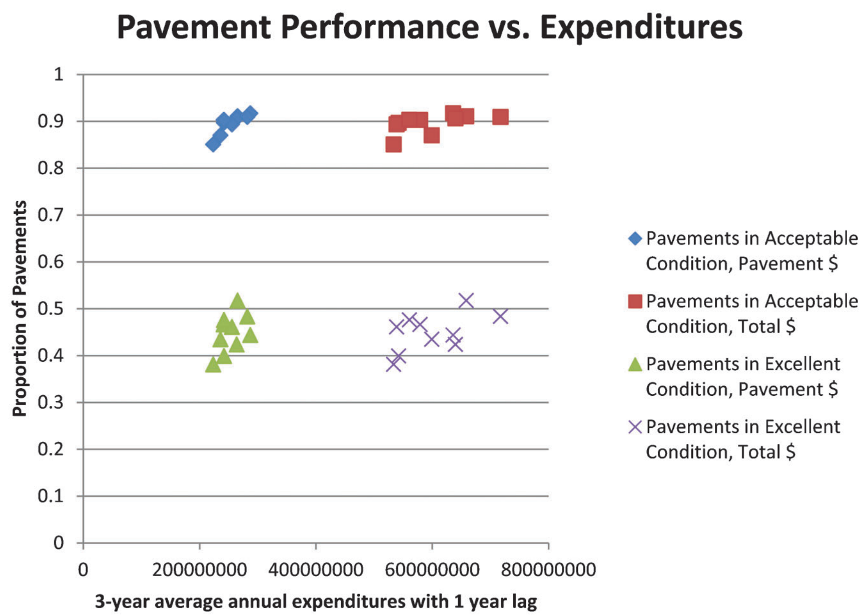

Figure F.1 Statewide pavement performance versus expenditures.

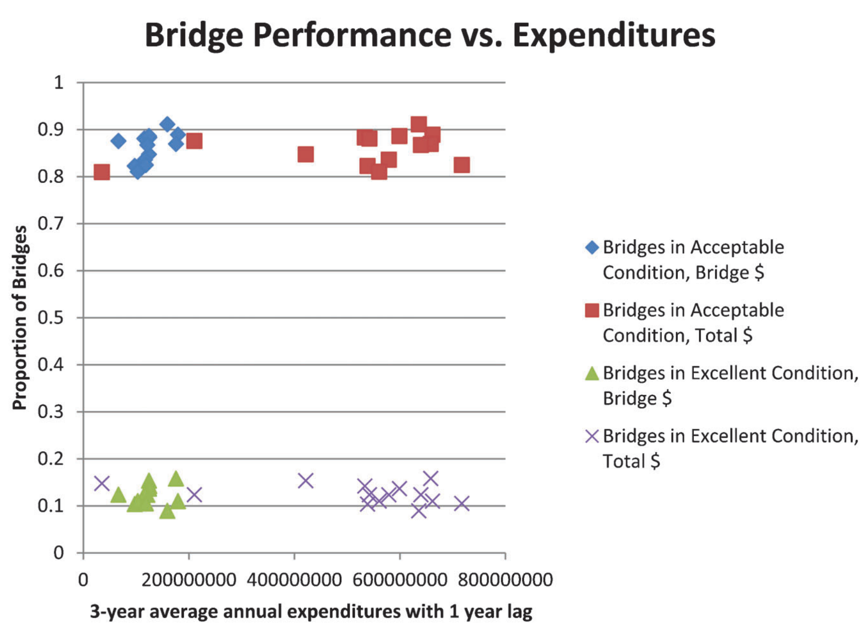

Figure F.2 Statewide bridge performance versus expenditures.

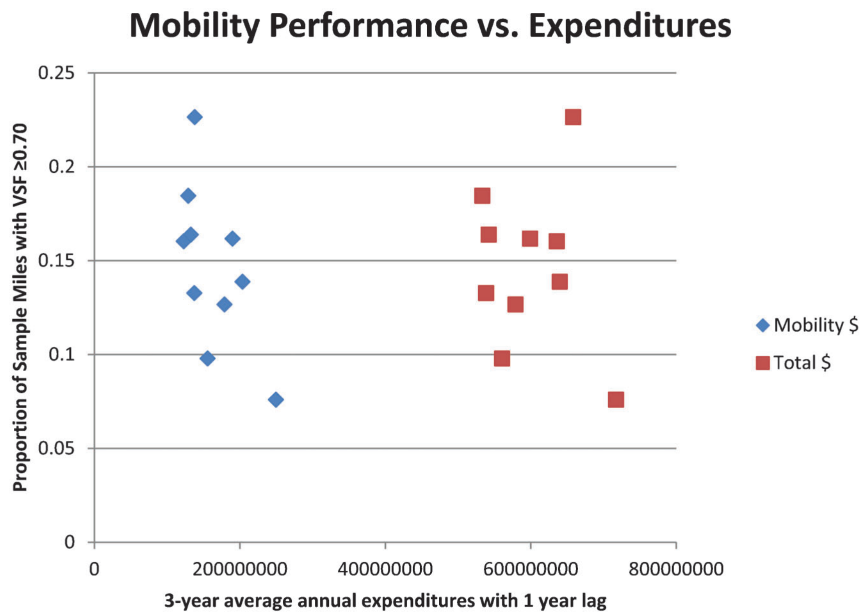

Figure F.3 Statewide mobility performance versus expenditures.

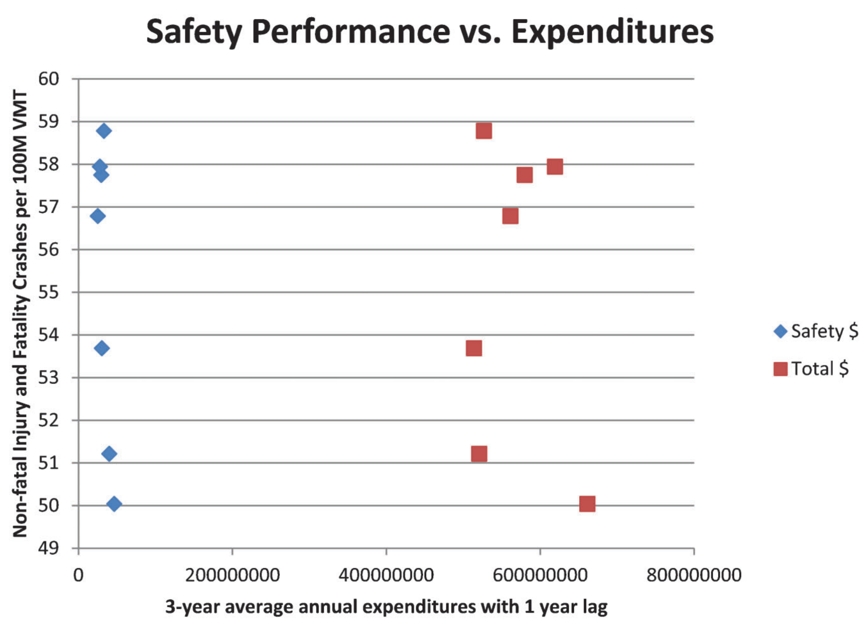

Figure F.4 Statewide safety performance versus expenditures.

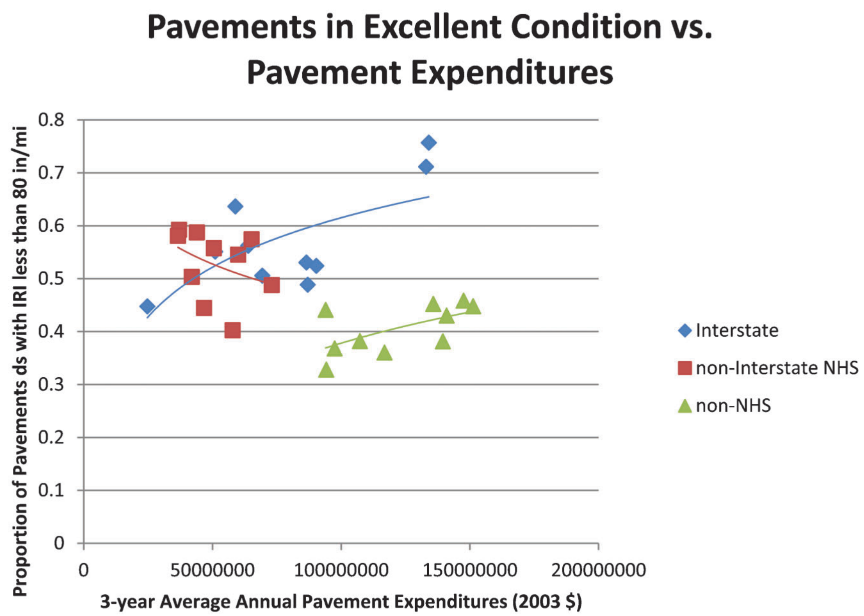

Figure G.1 Proportion of pavements in excellent condition versus pavement expenditures for all road classifications.

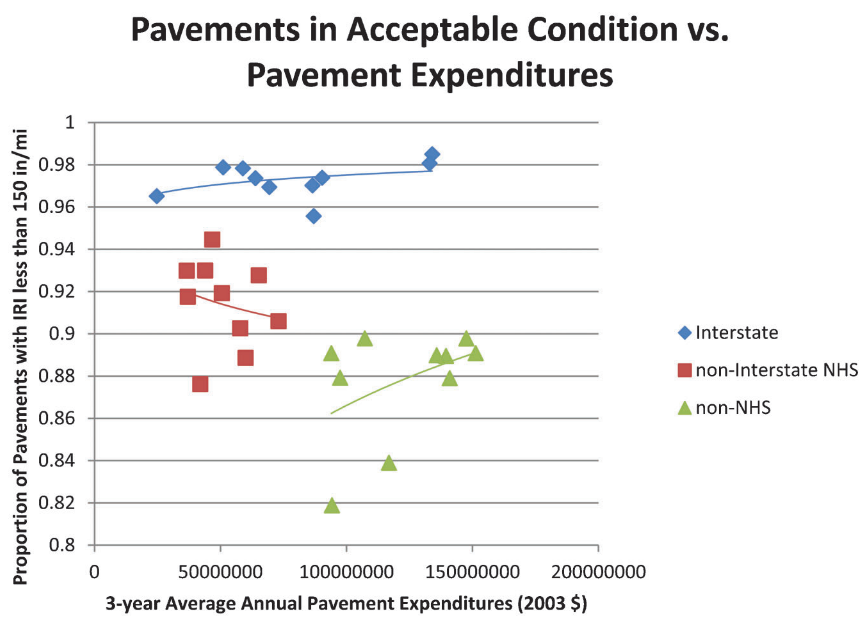

Figure G.2 Proportion of pavements in acceptable condition versus pavement expenditures for all road classifications.

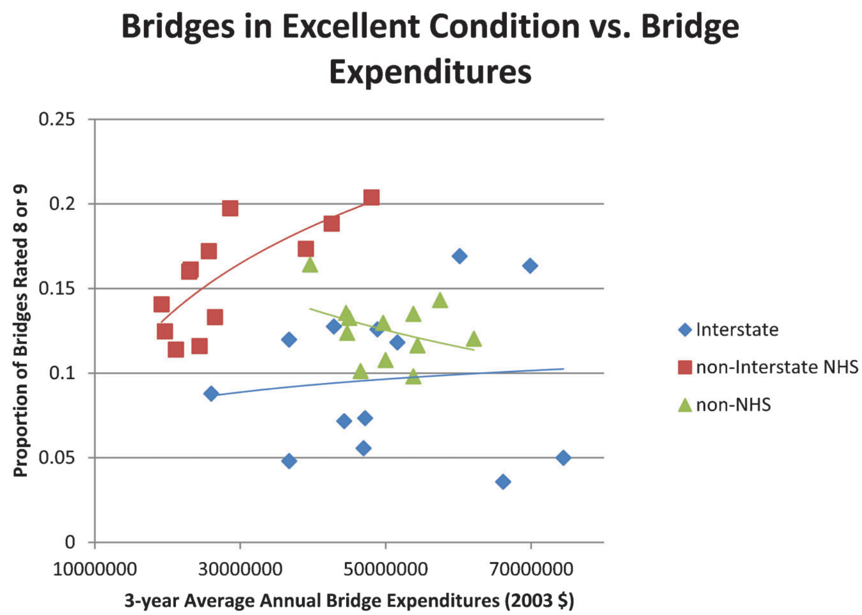

Figure G.3 Proportion of bridges in excellent condition versus bridge expenditures for all road classifications.

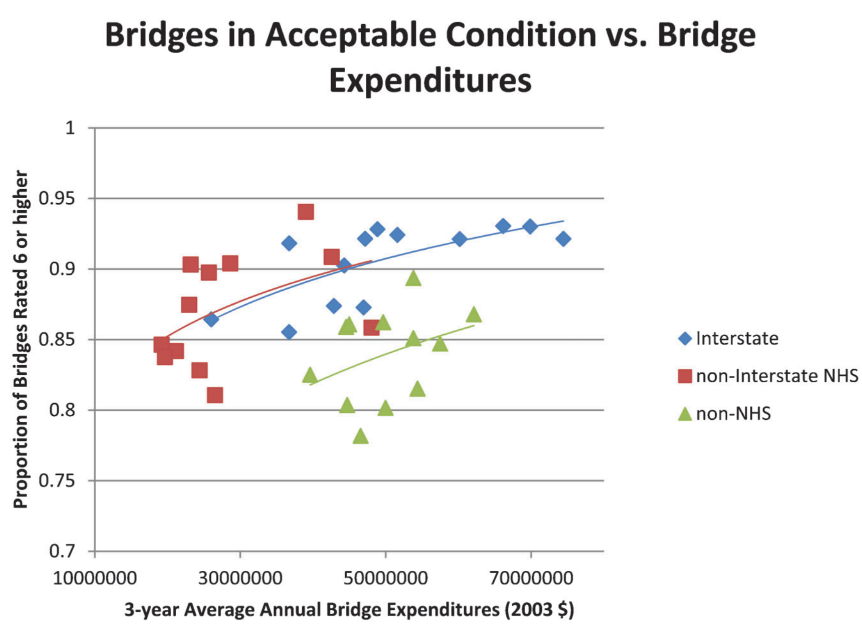

Figure G.4 Proportion of bridges in acceptable condition versus bridge expenditures for all road classifications.

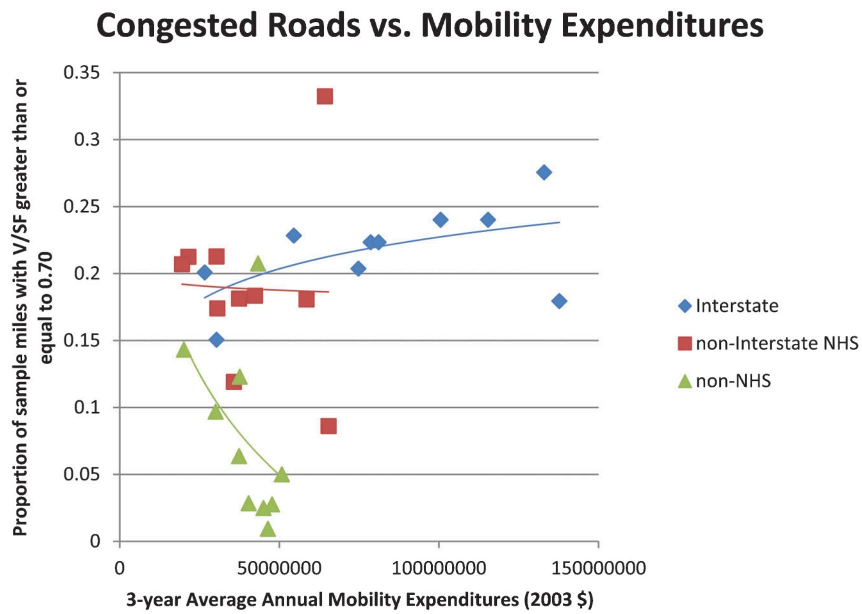

Figure G.5 Proportion of roads with VSF ≥ 0.70 versus mobility expenditures for all road classifications.

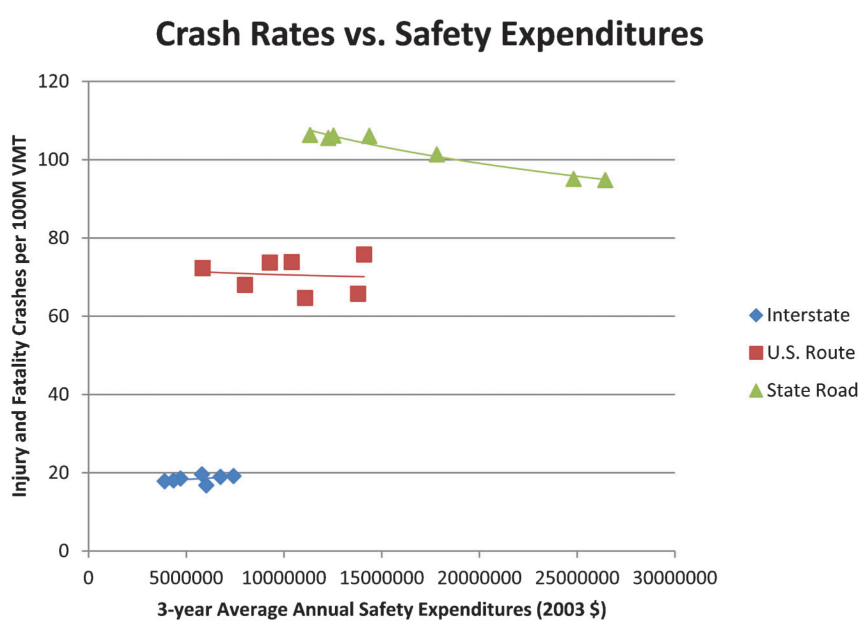

Figure G.6 Fatality and non-fatality injury crashes per 100 million VMT versus safety expenditures for all route types.

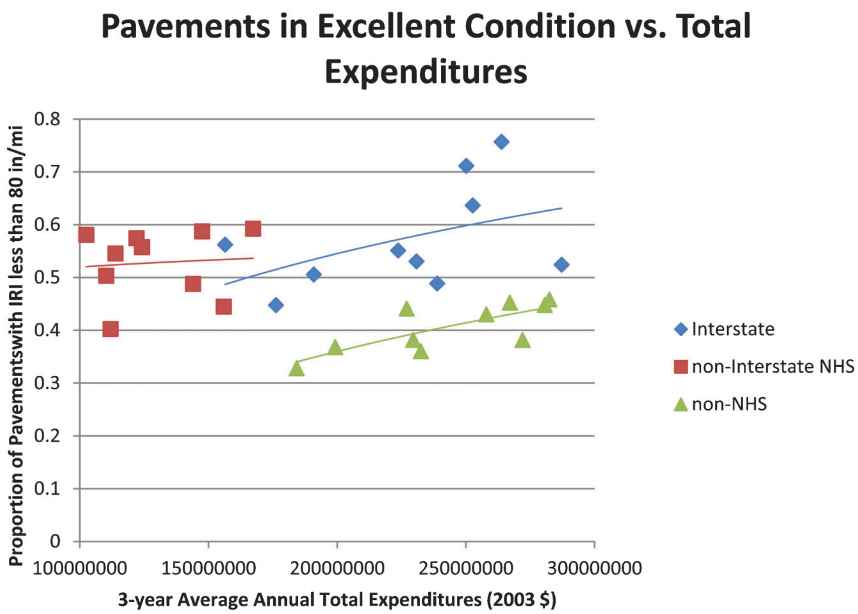

Figure G.7 Proportion of pavements in excellent condition versus total expenditures for all road classifications.

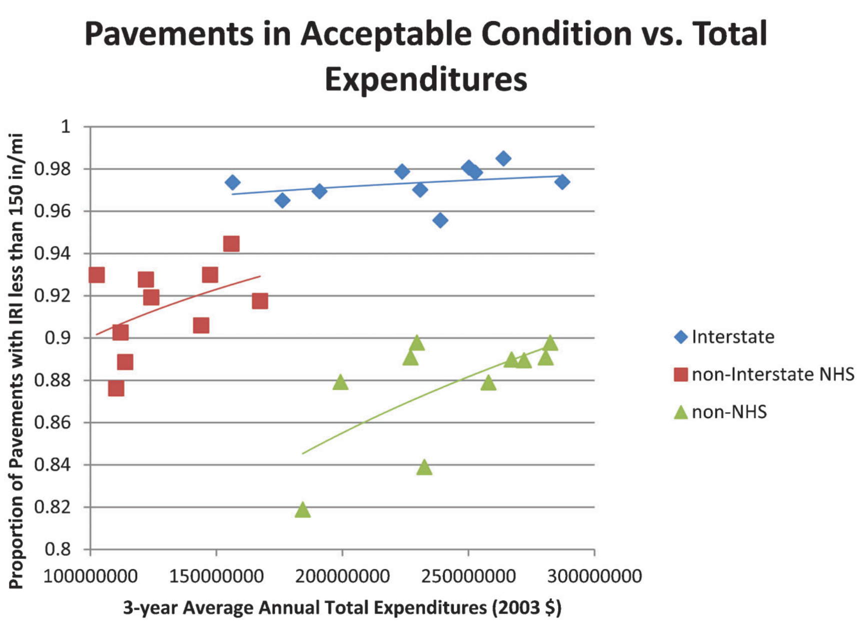

Figure G.8 Proportion of pavements in acceptable condition versus total expenditures for all road classifications.

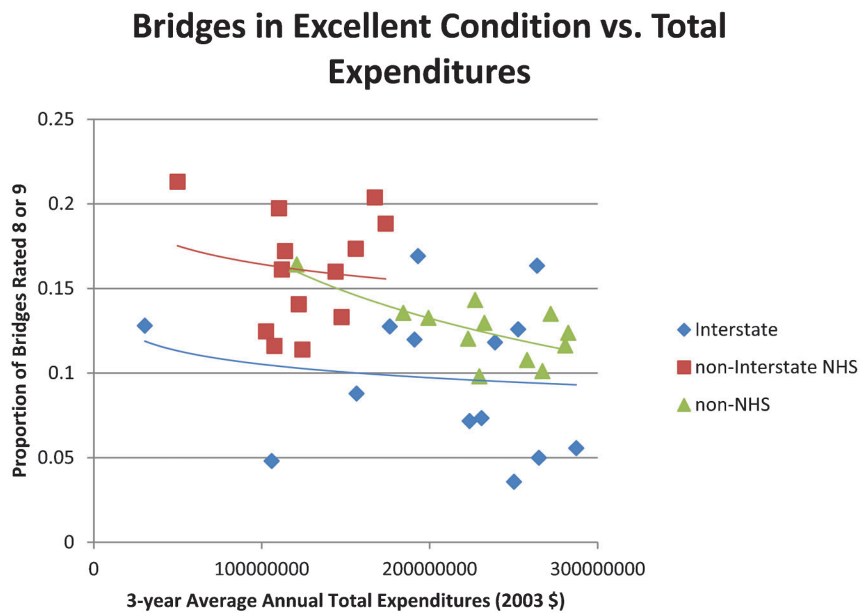

Figure G.9 Proportion of bridges in excellent condition versus total expenditures for all road classifications.

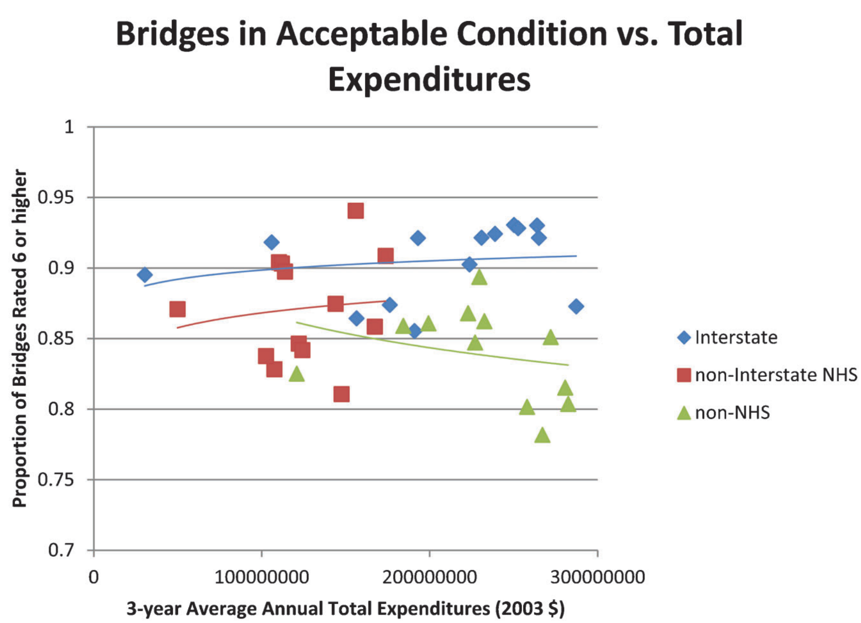

Figure G.10 Proportion of bridges in acceptable condition versus total expenditures for all road classifications.

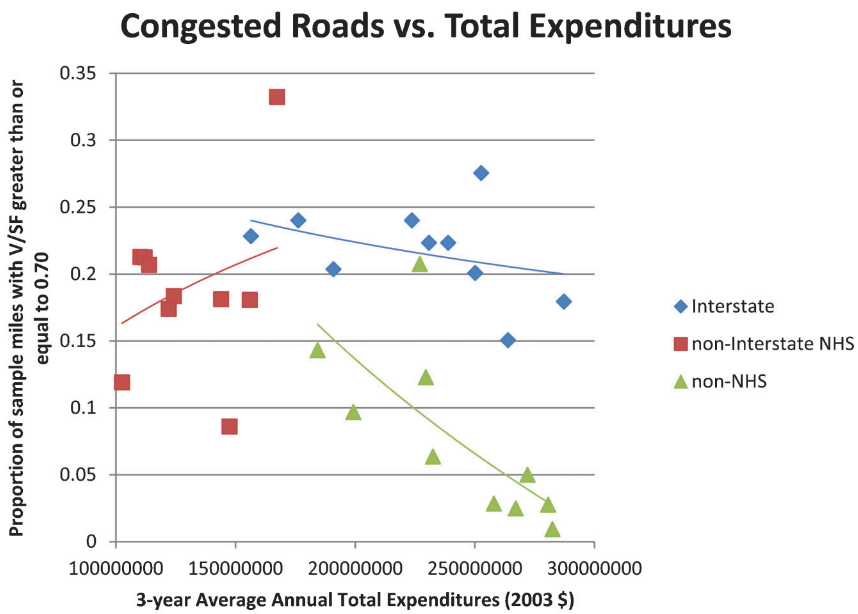

Figure G.11 Proportion of roads with VSF ≥ 0.70 versus total expenditures for all road classifications.

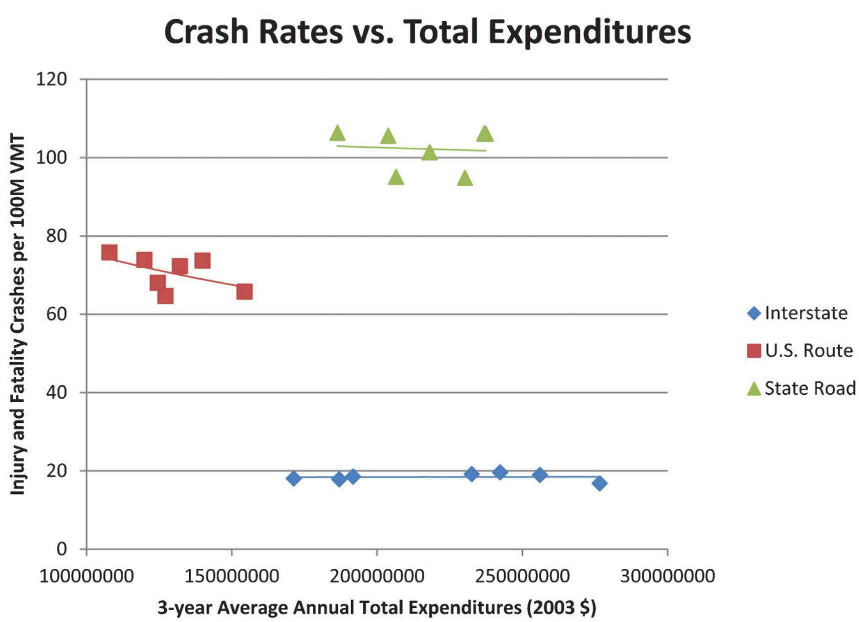

Figure G.12 Fatality and non-fatality injury crashes per 100 million VMT versus total expenditures for all route types.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

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