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REPORT 463

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Economic Implications of Congestion

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

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NCHRP REPORT 463

Economic Implications of Congestion

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SUBJECT AREAS
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation Research Board

This report will be of interest to individuals who are concerned about the economic implications of congestion. This study examines how traffic congestion affects producers of economic goods and services in terms of business costs, productivity, and output, and how producers are variously sensitive to congestion.

Past attempts to assess the economic implications of congestion have found that this is a difficult relationship to document. This study should be viewed as an incremental step toward a broader definition of the economic costs of congestion. The research shows the many facets of congestion impacts on businesses and local economies, by illustrating the types of data necessary to document those costs and demonstrating how analysis can be carried out and ultimately improved.

Under NCHRP Project 2-21, "Economic Implications of Congestion," the research team of Economic Development Research Group, Cambridge Systematics, Inc., and Regional Economic Models Inc. conducted the research and prepared the final report. *NCHRP Report 463, Economic Implications of Congestion,* measures the real monetary cost of congestion to local and regional economies. The analysis goes beyond accounting for user expense and travel time costs and includes additional productivity costs associated with travel time variability, worker time availability, freight inventory and logistics/scheduling, just-in-time production processes, and economies of market access. The study also demonstrates how congestion shrinks business market areas and reduces (or eliminates) the "agglomeration economies" of operating in large urban areas.

The report, which includes eight chapters and two appendices, presents the following:

Summary of prior research, which focuses on two areas: the measurement of congestion impacts on transportation system performance (Chapter 2) and the measurement of business costs affected by congestion (Chapter 3). References for the two literature reviews are presented in Appendix A.

Analytic framework which provides a means for assessing the extent of business sensitivity to congestion and the aggregate economic impacts of incremental changes in congestion levels in various locations. A statistical analysis model estimates the extent to which specific changes in congestion levels affect business costs in different industries and urban locations.

Case studies which examine alternative congestion scenarios for Chicago and Philadelphia based on the application of the analytic framework, using available data from these two cities. The case studies address the affects of congestion on product and service delivery costs and on workforce availability and associated costs.

Sketch planning tool, called the "Congestion Decision Support System" (CDSS), which was developed during the course of this project for analyzing the economic impacts of congestion on businesses. The researchers documented the sketch-planning tool on a CD-ROM. The CD-ROM, not included herein, is available upon request to NCHRP. The sketch-planning tool will be of value to researchers and transportation professionals with expertise in transportation and microeconomics.

Conclusions, key findings, and suggested directions for future research, which are presented in the final chapter of the report.

CONTENTS

AUTHOR ACKNOWLEDGMENTS

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Valuable assistance in the conduct of this study was provided by Ron Macready and Dianne Schwager of the Transportation Research Board, who supervised this project, and by members of the topic panel: Clyde Pyers of the Maryland Department of Transportation, Kazem Attaran of the California Department of Transportation, Carla J. Berroyer of the Illinois Department of Transportation, Susan Binder of FHWA, James Gosnell of the Southern California Association of Governments, Charles Hulten of the University of Maryland, Kenneth Leonard of the Wisconsin Department of Transportation, and Thomas Keane of FHWA.

The case study analyses were made possible through the cooperation and assistance of the Delaware Valley Regional Planning Commission (Tom Walker), the Chicago Area Transportation Study (Dan Rice and Dave Zavaterro), and Reebie Associates (Joe Bryant).

ECONOMIC IMPLICATIONS OF CONGESTION

SUMMARY

BACKGROUND

An important motivation for transportation investment in many urban areas is to address increasing traffic congestion. This has led local and state transportation officials, including the American Association of State Highway and Transportation Officials (AASHTO), to be concerned about how increasing congestion can affect economic growth. Regardless of what transportation modes or policy strategies are used to address congestion in urban areas, the fact remains that we cannot assess the economic benefits of any congestion reduction strategy unless we can first understand how congestion affects economic growth and productivity.

Past attempts to assess the economic implications of congestion have found that this is a difficult relationship to document. The most obvious approach, asking businesses in congested areas how they are affected, is problematic because those that have been driven out of business or driven away because of congestion are no longer present, and the remaining businesses typically are unable to report how different their operations would be under a hypothetical scenario of no congestion. As a result, this study has been designed to assess the economic implications of congestion by using an empirical analysis approach, which documents the many aspects of congestion-related costs incurred by different types of business operations in different types of urban settings; statistical analysis is then used to show how transportation costs have affected patterns of businesses in two major metropolitan areas.

Given the complexity of the problem and the limitations of available data, this study does not provide the final word on the economic costs of congestion. Instead, it represents a starting point—showing the many facets of the effects of congestion on businesses and local economies, illustrating the types of data necessary to document those costs, and demonstrating how analysis can be carried out and ultimately improved.

Key Features of This Study

This study examines how urban traffic congestion affects producers of economic goods and services in terms of business costs, productivity, and output, and how producers are variously sensitive to congestion. This sensitivity to traffic congestion is attributable to a particular industry sector's reliance on skilled labor or specialized inputs and a large, transportation-based market area to obtain those inputs. Congestion effectively contracts the market area for inputs, bidding up their costs, thus increasing production costs. Industries can compensate for congestion and reduce costs partially by location choices as well as other strategies. This study is of particular interest for four reasons:

- More complete measurement. The most important aspect of this study is that it provides a measure of the real monetary cost of congestion to local or regional economies, which is more complete than the accounting of user expense and travel time cost only. This includes incorporation of additional productivity costs associated with travel time variability, worker time availability, freight inventory and logistics/scheduling, just-in-time production processes, and economies of market access.
- Link to productivity studies. The study also incorporates realistic production functions, which recognize the ability of businesses to substitute among inputs (and workers) to some degree, as they adjust to the higher costs of travel. This effect is of particular note, for it helps to reconcile transportation impact analysis methods with more aggregate studies of the relationship between business productivity and transportation investment. It also provides insight into the effect of travel time reduction on induced growth of traffic.
- Scale economies. The economic analysis further demonstrates how congestion effectively shrinks business market areas and reduces (eliminates) the scale economies (agglomeration benefits) of operating in large urban areas.
- Application for policy testing. The end product is the demonstration of a general approach that can be applied for broad analysis of the economic costs of congestion around the country. The model results indicate that a congestion alleviation strategy that explicitly considers effects on firms in terms of their costs of doing business can provide a fuller picture of the trade-offs among alternative investments than a traditional comparison based on user costs (and occasionally also external costs).

IMPORTANCE OF NONUSER BUSINESS COSTS OF CONGESTION

The economic impact of traffic congestion is not simple to calculate. There are two reasons for this:

- Additional cost factors. Traffic congestion imposes costs to businesses beyond the mere vehicle and driver costs of delay, including potential effects on inventory costs, logistics costs, reliability costs, just-in-time processing costs, and reductions in market areas for workers, customers, and incoming/outgoing deliveries.
- Business adjustment. Businesses may respond to worsening traffic congestion in a variety of ways, including moving away, going out of business, and adjusting to smaller market areas for workers, suppliers, and customers—with some resulting loss of productivity.

Past studies that surveyed or interviewed business leaders found it difficult to document congestion costs, because those that had moved away or gone out of business could not be found, and those that remained had evolved over time in ways that made it difficult for their staff to assess how the business would have been different under a hypothetical situation with no traffic congestion. For those reasons, it was recognized that the business productivity loss associated with congestion would have to be inferred from existing business and travel patterns by using economic models.

METHODOLOGY

Elements of the analysis. The analysis process used in this study utilized three elements:

- Data: Detailed microdata on patterns of business locations and patterns of commuting trips, truck trips, and other business travel patterns based on case study data for the Chicago and Philadelphia metropolitan areas;
- Cost factors: Application of the best available information on how the pattern of business inventory, logistics, reliability, and production process costs differ by type of business, type of worker occupation, type of commodity shipped, and type of vehicle; and
- Models: Calibration of business production function models to estimate the effect of higher commuting and shipping costs (and hence reduced market areas) on business productivity.

Types of Business Costs

This approach considered commuter and business delivery movements between locations in terms of two types of changes in business costs:

- Change in direct cost of production. A reduction of transportation costs directly translates into a reduction in the cost of obtaining workers and delivering products/ services to customers, and hence in total production cost.
- Additional change in accessibility to specialized inputs. Furthermore, lower transportation costs change the distribution of shipments and trips as more specialized workers and customer markets become accessible. Therefore, an additional reduction of costs occurs because firms are able to use labor that more specifically meets their production needs and serves broader customer markets. Effects on productivity may come from improved access to broader worker and customer markets as well as from logistic and scheduling efficiencies and scale economies.

Production Response

A business production function model was used in this analysis to relate levels of business activity in urban zones to differences in relative costs of labor and materials, including worker commuting and business product/service delivery costs. Three basic facts underlie this economic modeling approach:

- Business markets. The observable location pattern of businesses reflects the fact that some types of business have a few large establishments serving a wide area, whereas other types of businesses have many small establishments, each serving a smaller local area. These patterns reflect the fact that different types of businesses have different worker (occupation) and supply (commodity) needs as well as different product/service delivery markets. They reflect the degree of specialization of the different types of businesses in terms of workers and products.
- Business production functions. The degree to which different types of business incur productivity losses from traffic congestion depends on how congestion affects their direct travel-related costs, their production costs, and their ability to adjust to smaller markets (which in turn reflects the extent to which they depend on access to specialized workers or materials).

- Business mix. The mix of businesses in downtown business districts, outlying industrial areas, and bedroom communities are very different, reflecting their different needs for access to specialized worker skills, specialized materials, or specialized markets.

RESEARCH FINDINGS

Statistical Relationships

The research team conducted extensive data assembly and statistical model analysis for the Chicago and Philadelphia metropolitan areas. The analysis models were developed to examine the degree of sensitivity of various types of business activity to the costs of transporting products and the costs of worker commuting. The estimation and application of these parameters are the subject of considerable discussion in this report. In general, the calibrated models for Chicago and Philadelphia yielded consistent results:

- Industry differences in congestion costs. The results for both areas indicated that industries with broader worker requirements and higher levels of truck shipping absorb higher costs associated with congestion. They also benefit the most from reduced congestion.
- Industry sensitivity to congestion costs. The production function models also indicated that firms with lower-skilled labor requirements or nonspecialized (commodity) input requirements tend to be hurt relatively less by congestion (and benefit relatively less from reduced congestion) than those with requirements for highly skilled labor or highly specialized material inputs.
- Effect on travel patterns. The models confirmed that congestion does reduce the agglomeration benefits of urban areas by reducing access to specialized labor and delivery markets, whereas businesses adjust with shorter trip lengths. Conversely, congestion reduction can provide greater benefits to businesses associated with increased access to labor and delivery markets, although that is accomplished through some increases in vehicle-miles of travel.
- Economies of scale. The models also illustrated how traffic congestion has the effect of nullifying some of the agglomeration benefits of operating businesses in larger urban areas. The labor cost model, for instance, indicated that doubling the effective labor market size leads to an average 6.5 percent increase in business productivity.

Impacts of Congestion Scenarios

The actual economic impacts of traffic congestion can differ by metropolitan area, depending on its economic profile and business location pattern. Nevertheless, the two case study areas presented here illustrate how congestion impacts can differ depending on the nature of the congestion scenario. Although it was beyond the scope of this study to define or investigate the effectiveness of any particular transportation policies or strategies, some hypothetical scenarios were created to illustrate how they differentially affect business activity and costs.

Four types of scenarios were investigated: metropolitan-wide congestion reduction, congestion reduction focused on the central business district (CBD) only, congestion reduction focused on an older working class and industrial area, and congestion reduction focused on a white collar commuter area. The results were as follows:

- Truck delivery delays in the CBD. The economic effects were dramatically different depending on where the congestion occurred. When congestion reduction centered on the CBD of both cities, the economic benefit was largely concentrated on those businesses located in the CBD. That is because many of those CBD businesses are service oriented; they rely on incoming deliveries of supplies with relatively modest movements of outgoing truck deliveries to other parts of the metropolitan area.

- Truck delivery delays in industrial zone. In contrast, when the congestion reduction was centered around an older industrial area in both cities, then the economic benefits were widely distributed among industries and business locations throughout the metropolitan area. That is because the directly affected businesses had a high level of outgoing truck shipments, serving broad industries and locations—from the CBD to outlying fringe areas.
- Regionwide worker commuting delays. The economic impacts associated with worker access were also dramatically different depending on where the congestion occurred. When congestion reduction was evenly distributed regionwide, the economic benefit remained largest for those businesses located on the periphery of the metropolitan area. That is because there tend to be longer travel distances for workers and incoming deliveries coming into those businesses, and hence they are most affected by increases and decreases in congestion costs.
- Commuting delays for outlying residential areas. In contrast, when the congestion reduction was centered around an area with many skilled and educated workers, the economic benefit was broadly distributed among locations throughout the metropolitan area. It was also greatest for types of businesses employing executives and precision-skilled workers.

The estimated costs of congestion depend on the specific scenario. For the test scenarios used for this study, annual changes in business costs associated with product and service deliveries ranged from $20 million/year to $1 billion/year in a single region. The annual changes in business costs associated with labor ranged from $1 million/year to $3 million/year in a single region.

DIRECTIONS FOR FUTURE RESEARCH

The findings from this study indicate three key directions for future research.

1. Analysis of the effectiveness and costs of alternative options for addressing different types of congestion in different types of land use and economic settings, an issue not addressed in this study. It specifically includes estimating specific transportation policies and strategies. This study examined the effects of simplified, hypothetical scenarios concerning reductions or increases in congestion. It did not examine relative costs and benefits of alternative transportation projects and policies to mitigate congestion. To address those issues in the future, methods developed from this study will have to be applied in combination with separate analyses of the effect of potential transportation investments (and policies) on reduction of delays due to congestion.
2. More complete analysis of the economic implications of increasing or reducing congestion levels, the central focus of this study. It specifically includes the following:
   - Examination of congestion effects for additional classes of trips. This study focused on measuring congestion impacts on business product delivery and workforce-related costs. It did not cover the value of congestion delay for personal travel or for shopping trips. In both cases, this was due to a lack of available interzonal data on trip patterns and trip lengths. Future research should attempt to acquire and analyze data on those classes of trips and how congestion affects them.
   - Development of improved data on truck movements within metropolitan areas. Future improvements in congestion cost estimation will also have to await an

improvement in the availability of data on business-related travel patterns. Although metropolitan planning organizations have highly detailed origin-destination data on commuting patterns by industry and occupation (from census journey-to-work data), typically data on truck movements is scant. This includes a lack of data on truck origin-destination zonal patterns, coverage of truck trips with outside origins or destinations, and industry/commodity breakdown for products being carried. Much of the existing metropolitan data on truck movements misses delivery of business products and services via car, van, and light-delivery vehicle. Often these data are synthesized on the basis of partial information. In the future, the quality of such data can be improved through detailed breakdowns of the commodity flow survey (as specially obtained for this study) and better survey coverage of noncommodity business travel.

- Additional research on the service sector. This study treated producers of services as a single industry and considered a particular class of modeled trip—work-to-work trips—as a suitable surrogate. However, there is considerable variation within service sector businesses in terms of reliance on transportation for their inputs and delivery of their services. A useful extension of this study would be to develop a more detailed understanding of the service industry through carefully designed surveys. Such an effort could provide quantitative information useful for model estimation as well as qualitative information on the relationship between congestion and the service industry, thus benefiting planners and decision makers.
- Model calibration and verification for additional metropolitan areas. This study involved substantial effort working with metropolitan planning organizations to obtain and derive interzonal data on trip patterns for specific trip purposes, industries, and occupations. Now that the methodology has been demonstrated to be feasible, further testing is needed to establish the level of consistency in statistical relationships (model elasticities) among a broader range of metropolitan area sizes and locations.

3. Analysis of the long-term implications and overall benefits and costs of alternative congestion reduction strategies, issues not addressed in this study. It specifically includes the following:
   - Analysis of long-term economic adjustment to congestion. This study focuses on developing estimates of the cost changes incurred by business when congestion is increased or decreased, given patterns of business location, scheduling, and operating technologies. In fact, in the long run businesses can adjust operations and locations in response to congestion increases or decreases. In addition, changes in regionwide congestion levels can affect the cost-competitiveness of doing business in a region and hence its longer-term economic growth. There is a need for further research to examine business behavior and to apply methods for estimating the magnitude of potential future impacts on regional economic growth associated with congestion changes.
   - Analysis of the productivity benefits and costs of transportation investments in congestion reduction. This study did not examine the costs or effectiveness of alternative actions to address congestion, so it cannot be used by itself to calculate benefit/cost ratios or return-on-investment rates for transportation spending to address congestion. However, once those research topics are addressed, the approach developed in this study will provide a foundation for conducting assessments of spending and investment alternatives.

CHAPTER 1

INTRODUCTION

In many metropolitan areas, there are increasing concerns about how the growth of traffic congestion may adversely affect the area's economy (business sales and income) as well as concerns about the relative benefit-cost ratio or return on investment associated with alternative projects or policies to address those problems. Unfortunately, the severity and pattern of congestion, as well as the effectiveness of alternative projects or policies to address it, can vary widely from area to area, depending on the size and layout of the metropolitan area, its available transportation options, and the nature of its traffic generators. Similarly, there is no single rule of thumb for the economic cost of worsening congestion or the economic benefit of congestion reduction, for that can also differ depending on an area's specific economic profile as well as its unique pattern of congestion. All these issues need to be addressed to conduct benefit-cost analysis or return on investment for alternative congestion reduction strategies.

This report represents a step in the process of addressing these issues. It provides an overview of the problem of traffic congestion in urban areas, a description of existing literature on the many facets of its economic impacts on travelers and other affected parties, and an analytical methodology to estimate these effects. It also provides findings from case studies conducted to estimate the economic impacts of alternative congestion scenarios in two metropolitan areas. Finally, it describes a computer analysis approach that can be used by others to assess the costs of congestion for other metropolitan areas.

Altogether, the tools, methods, and findings in this report are intended to provide a starting basis for subsequent work to better refine the economic costs of congestion and, ultimately, for later studies to assess the benefit-cost ratios for alternative congestion-reduction strategies.

DEFINITION OF CONGESTION

Traffic congestion is defined as a condition of traffic delay (when the flow of traffic is slowed below reasonable speeds) because the number of vehicles trying to use the road exceeds the traffic network capacity to handle them. Traffic congestion is widely viewed as a growing problem in many urban areas across America as well as in other countries, because the overall volume of vehicular traffic in many areas (as reflected by aggregate measures of vehicle-miles or vehicle-kilometers of travel) continues to grow faster than the overall capacity of the transportation system. The resulting traffic slowdowns can have a wide range of negative effects on people and on the business economy, including impacts on air quality (due to additional vehicle emissions), quality of life (due to personal time delays), and business activity (due to the additional costs and reduced service areas for workforce, supplier, and customer markets). This report focuses specifically on the latter type of impact—how roadway traffic congestion affects the economy in terms of business costs, productivity, and output.

Congestion has three important dimensions of variation:

- The spatial pattern of traffic congestion may vary—it can be areawide or location specific.
- The temporal pattern of traffic congestion may vary—it can occur during morning or afternoon peak periods or during off-peak periods.
- There is also a stochastic element of traffic congestion—it can occur on a continuing basis at predictable times or sporadically (at random times) as a result of traffic accidents or other types of incidents.

However, regardless of location or timing, the frequency and severity of congestion delays increase as traffic volumes grow to exceed road system capacity.

THE PROBLEM AND NEED TO ASSESS ECONOMIC IMPLICATIONS OF CONGESTION

Why It Is Difficult to Measure the Severity of Congestion

From a traffic point of view, congestion creates travel time delays and results in expenses for commuters and business travelers. There is significant literature on the measurement of congestion delays in cities around the country. From an economic point of view, congestion clearly causes households and businesses to incur excess time and money costs. However, the current literature on the subject does not satisfactorily address these issues, nor has there been any real exploration of the true economic costs of urban road congestion. There are two key reasons:

- Problem 1: Severe congestion is often localized and cannot be adequately represented by regional traffic indicators. The relationship between traffic levels and congestion delay is not linear. Up to the point at which traffic volumes approach road design levels, there may be no delay at all. Once traffic volumes exceed road design levels, delays may increase exponentially. The delays are often location specific, generated by bottlenecks, which can then produce "queues" (backups) on otherwise free-flowing roads. Major delays can also be sporadic or unpredictable. As traffic levels increase, the rate of traffic incidents and the amount of traffic delay caused by them may both increase sharply. For these reasons, the extent and frequency of delays at some locations and times can be much more severe than an average areawide measure of delay.
- Problem 2: The economic costs of congestion vary by type of business and cannot be adequately represented by traditional measures of user time and average vehicle operating costs. The cost of delays for businesses can be substantially greater than the cost of driver time and vehicle operating time alone. For some types of businesses, there can also be implications for revenues and costs related to the size of the business market and/or service areas, business inventory and logistics costs, just-in-time production costs, and workforce attraction.

Why It Is Difficult to Measure the Economic Impacts of Congestion

There have been prior attempts to estimate the economic impacts of congestion through business surveys, including most notably NCHRP Project 2-17(5) (see *NCHRP Research Results Digest Number 202*, Sept. 1995). The problem is that such prior attempts found that business managers do not explicitly track the costs of congestion and hence seldom make any specific attribution of their business costs to congested roads. There are several reasons why they do not do so:

- Self-selection: only survivors can be interviewed. A survey of businesses in congested areas will include only the existing businesses, because any business that could not survive in a congested area has already closed up or moved out. Hence, the remaining businesses tend to be those that are not adversely affected by congestion. This includes offices that are not highly dependent on truck deliveries or in-store shopper visits. It also includes businesses that have the ability to minimize congestion impacts on their operations through flexible scheduling, reliance on Internet or telecommunications activities, or use of transit alternatives.
- Business staff have difficulty predicting their hypothetical responses to what they perceive to be nonrealistic scenarios. For a business manager operating in an area of traffic congestion, the existing conditions (including longer commutes, higher costs of parking, and longer delivery times) may be viewed as a pervasive phenomenon or otherwise accepted as part of the cost of doing business. Many people in urban businesses cannot estimate the cost of congestion to their business because they cannot imagine how different the business would be under the purely hypothetical situation in which such congestion is not present.
- Some businesses thrive in high-density business districts, and their staff cannot easily distinguish the advantage of density from the disadvantage of congestion delay. For some types of businesses (offices of banking, finance and business service companies, and restaurants serving them), there can be productivity benefits associated with agglomeration—locating together in high-density business districts, which offset the higher travel and parking costs of doing business in those areas. For those types of businesses (which typically have low needs for incoming or outgoing freight deliveries), congestion may not even be recognized as a major problem.

Why Statistical Methods Are Needed to Assess Economic Impacts of Congestion

Findings from the past surveys of individual businesses are instructive, for they suggest that perceptions of individual business managers are an unreliable means of assessing economic impacts of congestion. They also indicate that business sensitivity to congestion is reflected in business location patterns and that different types of businesses have different abilities to compensate for congestion impacts on their operations. For all these reasons, it is useful to use some form of economic modeling that recognizes business productivity and business adjustment factors. Because the nature of congestion impacts differs by spatial location and the associated business productivity impact differs by industry category, it is also necessary to adopt a methodology that examines how changes in congestion levels uniquely affect business costs in different industries and at different locations within urban regions.

APPROACH AND CONTRIBUTION OF THIS STUDY

Approach: Focus on Linkages Between Congestion and Economic Impacts

Theory

Figure 1.1 summarizes the five elements of factors that affect congestion and its economic impacts:

A. Transportation-related investment and pricing—affecting the capacity of facilities;
B. Transportation system performance—network demand and congestion levels;

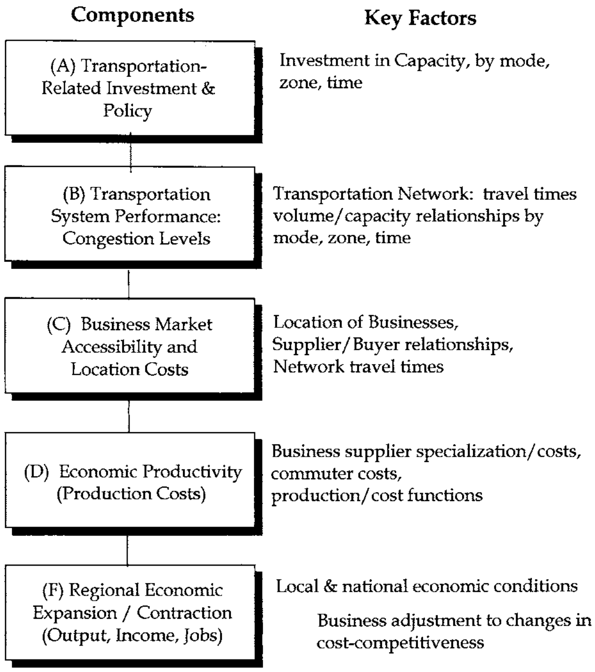


Figure 1.1. Components of the economic impacts of congestion.

C. Business market accessibility and location costs—operating costs related to the accessibility of various locations;
D. Productivity effects—output levels and cost economies of scheduling and market scale; and
E. Economic growth—adjustments in response to changes in the cost competitiveness of business location in various urban areas.

In theory, these elements represent a progression of steps, although in reality there can be a much more complex interaction between them.

This study assumes that transportation system supply, demand, and resulting congestion levels (elements A and B) represent given conditions, referred to as scenarios. Our research then focuses on estimating how alternative scenarios, representing changes in transportation conditions, would affect short-term business operating costs and productivity (elements C and D). In the long term, changes in these costs can also change a region's business competitiveness and lead to shifts in regional business location and expansion patterns (element E). Those long-term effects potentially can be assessed with a regional economic forecasting model, but such analysis is not covered in this study.

Relationship to Other Studies

It is also important to clarify the relationship between this study and more aggregate studies of the economic productivity implications of transportation investment. In particular, there have been a line of studies, pioneered by Aschauer (1989) with more recent enhancement by Nadiri (1996) that have examined the long-term relationship between transportation spending (element A in the schematic) and long-term changes in business productivity or output (elements D and E). Those studies have basically sought to show an aggregate relationship between transportation spending and economic growth, without distinguishing any of the intermediate elements of changes in transportation system performance or accessibility changes (elements B and C). The limitation of those studies, from the viewpoint of studying congestion impacts, is that they do not allow us to distinguish the extent to which economic growth has been due to improvements in rural accessibility, interstate connectivity, urban congestion reduction, or other factors.

This study, in contrast, focuses specifically on major urban areas facing transportation congestion delays and examines how congestion levels (element B) affect business production costs (element C) and productivity (element D). This study thus complements the more aggregate studies by addressing the behavioral component of productivity that they have not addressed.

Contribution of This Study

The most important aspect of this study is that it provides a measure of the real monetary cost of congestion to local or regional economies. This is more complete than the accounting of user expense and travel time cost only. Our analysis includes the incorporation of additional productivity costs associated with travel time variability, worker time availability, freight inventory and logistics/scheduling, just-in-time production processes, and economies of market access. In addition, the economic analysis in this study indicates how congestion effectively shrinks business market areas and reduces (or eliminates) the agglomeration economies of operating in large urban areas.

The end product is the demonstration of a general approach that can be applied for broad analysis of the economic costs of congestion for urbanized areas around the country. It is important to note, though, that this study focuses only on the measurement of business productivity costs of congestion. It does not cover the value of congestion delay for personal time. Nor does it examine the relative costs and benefits of alternative measures to mitigate congestion. To address that, the findings from this study must be combined with future analyses of the effects of transportation investments (and policies) on reduction of congestion delays.

ORGANIZATION OF THIS REPORT

The remainder of this report is organized into the following chapters.

- Summary of prior research. Chapters 2 and 3 discuss findings from a detailed review of prior research studies. From the transportation literature, Chapter 2 discusses measures of congestion impacts on transportation system performance (including user value of time delay, travel time reliability, and schedule flexibility). Chapter 3 discusses the measurement of business costs affected by congestion (including transport spending, business accessibility and location costs, logistics costs, and overall productivity impacts). References for the literature are provided in Appendix A.
- Analytic framework. Chapter 4 describes the elements of analysis in terms of a general framework and series of analytic steps. This framework provides a means for assessing the extent of business sensitivity to congestion and the aggregate economic effects of incremental changes in congestion levels in various locations. A key element of the analysis is the use of a statistical analysis model to estimate the extent to which specific changes in congestion levels affect business costs in different industries and urban locations.
- Case studies. Chapters 5 and 6 summarize analysis findings from case studies of alternative congestion scenarios for Chicago and Philadelphia. These case studies present application of the analytic framework, using available data sources. They also indicate how economic impacts of congestion vary by industry and the location pattern of the traffic conditions. Chapter 5 focuses on how congestion affects business (product and service) delivery costs, whereas Chapter 6 focuses on how congestion affects workforce availability and associated costs.
- Sketch planning tool. Chapter 7 provides an overview of CDSS (congestion decision support system), a free sketch planning software tool for analyzing the economic impacts of congestion on businesses. Further user instructions for CDSS are provided in Appendix B.
- Conclusions. Chapter 8 summarizes the key findings and suggested directions for future research.

CHAPTER 2

MEASURING USER IMPACTS OF CONGESTION: LITERATURE REVIEW

This chapter presents a broad review of the literature on different techniques for measuring congestion and transportation system user (traveler) costs associated with it. These measurement techniques cover a number of different categories that include congestion level indicators, valuation of travel time delay, costs of reduced reliability, and adjustment made by travelers to avoid peak-period congestion.

Broader impacts of congestion on business and the economy are addressed in Chapter 3.

ALTERNATIVE MEASURES OF CONGESTION

A great deal of attention has been devoted to defining and measuring congestion in existing research and is reflected in the development of congestion management systems. Indicators of congestion are available for urban areas and are reported in FHWA's *Highway Statistics* and Bureau of Transportation Statistics' (BTS's) *National Transportation Statistics*.

There are several different ways to define and measure the level of congestion on roadways. Some of the techniques are consistent with the definition and use of congestion thresholds, including the following:

- A congestion index related to the rate of travel that is being advanced in a number of research projects at the Texas Transportation Institute (TTI);
- An excess delay measure for urban areas that is tied to the amount of time spent at an intersection or along a roadway segment operating below a certain level of service (LOS); and
- The percentage of time at a given point on a highway system, the average speed drops below some threshold value.

These measures potentially can all be applied to vehicular travel in automobiles, vans, buses, and trucks.

Different Measures of Congestion

Table 2.1 presents a list of different measures of roadway congestion. Many of the measures are currently used by transportation agencies in evaluating system performance. Others are measures that may be possible for future evaluations. The measures are grouped into five categories: time-related measures, volume measures, congestion indices, delay measures, and LOS measures.

Each of the categories and measures is described in more detail below. Studies or agencies that have used the measures are also identified.

Time-Related Measures

Time-related measures, which include travel time and travel rate, are widely used to evaluate congestion. One key reason is that measurement of the time it takes to travel a particular distance can be done repeatedly and can apply to all modes of travel, including the movement of goods. Travel times are the primary means of measuring performance in several ongoing intelligent vehicle-highway system–related research projects including Houston's Real-Time Traffic Information System, which uses both cellular telephone reporting and automatic vehicle identification techniques to record travel times; the TRANSCOMM Electric Toll and Traffic Management Project in New Jersey, which was designed to monitor the travel times of specially tagged vehicles; and the ADVANTAGE project in Chicago, which uses satellite global positioning system technology and probe vehicles to record travel times.

Specific time-related measures are described as follows:

- Travel time. This is a widely used measure, applicable to a distinct starting and ending point, that highway users generally understand, with lower travel time generally interpreted as an indicator of less congestion. It is considered by many to be the best measure of system congestion. Travel time is inversely related to speed.
- Origin-destination travel times. This is an output of the traffic assignment process of travel demand modeling, defined as the estimated time necessary to travel from an originating zone to a destination zone of a given highway network. These travel times can be estimated by calculating minimum time path skim trees.
- Travel time contours. The travel time contours from a single point to/from multiple destinations/origins can be plotted on a map showing times in discrete intervals (for example, 5 or 10 minutes at a time). These are most useful for studying travel to a major employment center such as the central business district of a large city.

TABLE 2.1 Measures of congestion

Category/congestion measure
Time-related measures
Average travel speed
Average travel time
Average travel rate
Travel time contours
Origin-destination travel time
Percent travel time under delay conditions
Percent of time average speed is below threshold value
Volume measures
Vehicle miles traveled/lane mile
Traffic volume
Congestion indices
Congestion index
Roadway congestion index
TTI's suggested congestion index
Excess delay
Delay measures
Delay/trip
Delay/vehicle miles traveled
Minute miles of delay
Delay due to construction/incidents
LOS measures
Lane miles at/of LOS *x*
Vehicle hours traveled/vehicle miles traveled at/of LOS *x*
Predominant intersection LOS
Number of congested intersections

FHWA; *Analytical Procedures to Support a Congestion Management System*; Technical Memorandum 1; prepared by Cambridge Systematics; Feb. 1994.

- Percentage of time average speed is below threshold value. This spot-speed measure uses information collected from automated speed monitoring equipment. The measure uses data that can be collected in a completely automated fashion, with an increase in the value of this measure corresponding unambiguously to an increase in the degree of congestion. This measure appears to be practical as long as the threshold speed is set at 20 mph, 25 mph, or higher because of potential equipment inaccuracies at lower speeds.

Volume Measures

The wide availability of traffic volume counts and vehicle miles traveled (VMT) data make volume measures attractive to use. Because volume is a representation of the level of demand, it is often compared with the available supply, and this relationship is typically expressed in terms of a volume-to-capacity ratio (V/C). It should be noted that VMT, an important measure for the purposes of air-quality analysis, is not a strong measure of congestion by itself. Density, which is also a measure of congestion, is a function of both volume and speed on a roadway segment of a given length and is directly related to freeway LOS.

Real-time monitoring systems currently in use or in development can be useful for measuring travel rate, congestion levels, and even goods movement. As with other measures, the information that is produced must be recorded in a simple and cost-effective manner so as to be able to make comparisons of changes in system performance over time. Traffic monitoring systems also are important for providing data on transportation system utilization.

V/C is described as follows: The Highway Performance Monitoring System (HPMS) data set includes peak-period V/C as a data item. Also, the distribution of total traffic by

V/C can be estimated with the HPMS data items annual average daily traffic (AADT) and capacity, together with tables showing the distribution of traffic by V/C for different values of AADT/C. V/C are used as the basis for estimating network link speeds in traffic assignment models, in a function known as the BPR (Bureau of Public Roads) curve.

Congestion Indices

Much previous research on congestion indices has facilitated comparisons of relative levels of congestion among U.S. cities. These are valuable tools for estimating overall levels of congestion but may not be applicable at the regional level and across multiple modes of travel. To expand on the work done in the past, TTI developed an index that takes all modes of transport into account and is based on a measure called the volume/acceptable flow rate. The acceptable flow rate, simply that flow rate deemed acceptable by local officials, is weighted according to a number of local roadway characteristics. This index is based on the travel rates of all travel modes multiplied by the VMT for each mode and then divided by freeway VMT plus arterial VMT, adjusted to reflect roadway classification variables (derived from local information). Other indices of congestion such as excess delay are also being proposed at the regional level.

Another specific congestion index is the roadway congestion index. This index is a systemwide measure of congestion on the street and freeway system. The roadway congestion index uses daily VMT per lane mile of roadway for both freeways and principal arterial streets within an empirically derived formula. The index equation weighs the daily VMT per lane mile values for the two functional classes by their respective daily VMT, which is then normalized by daily VMT per lane miles representing the threshold of congestion (LOS D or worse).

Delay Measures

Delays of any type increase travel time and reduce travel speeds. As such, measures of delay are closely tied to time-related measures. By focusing on delay as a performance measure, specific problem locations or areas can be identified whether they are recurring or nonrecurring. A number of recent studies, focused on nonrecurring congestion, have demonstrated the importance of incident-related delays and the benefits that can be derived from their reduction.

Specific delay measures are described as follows:

- Delay. The difference between desired or free flow and actual travel time is considered a good measure of congestion intensity on a roadway link or in an overall system. However, this measure does not give much insight into the specific causes of congestion.
- Minute miles of delay. Minute miles of delay is the product of the length of a roadway segment and the difference between an acceptable travel rate and the actual travel ratio (where the actual travel ratio is equivalent to 60 minutes divided by the speed on the segment).
- LOS measures. LOS classifications, which are widely used as a measure of congestion, are derived from other performance measures. As stated in the *Highway Capacity Manual*, "the concept of level of service" is defined as a qualitative measure describing operational conditions within a traffic stream and their perception by motorists and passengers (TRB 1985).

The LOS measure does have limitations. Although it is used as a measure of areawide congestion, there is debate about its utility and applicability, because an average measure can mask specific congestion locations or be unduly influenced by a few locations of serious congestion. LOS is a good measure of intersection delay or roadway density but cannot be forecast easily and has not generally been applied to person movement. Nevertheless, measures such as LOS will remain important for determining a number of factors, including systemwide characteristics such as the number of intersections exceeding a threshold LOS. The NCHRP quantifying congestion literature review indicated that this measure is used by 90 percent of the agencies surveyed but was suggested by only 9 percent as an appropriate congestion performance measure.

Implications

The review of congestion measures demonstrated at the outset of this project that a number of different approaches are used to quantify the level of congestion for an urban area. Although there are a number of different congestion measures, travel time measures offer the best means for estimating the economic impacts of the congestion. There are several reasons for this:

1. Travel time corresponds directly to the traveler's experience of congestion, when measured from a given origin to destination;
2. As indicated below, efforts to estimate the direct user costs of congestion are based on placing a value on travel time, often as a percentage of the wage rate; and
3. Most traffic models produce estimates of speed and time for individual roadway segments and origin and destination zones. More sophisticated techniques allow for the calculation of travel times between specific, nonzonal locations on a transportation network.

COSTS OF TRAVEL TIME DELAY

To estimate the impact of congestion on economic activity, it was first necessary to quantify the direct costs of congestion.

The cost of time to drivers and passengers is one of the largest components of direct congestion costs. This section reviews a few key studies that have presented estimations and methods for estimating the value of travel time for passenger and freight travel.

A significant number of studies have been conducted on estimating the value of passenger travel time through a variety of different methodologies. However, relatively few studies have attempted to quantify the value of freight travel time. This review presents some of the results developed in this area but does not attempt to cover the extensive literature on passenger travel valuation. A more detailed review of the freight travel time estimations is presented.

Value of Passenger Travel Time

One of the more extensive reviews of the value passenger travel time was Miller's (1989) literature synthesis that examined the results of a number of different methods of estimating travel time costs. The synthesis found that the most common way to estimate the value of time is by examining trip-specific behavior choices. Mode choice models may underestimate the value of automobile travel time savings because they incorporate other factors such as relative comfort, convenience, and reliability. The results indicated that, for project evaluation purposes, a value of travel time of 60 percent of the wage rate should be used for drivers, pedestrians, and cyclists, and a value of 40 percent of the wage rate should be used for passengers. These values should increase to 90 percent and 60 percent, respectively, for travel in congested conditions.

The NCHRP 2-18 (1995) study focuses on two aspects of travel time valuation, the premium placed on travel-time savings for passenger and freight transport during periods of congestion and the value placed on the predictability of travel times. The study used a stated preference survey methodology for measuring the effects of congestion on the values highway users place on travel-time savings and predictability. With data from the stated preference passenger survey, separate models for calculating the impact of congestion on values of travel time and travel-time predictability were developed by logistic choice estimation techniques. In one model formulation, the value of travel time was stratified by annual household income, and the results indicated that income levels of $15,000 valued travel time at $2.64 an hour, income levels of $55,000 valued travel time at $5.34 an hour, and income levels of $95,000 valued travel time at $8.05 an hour. These findings were within the range found in the value of travel time literature but on the lower end of the range.

The U.S. Department of Transportation (DOT) Office of the Secretary has developed guidelines to be followed by agencies for evaluating savings of losses of travel time that result from investments in transportation facilities or regulatory actions, and all cost-benefit and cost-effectiveness analyses prepared by DOT. The DOT guidelines have adopted a single measure of income and value of time applicable to all local personal travel across all transportation modes; however, for intercity travel, differences between modes are reflected. The values are based on a review of the academic literature, which showed that besides transportation mode, trip purpose (business or personal), and income, a major source of variation in the value of time is distance, particularly the large differences between local and intercity trips. The review concluded that intercity travel time is likely to be more valuable than time spent in local travel.

DOT-recommended values are applicable for all local personal travel, with 50 percent of the wage rate recommended for use regardless of the mode employed. Seventy percent of the wage is recommended for all intercity personal travel and 100 percent of the wage rate (plus fringe benefits) is recommended for all local and intercity business travel, including travel by bus drivers. Hourly wage rates were developed from Bureau of the Census data.

Value of Freight Travel Time

The HERS (Highway Economic Requirements System) Technical Report presents the methodology for developing value of time estimates to be used in the user benefit calculation of the HERS needs analysis. HERS is a computer model designed to perform highway needs analysis that reflects both the current condition of the highway system and the estimated costs and benefits of potential improvements to the system.

The value of time estimation is divided into two components: on-the-clock trips (trips drivers take as part of their work) and off-the-clock trips (other trips). Time savings during on-the-clock trips are valued on the basis of savings to employers that include wages, fringe benefits, vehicle costs, and inventory carrying costs of the cargo (vehicle and inventory costs are applicable only for specific truck types). Off-the-clock time savings that include commuting to and from work, personal business, and leisure activity were based on a review of the value of time studies. These values are presented in Table 2.2.

Hourly compensation wages and benefits for automobiles were assumed to be equal to the U.S. average for civilian workers for each occupant of the vehicle. This value was multiplied by average occupancy rates to compute employee costs per hour of work travel time. Vehicle costs for automobiles were computed as the average vehicle cost per year (assuming a 5-year life, with a 15 percent salvage value at the end, with initial cost from the Motor Vehicle Manufacturers Association) divided by 2,000 hours per year of signout time.

For heavier trucks, the cost per hour was computed as the average vehicle cost per year divided by the number of hours in service per year. Six-tire trucks and four-axle combination trucks were assumed to be in service 2,000 hours per year; five-axle combinations were assumed to be in service 2,200 hours per year. Because three- and four-axle single-

TABLE 2.2 HERS value of travel time by benefit category and vehicle type

$ per Person-Hour	Vehicle Class						
Category	Small Auto	Medium Auto	4-Tire Truck	6-Tire Truck	3-4 Axle Truck	4-Axle Comb.	5-Axle Comb.
On-the-Clock							
Labor/Fringe	26.27	26.27	8.02	21.88	18.22	21.95	21.95
Vehicle	1.72	2.02	2.18	3.08	8.80	7.42	7.98
Inventory	0.00	0.00	0.00	0.00	0.00	1.65	1.65
Total	27.99	28.29	20.20	24.96	27.02	31.02	31.58
Other Trips							
Percentage of Miles	90%	59%	0%	0%	0%	0%	0%
Value	12.78	12.78	NA	NA	NA	NA	NA
Weighted Average	14.30	14.33	15.08	25.27	27.91	31.64	32.25

Source: Federal Highway Administration, The Highway Economic Requirement System: Technical Report (updated 3/97).

Note: 1995 dollars.

unit trucks include many dump trucks that have down time between jobs, especially during cold periods of the winter, they were assumed to be used only 1,600 hours per year.

To compute the inventory costs for heavy vehicles, an hourly discount rate was computed and multiplied by the value of a composite average shipment. The average payload of a five-axle combination was assumed to be 35,000 lb (15,875 kg). The payload for four-axle combinations are lower than for five-axle trucks, but the value of the cargo is probably higher, so the value per shipment was assumed to be similar for both types of trucks.

The HERS estimation found no compelling evidence that the average value of travel time differs between off-the-clock trips, which include commuting to and from work, personal business, and leisure activities. Based on a survey of studies with route-choice models, surveys, speed-choice models, and models of housing-location choice, it was found that most previous research reported the value of off-the-clock travel time between 55 and 65 percent of the wage rate.

The NCHRP 2-18 study conducted a stated preference survey of freight carriers, similar to the passenger survey described above, although on a much smaller scale. For the purposes of that study, 20 telephone surveys were completed from selected freight carriers. Compared with the passenger survey, the results were somewhat inconclusive and failed to develop a statistically significant model for both the value of travel time and transit-time predictability. The survey found that carriers value transit time at $144.22–$192.83 per hour and savings in late schedule delays at $371.33 per hour.

The study includes a review of empirical contributions to the valuation of travel time reliability. These studies vary in approach as well as the metric used to report results, which makes valid comparisons across studies difficult. The individual study designs clearly served the needs of the research purpose. However, the variety of results indicated in the literature review implies that considerable work remains to attain a state of the practice in the methodological approach to estimating the value of reliability among shippers and receivers. These results underscore the need to differentiate across broad commodity classifications in estimating the value of travel time reliability, because there is considerable sensitivity to time variations across firms. The review is summarized in Table 2.3.

U.S. DOT Guidelines for Valuation of Travel Time in Economic Analysis

The U.S. DOT Office of the Secretary has developed guidelines to be followed by agencies when evaluating savings of losses of travel time that result from investments in transportation facilities or regulatory actions and all cost-benefit and cost-effectiveness analyses prepared by DOT. The DOT guidelines have adopted a single measure of income and value of time applicable to all local personal travel across all transportation modes; however, for intercity travel, differences between modes are reflected. The values are based on the value of time literature, which indicated that besides transportation mode, trip purpose (business or personal), and income, a major source of variation in the value of time is distance, particularly the large differences between local and intercity trips. The review concluded that intercity travel time is likely to be more valuable than local travel time.

Table 2.4 summarizes the recommended values of time presented in the DOT guidelines. For all local personal travel, 50 percent of the wage rate is to be used regardless of the mode employed. Seventy percent of the wage rate is to be used for all intercity personal travel, and 100 percent of the wage rate (plus fringe benefits) is to be used for all local and intercity business travel, including travel by bus drivers. Hourly wage rates were developed from Bureau of the Census data and are also included in the table.

Additionally, the DOT guidelines recommend specific procedures for recognizing the uncertainty that characterizes empirical research in this area and, so that decision makers are aware their actions have a range of plausible outcomes, ranges of travel time values are specified in each category

TABLE 2.3 Research summary: business value of freight delay

Source	Approach	Findings
Watson et al. (1974)	Data for model derived from audit copies of freight bills	Shipper of large household appliances willing to pay $34.31 to reduce standard deviation of travel time by 1 day.
Winston (1981)	Revealed preference survey	Value of reducing standard deviation of transit time by 1 day estimated by probit model as follows: • Unregulated agriculture: $404 • Regulated agriculture: $4,110 • Stone, clay, and glass products: $3,244 • Primary and fabricated metals: $1,279
Wilson et al. (1986)	Revealed preference survey	Shippers willing to suffer an extra 1.3 days of transit time to reduce late shipments by 1%
Ogwude (1990, 1993)	Revealed preference survey	Firms willing to pay 1.6 Naira per ton to reduce standard deviation of transit time by 1 h for consumer goods; equivalent amount for capital goods is 0.6 Naira per ton
Abdelwahab and Sargious (1992)	Model based on commodity flow survey	$323/lb of shipment for each day of improvement in reliability Reliability is measured as number of days above average travel time on which 95% of arrival is achieved.
Richardson and Cuddon (1994)	Stated preference analysis	Reliability expressed as percentage difference between expected and maximum time. Findings indicate value of reliability for large trucks, which make longer trips and fewer trips relative to smaller trucks, was not significant. For small trucks, the willingness to pay for a 1% reduction in difference from expected travel time was $0.37.
Fowkes et al. (1991)	Stated preference survey	Increasing on-time deliveries by 5% was valued equivalently to a one-half day decrease in scheduled journey time.
Small et al. (1997)	Stated preference survey	Value of reduction of "schedule delay late" of $371.33 per h for composite of several industries. Transit time valued at $144–$193. However, sample size was small (20 surveys) and several parameter estimates provided counterintuitive results.

Source: NCHRP 2-18(2).

for sensitivity testing. The plausible ranges, presented in Table 2.3, reflect the degree of uncertainty in the empirical estimates and are useful in highlighting the implications of alternative assumptions.

Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation

This study focused on two aspects of travel time valuation: the premium placed on travel-time savings for passenger and freight transport during periods of congestion and the value placed on the predictability of travel times. The study used a stated preference survey methodology for measuring the effects of congestion on the values highway users place on travel-time savings and predictability.

With data from the stated preference passenger survey, separate models for calculating the impact of congestion on values of travel time and travel-time predictability were developed with logit choice estimation techniques. The value of travel time was stratified by annual household income, and the results indicated that income levels of $15,000 valued travel time at $2.64 an hour, income levels of $55,000 valued travel time at $5.34 an hour, and income levels of $95,000 valued travel time at $8.05 and hour. These findings were within the range found in the value of travel time literature but on the lower end of the range.

Implications

The value of time literature is extensive and has been thoroughly reviewed in several previous studies. The U.S. DOT recommendations are based on recent reviews of the academic literature and are a source of credible, accepted per-hour values. For this study, the U.S. DOT recommendations for percentage of wage rates are used in direct cost estimation and are applied to average wage rates reported by Bureau of Census.

TRAVEL TIME RELIABILITY AND NONRECURRING CONGESTION

Reliability refers to the degree of certainty and predictability in travel times on the transportation system. Reliable

TABLE 2.4 U.S. DOT recommended values of travel time for surface modes

	1995 $ Per Person-Hour			
Category	Percent of Wage Rate	Hourly Earnings Rate	Value of Travel Time	Plausible Ranges
Local Travel				
Personal	50%	$17.00	$8.50	$6.00 - $10.20
Business	100%	$18.80	$18.80	$15.00 - $22.60
All Purposes			$8.90	$6.40 - $10.70
Intercity Travel				
Personal	70%	$17.00	$11.90	$10.20 - $15.30
Business	100%	$18.80	$18.80	$15.00 - $22.60
All Purposes			$12.20	$10.40 - $15.70

Surface mode figures apply to all combinations of in-vehicle and other transit time. Walk access, waiting and transfer times should be valued at $17.00 per hour for personal travel and $18.80 per hour for business travel when actions affect only these elements of transit time.

Source: Office of the Secretary of Transportation, Guidance for the Valuation of Travel Time in Economic Analysis, U.S. DOT, April 1997.

transportation systems offer some assurance of attaining a given destination within a reasonable range of an expected time. An unreliable transportation system is subject to unexpected delays, incurring costs whose valuation and estimation are part of the focus of this study. Nonrecurring congestion is the principal source of this unreliability. Accidents, mechanical breakdowns, special events, and hazardous material spills are all sources of nonrecurring congestion on highway networks. Lindley found that freeway incidents accounted for 60 percent of total congestion on freeways and 52 percent on arterial roadways. Giuliano found similar results in a study of incidents in California. Research conducted in California indicates that truck accidents are responsible for about half of all nonrecurring congestion delays (Harris).

Reliability is often expressed statistically as the standard deviation from a mean travel time or route or as the coefficient of variation, the standard error divided by the mean. It is an appropriate measure of congestion at several levels of geographic specificity, including individual roadways, corridors, and areawide networks (TTI et al.).

Estimates of Incident Delay

TTI produced estimates of recurring congestion and incident costs for metropolitan areas in the United States (TTI 1996). In this work, incident delay is estimated by using ratios of incident delay to recurring delay developed by Lindley. The costs of incident delays are derived by applying an average cost of time, valued at $10.75 per h, to an estimate of daily hours of vehicle delay derived in part from demand and supply data available from the Highway Performance Monitoring System (HPMS). The ratio of incident to recurring delay ranges from a low of 0.4 to a high of 3.5. On average, nonrecurring delay is estimated to cause 1.5 as much delay as recurring delay, or 58 percent of total delay. This underscores the importance of nonrecurring delay and the potential cost-effectiveness of low-cost, low-tech measures such as freeway incident response teams to reduce the impact of these delays.

Sullivan and Taft (1995) have developed empirical relationships among a number of factors that contribute to the frequency, severity, and duration of freeway incidents. Values for these three parameters are estimated for seven aggregate incident types with different impact characteristics. These relationships formed the basis of the development of a freeway incident forecasting tool, known as *Impact*. Based on an analysis of incident data obtained from four major metropolitan areas, peak and off-peak incident rates are stratified by three separate average daily traffic/capacity ratios and seven types of incidents: abandoned, accidents, debris, mechanical/electrical, stalled, tire, and other. Total delays are also a function of the following:

- Lateral location of incident, based on averages developed from national data;
- Roadway capacity during and after the incident, with the values of reduced capacity associated with prevailing roadway geometry and incident type; and
- Accident durations, based on a model developed from national incident data.

The estimates of incident duration and capacity reductions are applied to a delay model that accounts for the buildup and dissipation of queues. Delays are estimated with a cumulative arrival equation.

COMSIS Corporation and SAIC applied sophisticated simulation tools to estimate vehicle delays resulting from accidents and incidents. With much of the data developed by Sullivan and Taft, microscopic simulation software was used to reestimate speed equations used in the HPMS analytical process (HPMS AP) to account for the average impacts of incidents. In this study, speed and delay impacts were estimated for both arterial and freeway sections. One unexpected finding from the analysis was that freeway capacity during a so-called transition period—the time when the queues caused by an incident are clearing—are higher at the point of the incident by nearly 7 percent. Behavioral factors and reduced headways are cited as causal factors for the increased capacity.

Behavioral Models Incorporating Reliability

Small et al. (1997) provide a summary of theoretical and empirical contributions to the development of behavioral models of travel time reliability. Numerous discrete choice models estimated with data collected from stated preference surveys find that reliability, as measured by the standard deviation of travel time or by other means, has a significant and negative coefficient, which implies that reliability is an important factor in travel choices. Reliability has been incorporated into several model formulations, including those estimating route choice (Abdel-Aty et al. 1994), mode choice (Benwell and Black 1984), and departure time choice (Small et al. 1995). Black and Towriss (1993) estimate values of travel time and reliability separately for users of different modes of travel, including the use of company cars.

Small and Noland (1995) present a cost model that accounts for scheduling costs in the face of travel time uncertainty as well as the cost of delayed arrivals for commuters:

$$EC = \alpha ET + \beta E(SDE) + \gamma E(SDL) + \Theta P_L$$

where *ET* is travel time, including congestion and incident delay time, *SDE* is schedule delay early, *SDL* is schedule delay late, and *D* is the probability of lateness. *SDE* and *SDL* are defined as schedule delay with respect to an official work start time.

These terms account for the costs associated with a decision to adjust departure times in the face of uncertain travel times. P_L is a penalty applied for late arrivals. Given a uniform and an exponential distribution for the incident delay time, the head start time or late start time that minimizes the expected cost of travel is calculated. With a uniform probability distribution for incident delay, the costs associated with incident delay (P_L) and schedule delay (*SDE*, *SDL*) are roughly equal. Under an assumption of exponential distribution of incident delay (which allows more short-duration incidents and fewer long-duration incidents), schedule delay assumes a much higher proportion of the expected total cost of travel time variability. Small et al. (1997) present alternative model specifications to account for different income levels and household compositions in NCHRP 2-18(2). Noland (1997) combined the model described above with a simple congestion model to estimate the impacts of congestion-reducing policies. His findings, which include the beneficial effects of scheduling, indicate that reducing travel time uncertainties may in some instances provide greater benefits than do increases in highway capacity.

Implications

Unpredictable delay is an important source of congestion that, in a policy sense, deserves explicit and separate consideration, as it cannot be addressed by conventional means. Numerous empirical studies have validated that premium travelers and the business community are willing to pay to avoid the costs of unreliability in the transportation system. These findings point to the need to include explicit consideration of the effects of changes to system reliability in the methodology developed here.

DEPARTURE TIME ADJUSTMENT

Forms of Travel Adjustment

There is also a literature on how some travelers try to adjust to highly congested conditions by shifting their time of travel. This is a notable element of the research literature, although it can be fully taken into account only for planning and analysis studied that distinguish travel times, speeds, and costs by time of day.

In general, travelers in increasingly congested urban areas try to minimize their exposure to congestion in a number of ways. Among the potential adjustments in the short run are changes to choice of route and choice of mode. If the cost of travel is large enough, the trip maker can choose not to make the trip at all or can satisfy the trip purpose through other means such as telecommuting, teleshopping, or chaining the trip with other, necessary travel (Cohen 1994). Particularly for nonwork travel, changes in choice of destination are possible as well. In the longer run, residents and businesses adjust by relocating, often well outside core urban areas. This is a factor that contributes to the reported stability of average travel times in some metropolitan areas (Gordon et al. 1989). Workers with some flexibility in their working arrangements may choose to work at home or at remote satellite locations with communications links to a main office.

Behavioral Models of Departure Time Choice

For many travelers, adjusting the time of departure is an effective and convenient short-term congestion avoidance strategy. As travelers with flexible schedules choose to move departure times out of the peak hour of travel in response to congestion, the percentage of total daily travel that occurs during the peak hours and peak periods of travel decreases. As a result, less-congested urban areas exhibit more sharply peaked travel characteristics; conversely, more congested areas exhibit less-peaked characteristics. Efforts to capture this adjustment through the development of behavioral models have focused largely on work travel, although some efforts have been made to examine nonwork travel as well (Luiz Senna 1994).

Behavioral models of departure time choice are not in widespread use in current modeling practice (Cambridge Systematics 1996a). However, considerable research has been conducted on the subject, and there have been limited attempts to implement empirically based behavioral models of departure time choice. One working model (Montgomery County Planning Department 1993) for personal travel uses a binomial logit formulation to obtain estimates of peak-hour trips from a matrix of peak-hour trips. The independent variable for this model is the ratio of congested travel time (derived from household surveys) to uncongested travel time (derived from travel time skims). Of course, other factors that are difficult to capture in revealed preference surveys affect the propensity to shift travel times, such as the following:

- Travel time flexibility for work and other trips (such as school trips),
- Hours of operation of the destination,
- Pricing differentials, and
- Availability of alternative routes and modes.

For the binomial logit model, two models are estimated, one for work and one for nonwork trips. The probability that a peak-period trip will occur in the peak hour is

$$P = \exp(B \times R_t)/[\exp(B \times R_t) + 1]$$

where

P = probability a trip will occur in the peak hour,
B = estimated model coefficient, and
R_t = congested/uncongested travel time ratio.

By using a household survey conducted for the Washington Metropolitan region, coefficients of –0.332 for work trips and –1.047 for nonwork trips were obtained.

A substantial body of work based on traveler observations is providing additional insights into commuter and general traveler behavior. Jou and Mahmassani (1995) indicated that variations in departure time are influenced by a number of factors, including tolerance for lateness at work, commuter's age, availability of flexible schedule options, travel time variability, and job status. Departure time switching was shown to be a more common response to congestion and travel time variability than route switching. The authors claim this result to be consistent with previous laboratory experiments and field studies. The study also found a city size effect, with respondents in the larger city in the study exhibiting a greater propensity for departure time shifts. It is plausible as well that employment composition plays a role in explaining the differences in departure choice behavior, with heterogeneous employment compositions exhibiting a greater propensity for greater flexibility in departure time choice.

Approaches to Schedule Flexibility in Travel Demand Models

Traditional four-step travel demand models have long used static time-of-day factors derived from surveys or traffic counts to produce estimates of traffic volumes by time of day. In one typical application, peak-hour factors are applied to estimates of trip tables and assigned to a traffic network. In another, a link-based directional and peak-hour factor is applied to individual links on a network after a daily trip table has been assigned. The main drawback of these approaches is that they cannot reflect peak spreading behavior in a systematic way, and they assume that current time of departure choices reflected in observed data will persist into the future (Cambridge Systematics 1995).

One application of link-based peak spreading models converts assigned peak-period traffic volumes to peak-hour volumes (Loudon et al. 1988). The model is applied at each iteration of a peak-period equilibrium traffic assignment, generating peak-hour trips used to produce revised link travel times via a peak-hour speed model.

The form for this model is

$$P = 1/(3 + ae^{b(\mathrm{V/C})})$$

where

P = ratio of peak-hour volume to peak-period (3-h) volume,
V/C = V/C ratio for the 3-h period, and
a, b = model parameters estimated for each facility type.

The peaking factor function was estimated with time series and/or cross-sectional vehicle count data. As each link is considered, in turn, during the equilibrium assignment's travel time updating, peaking factors representing the ratio of peak-hour volume to peak-period volume are computed by using a decreasing function of the link 3-h V/C ratio. This model was applied in the Phoenix area model and resulted in a much closer match to average speeds and VMT than had previously been obtained.

One limitation of this approach is that continuity of flow on contiguous links is not guaranteed. A second drawback of link-level peak-spreading models in general is that they may not reflect upstream impacts of specific congestion points or general perceptions of congestion affecting travel behavior throughout a particular corridor.

Trip-Based Peak Spreading

Several techniques for applying peak-hour factors to travel matrices have been developed. These approaches have the advantage of selective application to particular matrix interchanges or trip purposes and can reflect behavioral adjustments to congestion considering the entire trip, as do the mode split and trip distribution models.

Rossi et al. (1990) developed a procedure to factor individual matrix interchanges according to congestion levels in particular corridors. With an assignment of daily to peak-hour trip tables from static factors derived from base year information, forecast link volumes above estimated maximum volumes are identified. A set of column and row totals that would reduce these link volumes is estimated. By using a selective iterative matrix adjustment method, the trip table is adjusted to match these totals. This approach provides realistic volumes for peak-hour assignments. The matrix column and row totals used as the basis for factoring the trip table and generated exogenously must be carefully considered, as they have a direct effect on the resulting assigned volumes.

Matrix-Based Peak Spreading Model

Allen and Schultz (1996) describe a congestion-based peak spreading model for a regional travel demand estimation. This model estimates the percentage of morning peak-period vehicle trips that occur in the peak hour. The resulting peak-hour factors are applied to daily trip tables for each trip purpose.

The model consists of a series of stepwise linear functions stratified by trip distance, trip purpose, and congestion, defined as the difference between free-flow and congestion travel time between origins and destinations. Through an analysis of the 1988 Washington home interview survey, the authors found that trip distance and congestion strongly influence total peak-hour vehicle hours of travel. With this survey, curves were developed for six separate trip purposes, including home-based work, home-based other, non-home-based to work, non-home-based at work, non-home-based at work, and non-home-based nonwork. The peak spreading model is applied to each cell of the morning peak-period vehicle matrix.

Analysis results indicate the following:

- Shorter work trips tend to have higher peaking than longer work trips. The peak-hour share of very long trips appears not to be greatly affected by congestion, whereas very short trips tend to be most sensitive to congestion.
- Other trips that are *not* commuting to work tend to be more sensitive to congestion than home-based work trips.

A model developed to estimate the traveler impacts of intelligent transportation systems (ITS) technologies allocates hourly trips in the peak period in an iterative fashion to ensure consistency between output volumes and speeds (Volpe 1996). This approach alters assigned volumes across the peak period based on congestion levels; the resulting speeds are used to reestimate automobile demand iteratively. It assumes the temporal response to congestion can be modeled on a systemwide basis because the ITS technologies impart a consistently valuable amount of travel information across the regional transportation system.

In this approach, static peaking factors are first assigned to peak-period trip tables; the resulting peak-hour demand is assigned to the highway network. Microsimulation models use the assigned volumes to obtain a better estimate of traffic speeds. The revised speeds are then reinput to the travel demand model. Oversaturated links are identified (those with $V/C > 1.1$). For these links and for each of the peak-hour assignments, a measure of normalized excess congestion is computed.

This approach focuses on impacts to individual facilities, although a single adjustment is applied to the system. It does not distinguish among trip purposes or between on-the-clock and personal travel. Users have the option of allowing trips to adjust over the first two hourly periods of the peak, reflecting more fixed arrival times or allowing adjustments over the last 2 h of the peak.

Implications

Departure time choice is one of the most readily available congestion-avoidance mechanisms available to transportation system users. The ability to change departure time varies by travel market and varies within travel markets as well. Although the transportation system as a whole benefits from such adjustments, it does impose a cost to the traveler.

Unfortunately, application of this literature to the current study of the economic impacts of congestion is very limited. Essentially, all the studies have focused on passenger car travel, instead of business deliveries. In general, we expect that deliveries of goods and services are significantly constrained by business operating hours, which makes them particularly susceptible to peak-period congestion and also most likely to bear additional costs associated with any peak-period limitations on truck movements. Among the categories of worker commuting, we also expect that occupations associated with manufacturing, retail, and service businesses are most constrained by normal business operating hours, whereas research and back-office jobs are more easily able to adjust to flexible work hours. Although the current literature provides limited insight into these issues, it remains important to examine differences in the cost of congestion among occupations and industries in empirical research studies.

CHAPTER 3

MEASURING NONUSER COSTS OF CONGESTION: LITERATURE REVIEW

This chapter examines and reviews existing research concerning the economic costs of congestion beyond the direct value of traveler time and vehicle operating costs. It covers additional business costs and income effects relating to customer and workforce market access, logistics, scheduling [just-in-time (JIT)], and overall business productivity.

CLASSIFYING BUSINESS COSTS OF CONGESTION

Differentiating Full Economic Value from Traditional User Valuation

The traditional measure of travel time value is based primarily on consideration of wage rates and imputed level of travelers' willingness to pay for time savings in their travel (mode/destination/route) choice decisions. It is based on consumer behavior theory (Small 1992), and the derived values reflect the choices individual travelers are observed to make in their travel choices (Kruesi 1997; Miller 1996). However, there is also a growing body of research indicating that the full cost businesses bear as a result of travel time delay can be substantially more than the marginal value of predicted time delay for the traveler.

Business Production/Delivery Costs

The literature indicates that additional elements of business costs of travel delay include logistic costs associated with production process and delivery costs as well as costs of reduced-scale economies associated with reduced access to diverse markets and suppliers (Evers 1988; Weisbrod and Treyz 1998). That defines the direct economic costs of congestion in terms of three broad classes of factors:

1. Travel expense. There can be an increased cost of producing the delivered product (at current output levels) due to increased vehicle and driver operating expenses (given no change from existing origin-destination patterns and activity levels for supplier shipments, product deliveries to buyers, and employee commuting). This represents the traditional measure of user cost discussed in Chapter 2.
2. Logistics and JIT processing costs. There can be a further increase in the cost of producing delivered product (at current output levels) due to increased inventory costs required to account for transportation bottlenecks and delivery uncertainty (affecting supplier speed, frequency and reliability of deliveries, and ability of firms to achieve economies from JIT production processes) (McCann 1993).
3. Market scale and accessibility costs. There can also be a decrease in demand and hence output for current production facilities due to a reduced market area, with resulting higher unit costs due to reduced-scale inefficiencies (in production and delivery) and reduced access to specialized inputs (Ciccone and Hall, 1996; Treyz and Bumgardner 1996).
4. Business cost of worker commuting. There can also be an increased business cost of labor associated with increased wage rates to attract and compensate workers for their higher commuting costs (Madden 1985; Zax 1991).

Driver Cost Versus Full Business Costs

Other related studies also indicate the importance of the above-cited logistic and scale factors. For instance, a recent study of the route choice behavior of urban goods delivery truck drivers (Beaton and Meghdir 1997) found a substantial difference in the value of time between truck drivers who are independent operators (and hence internalize the full business costs of their delays) and truck drivers who are paid an hourly wage. The former had a substantially higher willingness to pay tolls in order to avoid delay. Those study results reinforce the importance of distinguishing between types of deliveries and types of drivers to capture the full value of delay to business.

Business Adjustment Costs

Another important line of research concerns adjustment time for responses to changes in travel conditions. For instance, a study by Gunn (1997) points out that metropolitan transportation planning models implicitly assume that people respond to changes in travel conditions by changing travel routes, modes, and even workplaces; businesses also respond by changing delivery routes. His study provides data indicating that, in reality, such adjustments may take years to occur, and in the interim travelers (businesses as well as individuals) bear greater costs while planners see less beneficial results than are commonly forecasted. An implication is that actual business costs may be greater than that forecast under equilibrium conditions as assumed in travel demand models.

Definition of Productivity

Economic texts define productivity as the ratio (total business output)/(weighted average cost of business inputs), where business output is defined in terms of dollars of business sales and business inputs are defined to include costs of obtaining labor, equipment, supplies, transportation, and other services. In general, congestion delays can affect productivity in three ways: by increasing business costs of current delivery operations, by limiting or reducing business sales through a reduction in effective market size, and by increasing unit costs through loss of opportunities for scale economies in production and delivery processes. These happen as a result of logistic and scale factors previously discussed (Evers 1988; McCann 1993; Ciccone and Hall 1996; Treyz and Bumgardner 1996).

Implications

The literature on business costs and productivity clearly indicates that businesses incur costs associated with transporting goods and people that are beyond the direct personal value of driver time and direct operating cost. These can be examined in terms of overall productivity measures, which in theory encompass the net effect of all such costs. Alternatively, they can be examined in terms of their primary components:

- Market access costs,
- Logistics costs,
- Production scheduling (JIT processing) costs, and
- Overall productivity.

All these cost impacts can differ by industry, by location, and by specific economic market served. The following sections discuss the literature on these various aspects of business cost.

LOGISTIC COSTS

Product Value

Modern logistics are described most notably in reports by McCann (1993, 1996). He notes that the total logistics costs include the cost of ordering and inventory costs as well as direct transportation costs associated with both the use of inputs and the supply of final output. Thus, whereas simplistic models of spatial accessibility (which consider only direct shipping cost) tend to predict that firms using heavy and bulky goods will be located close to the supplier or market, total logistics cost considerations lead to a different solution in which the value of goods shipped and the ability to store goods are also important business costs and location factors. Because inventory holding costs are a significant part of total production costs, the value of inputs and outputs can determine the location of the producer as well as the wage and rent the producer is willing to pay at a given location.

Mode Choice and Shipping Frequency

In the logistics literature (McCann 1993), a key aspect of business decision making is the logistics-cost location production problem, which requires producers to trade off the cost of acquiring and transporting goods against the cost of holding inventory in selecting the optimal shipment frequency and model choice. In this context, transportation options such as truck, rail, and ship are viewed as offering a trade-off between costs per unit and frequency of trips. Whereas a large shipment of goods from one site to another may provide relatively lower average costs than would occur with smaller shipments, the reduced frequency of shipments may be an overall disadvantage to the firm. Because inventory costs are significant for many industries, the production location, transportation mode, and shipment frequency are interconnected decisions faced by manufacturers. Cost savings associated with JIT processing is just one example of such logistic cost considerations.

Concept of Time-Based Competition

A separate literature on time-based competition discusses how speed and reliability of product delivery have become increasingly important factors in business success. Blackburn (1991) notes that the nature of this time-based competition differs in each industry. In service industries (including health care and financial services), the ability to directly serve customers quickly has become an important competitive factor. In wholesale trade and telephone-order retail, the ability to deliver products to buyers quickly (for example, within 24 hours or less) has become a critical competitive factor. In manufacturing processes, JIT techniques have increasingly been adopted as a means of raising productivity and lowering costs for manufacturing. A recent survey of procurement professionals by *Purchasing* magazine found that 57 percent reported management emphasis on improved delivery performance (Cruz 1996).

JIT PRODUCTION COSTS

Time-sensitive manufacturing and delivery systems such as JIT systems are designed to improve productivity and increase profits. JIT systems rely on tightly scheduled and frequent deliveries of supplies and parts to reduce warehousing and inventory needs, thereby reducing production costs. Although many firms have embraced JIT techniques and have benefited from them, unreliability in the transportation network, if severe enough, can impose significant costs. Congestion increases transport times and costs; perhaps more important, it also introduces a measure of uncertainty in pickup and delivery operations. At a minimum, nonrecurring congestion imposes opportunity costs on producers as they take measures to protect themselves from the possibilities of missed deliveries and production deadlines.

Rao and Grenoble (1991) cite several potential long- and short-term strategies to reduce or eliminate the effects of congestion on the firm's operation. Fifteen logistics managers in selected manufacturing companies with facilities in congested metropolitan areas were asked to rate potential long- and short-term congestion mitigation strategies. The managers gave the highest ratings to off-peak deliveries, palletization and consolidation shipments, computer routing, price and preference incentives to shippers for improved performance, improved truck design, and speed delivery administration. The survey, conducted in 1989, found that logistics managers did not consider traffic congestion to be a significant impediment to their logistics operations; however, they did acknowledge the potential for congestion to become a significant problem in the future.

Although shippers and receivers appear to have means available to them to adjust to congestion, they nonetheless place a high value on reliable service. Small et al. (1997) cite shipper and carrier surveys indicating reliability or dependability of service one of the most significant factors in the choice of carrier or mode.

The authors discuss a range of long-term responses to congestion that are worth noting here. These include changes in facility location, establishment of intermediate handling facilities, development of closer working relationships between suppliers and customers, use of automatic vehicle identification systems, satellite and computer tracking, and other technologies and changes in buying patterns, such as favoring distributors over component manufacturers.

Estimating Congestion Impacts on JIT Operations

Typically, the benefits of highway improvements to firms engaged in JIT operations are not explicitly included in traditional cost-benefit analysis (Forkenbrock et al. 1996). Forkenbrock et al. propose a methodology for estimating logistical cost savings that expands the set of factors considered in typical highway analyses to include labor, inventory, and operating costs. This approach is easily adapted into the highway user-cost framework. The approach explicitly considers holding cost, in-transit inventory costs, safety stock carrying costs, and capital depreciation costs. The information requirements for measuring these cost components far exceed what is usually available to a typical planning agency and require the use of roadside surveys.

Literature on JIT manufacturing notes that this approach spans all aspects of the production process, including product development, setup, manufacturing, inventory, and delivery (Voss 1989; Satir 1991; Blackburn 1991). It does not affect only manufacturing plants, because it puts flexibility, speed, and reliability requirements on suppliers of input parts and services and on the transportation services that deliver them. For transportation and logistics planners, a key aspect of JIT is its implications for increasing demands on scheduling frequency and reliability of shipments. A variety of studies have documented the productivity and cost savings associated with JIT for manufacturing firms; the resulting savings are found to range from 2 to 30 percent for overall operations costs and from 30 to 84 percent for specific categories of space, labor, and inventory costs [see studies described in Voss (1987), Couvrette (1991), and Stuart (1993)].

There are two general sets of questions concerning the relationship between JIT and highway congestion: (*a*) Does adoption of JIT in the United States increase highway congestion? (*b*) Is highway congestion an impediment to adoption of JIT in the United States?

The first question relates to the effect of JIT on highway usage. The literature is consistent in noting that JIT leads to more frequent (but smaller) shipments (Voss 1987). A recent extensive survey of manufacturers who use JIT methods found that introduction of JIT methods increased deliveries by a factor of two and decreased the size of deliveries by about half (Minahan 1996). However, other studies note a countertrend toward firms streamlining deliveries and supply networks and eliminating redundant and overlapping suppliers. Recent studies indicate that purchases, particularly in maintenance, repair, and operations, may provide an easy target for cost-cutting measures within many companies. One recent study concluded that manufacturing companies in the United States place too many orders and work with more suppliers than necessary (Cruz 1996). In the future, then, we might expect reductions in some types of small-order deliveries.

The second question concerns the effect of congestion on the ability of firms to implement JIT methods, which require predictable deliveries of supplies. Here, it is important to distinguish among business sectors. The literature confirms that business sectors in which goods are perishable, costly, or difficult to warehouse; high value; or subject to rapid changes in value are most sensitive to transport reliability (Blackburn 1991). For example, retail sellers of foods and other perishable items must use costly transport methods and cannot always stockpile goods in case of delays in incoming or outgoing deliveries. Firms that produce high-tech and electronic goods face similar problems; because of rapid changes in the value of inventory, these firms and their suppliers attempt to minimize inventory levels and hence are more sensitive to the cost of delivery delays. Firms such as Federal Express and UPS, which serve these time-sensitive industries, have been locating many of their facilities outside major cities and major commercial airports specifically to better serve market demand by avoiding congestion.

Where adoption of JIT has led to increasingly complex supply logistics, some firms have responded with changes in transportation logistics—including outsourcing of supply logistics and use of local warehouses that store supplies shipped from outside the immediate region—that minimize the potential for interference from congestion problems (Minahan 1997). Finally, although delivery turnaround times have dropped dramatically in the past few years—a trend partly due to JIT—there is still relatively little reliance on same-day deliveries. A recent survey indicated that only 5 percent of purchasing departments at U.S. firms expect same-day delivery on orders and that only about one-third say the optimum delivery cycle time is 1 week or less (Cruz 1997).

A factor that further complicates the JIT-transportation relationship is that, with maturation, JIT is spawning variants that involve less reliance on transportation. Minahan (1996) describes JIT III arrangements, which emphasize colocation of suppliers and assemblers, with suppliers locating close to and in some cases across the street from assemblers. Thus, it appears that there may be a trend among U.S. producers toward fewer deliveries, a change that would reduce the importance of congestion issues, and a specific trend among JIT III adherents to rely less on highways for meeting delivery schedules. This does not necessarily mean congestion issues will become less important to U.S. firms, including those that practice JIT, but only that increased use of highways predicted by JIT theories may be partially offset by other changes in American business practices. A summary of findings on production cost savings associated with implementation of JIT processing is presented in Table 3.1.

Implications

In considering the effects of congestion on logistics costs for businesses, it is important to recognize differences among

TABLE 3.1 Summary of economic benefits of JIT

Economic Benefit	Sector	Firm	Reduction	Source
I. Productivity Measures				
Productivity	Paper products	Hunt Bienfang	- 2%	Reported in Stuart, 1993 (p.78)
Productivity	Foam-board	Hunt Bienfang	+ 6%	Reported in Stuart, 1993 (p.78)
Overall		Lucas	+35%	C.A. Voss (1987); preface
II. Manufacturing Costs				
Total manufacturing cost	Captive plate shop	N.A.	-30%	Couvrette, *et al.* 1991, p. 282
Scrap/rework $	Paper products	Hunt Bienfang	-12%	Reported in Stuart, 1993 (p.78)
Scrap/rework $	Foam-board	Hunt Bienfang	-27%	Reported in Stuart, 1993 (p.78)
Direct Labor Usage		Ford	-33%	C.A. Voss (1987); preface
III. Inventory Reduction				
Work-in-progress	Lucas		84%	C.A. Voss (1987); preface
Work-in-progress	Lucas		99%	C.A. Voss (1987); preface
Inventory reduction		Hewlett-Packard	20%	C.A. Voss (1987); preface
Inventory reduction		Repco	$20M	C.A. Voss (1987); preface
Total inventory	Printed circuit boards	N.A.	40%	Fisher and Roe (1991), p.319
Finished goods inventory	Heating equip	Baxi Heating	5 to 2 weeks	Cahill (1987), p. 227
IV. Space Requirements				
Overall space		Hewlett-Packard	-46%	C.A. Voss (1987); preface
Overall space		Rank Xerox	-30%	C.A. Voss (1987); preface
Overall space	Captive plate shop	N.A.	-40%	Couvrette, *et al.*,1991), p.282
Production space	Paper products	Hunt Bienfang	-30%	Stuart, 1993 (p.78)
V. Set-up Time Reductions				
Set-up time		Sumitomo	60 to 5 min	C.A. Voss (1987); preface
Set-up time		Lucas	30 to 5 min	C.A. Voss (1987); preface
VI. Investment				
Number of fork-lift trucks		Lucas	-52%	C.A. Voss (1987); preface
Number of M/C tools		John Deere	-25%	C.A. Voss (1987); preface
Facility Investment		Ford	-30%	Perkey (1987), p. 390
VII. Cycle/Lead Times				
Lead time		Lucas	5 day to 5 hrs	C.A. Voss (1987); preface
Lead time		John Deere	84%	C.A. Voss (1987); preface
Cycle time	Printed circuit boards	Texas Instruments	41 to 7 days	Fisher and Roe (1991), p.319
Throughput time	Heating equipment	Baxi Heating	5 day to 1.5 hr	C.A. Voss (1989); p. 227
VIII. Other Benefits				
Solder rejects		Hewlett-Packard	5000 to 20 ppm	C.A. Voss(1987); preface
Flexibility		Lucas	increased	C.A. Voss (1987); preface
Build credibility		Navistar International	85% to 97.5%	C.A. Voss 1987); preface
Cost of quality	Foam-board	Hunt Bienfang	-30%	Reported in Stuart, 1993 (p.78)
Supplier defects	Foam-board	Hunt Bienfang	-63%	Reported in Stuart, 1993 (p.78)

industries in the value of products, the degree of delivery frequency and scheduling flexibility, and the extent of shifting trends in production processes. It is also noteworthy that the logistics effects of transportation delays are all above and beyond the business supplier accessibility effects previously discussed.

MARKET SCALE AND ACCESSIBILITY IMPACTS

Productivity and Accessibility

Empirical studies (McConnell and Schwab 1990) confirm the value of agglomeration economies and accessibility factors through business location preferences. The importance of this literature is that it implies that congestion along specific routes—and highway projects to alleviate that congestion—can have an important spatial location characteristic insofar as it can affect the size of the market reach for businesses. With better accessibility, businesses can potentially realize economies of scale in serving broader markets. In addition, highway system improvements can also provide businesses with access to a greater variety of specialized labor skills and specialized input products, which can also help them become more productive (Evers et al. 1988).

Modeling of Trade Flows

A long line of trade and economic geography modeling links transportation accessibility and business productivity. The most notable of these studies, which trace back to Krugman (1979, 1995), use estimates of transportation costs and accessibility to differentiated inputs as a basis for explaining wide differences in regional productivity. Key aspects of these studies are the concepts that firms each produce a slightly differentiated product and there are potential scale economies in their production functions. Therefore, changes in accessibility will affect the scale of market demand and unit costs of products. This modeling framework has been most extensively applied in the area of international trade (Harris 1984; Deardoff and Stern 1986; Brown and Stern 1987).

Similar approaches based on transportation networks and differentiated labor and intermediate inputs have more recently become widespread in the regional and urban literature (Fujita et al. 1985; Fujita 1988, 1989; Ciccone and Hall 1996). Treyz and Bumgardner (1996) use these model approaches to demonstrate the role of accessibility in explaining county market shares and business location patterns for legal services in Michigan. That approach also indicates how it is possible to model flows of goods and services within states based on accessibility measures, and it provides a basis for identifying and measuring the value of accessibility improvements to industries (Weisbrod and Treyz 1998).

Another line of research has used survey data to document how spatial patterns of supplier-buyer shipments differ by industry. The implication of these studies is that accessibility improvements to specific corridors may benefit some industries much more than others, depending on the dominant direction of shipments in a given industry and the specific corridor direction of the proposed improvements (Weisbrod and Beckwith 1992; Black and Palmer 1993; Bernardin-Lochmueller 1997).

Agglomeration and Productivity Benefits of Accessibility

The importance of accessibility and market sizes in affecting business productivity becomes apparent through studies that look at the existence of major differences in productivity among locations. Industrial and urban agglomerations, with their greater accessibility, are found to provide high levels of productivity, presumably because businesses are able to gain access to a wider variety of labor skills and specific product inputs. The greater the variety of labor skills and input products available, the more likely it is that there is a specialized worker or input available that can minimize business costs. Accordingly, improvements in the transportation system are seen as a way to increase producers' access to specialized inputs (Fujita 1989; Krugman 1995; Ciccone and Hall 1996).

These studies on accessibility and market sizes also predict and explain the urban and regional location patterns of businesses based on the assumption that businesses locate where they can maximize net income (profits) and stay away from locations where they lose money or realize less net income. That urban geography literature thus also provides an important explanation for why interviews of existing businesses have failed to isolate the business impacts of congestion (Cambridge Systematics 1993). After all, in the long run businesses tend to locate and survive only in those locations that maximize net income, and they tend to stay away or move out of locations that lose money or provide insufficient return. As a result, businesses that locate and remain viable in a given location tend to be those that either operate in specific areas or serve specific markets that are less affected by traffic congestion problems or have already adjusted the nature of their operations and customer markets to mitigate the cost of traffic congestion to them. In those situations, the real economic cost of congestion is the loss of business activities, scale economies, and associated income that otherwise would have existed without traffic congestion. Although the workers at remaining businesses may not see those effects, the above-cited accessibility models can (and do) estimate them on the basis of the location pattern of businesses and the sizes of the markets they serve.

Recent research by Brakman et al. (1996) has extended this model of urban geography to indicate how congestion affects the economy. Their study showed that congestion represents a form of negative feedback, causing instability in urban centers and causing firms that would normally agglomerate there to relocated to the periphery. This effect explains the existence of small yet viable industrial clusters outside of (congested) big cities, as businesses trade off scale economies and market size against transportation costs. The implications of new congestion include productivity reduction, firm relocations, wage reductions, and requirements for some of the labor force to relocate.

Implications

The literature on accessibility offers a critical theoretical component for explaining how congestion affects business costs in urban areas. Although it explains the higher productivity observed in business and population agglomerations, it also offers an explanation of how rising congestion can effectively offset those advantages and decrease accessibility of businesses to supplies and markets. However, accessibility and scale economies are only part of the total impacts of congestion. Logistic factors must also be taken into account.

BUSINESS COST OF WORKER COMMUTING

Theory of Capitalized Commuting Costs

A long series of studies of metropolitan location patterns have examined how variation in location prices explain the spatial pattern of economic activities in an urban area (Moses 1962; Muth 1969; Mills 1972; White 1976). According to these theoretical models, it is logically expected that households and people pay more money for housing with lower commuting costs, and businesses tend to compensate workers for higher commuting expenses.

Wage Rate Variation Within Metropolitan Areas

Most empirical research on the connection between wage rates and accessibility has been more recent. In a study of municipal workers located in communities throughout the Chicago area, Eberts (1981) found statistical evidence of a negative relationship between wage rates and distance from the central business district. Using a nationwide study of people who recently changed homes or jobs, Madden (1985) assembled information on wages, occupations, and home-to-work distance and found strong statistical evidence that people who change jobs do effectively trade off commuting cost against wages—that is, they get higher pay when commuting costs are also higher. (His study also confirmed that wages are systematically lower in suburban jobs, where housing prices are also lower.) White (1988) subsequently derived a functional form of the wage gradient, which allowed for a value of leisure time as well as commuting time to affect wage rates. DeSalvo and Huq (1996) showed how wage rates should also differ depending on public transit availability and dependency within an urban area.

The most complete empirical study that tried to combine information on housing prices, wages, and commuting travel times was conducted by Zax (1991). He obtained private business payroll data in Detroit and matched it to worker locations by census tract (to obtain housing data) and by transportation analysis zone (to obtain travel time data) for the Detroit area. Regression equations were run to statistically estimate the relationship between wage rates and commuting travel times, controlling for housing quality, occupation, race, and education. The findings strongly confirmed that employers paid higher wages to compensate for higher commuting travel times. The relationship was greatest for men in white collar jobs, for which the commuting time wage differential (in terms of dollars per hour of additional commuting time) was twice the value of time reflected in the average wage rate.

Zax interpreted the commuting time wage differential as reflecting not only the incremental value of time spent commuting but also the value of additional out-of-pocket expense, lost leisure time, and added commuting hassle. A much lower commuting time wage differential was found for women (just one-fifth of the median wage), which was interpreted as reflecting the greater dominance of clerical jobs and a more constrained set of job choices for them. Of particular importance was the additional finding that workers who paid more for their housing also received significantly more compensation for their commuting times. That is fully consistent with the previously discussed trade-off in housing value and wage rates.

Overall, the findings to date suggest that it may be reasonable to expect no commuting time effect on wages outside of metropolitan areas and an effect within metropolitan areas that is slightly less than the full value of time reflected in wage rates (for example, in the range of one-half to two-thirds the wage rate). This level of wage rate premium more than offsets the direct increment in vehicle operating cost for commuting, so no further impact on disposable income is normally expected. The findings also imply that "labor market power may help determine the extent to which workers can shift the burden of commuting expenses onto their employers" (Zax 1991, p. 205). The implication is that the effect of commuting travel time on wages is greatest for skilled white collar jobs in large urban areas, and it can be much smaller for lower skilled jobs and for jobs outside major urban areas.

Implications

The results of studies to date lead to the conclusion that wages paid by employers to their employees differ by location and tend to reflect the extent to which workers incur greater costs and travel times for commuting to their jobs. Thus, a foundation of evidence suggests that businesses incur higher labor costs associated with increasing congestion.

OVERALL PRODUCTIVITY IMPACTS

Focus on Historical Output/Spending Relationships

A line of economic research has focused on how levels of spending on improving highway flows has ultimately affected private sector productivity (level of output per dollar of inputs) and hence generated income. This research has been summarized in several documents (Nadiri and Mamuneas 1996; Madrick 1996; Sturm et al. 1997). Basically, this research has used aggregate-level data to calibrate cost models or production models. Note that the difference between the two methods is that the cost function method evaluates productivity changes in terms of cost changes under a given level of output, and the production function method evaluates productivity changes in terms of shifts in output in response to cost changes cost models. [For further information about this, see FHWA (1992).] Coefficients from the cost or production function models are then used to provide estimates of the private sector business performance (sales and gross domestic product) associated with highway investment.

An advantage of this approach is that it yields estimates of overall effects on various types of business. A major limitation of this approach is that it uses historical data to calibrate models that relate productivity increases to levels of highway inventory instead of to actual accessibility improvements. As a result, the productivity factors represent average effects of past spending on the economic performance of various industries and regions. However, a recent FHWA-sponsored study of establishment-level productivity (Eberts 1997) is seeking to develop measures of localized productivity effects linked to changes in highway accessibility instead of levels of highway inventory.

Differential Business Response Elasticities

Productivity analysis is an area of ongoing research in which new and more useful results are still emerging. Although initial work in this area was done by Aschauer (1989), some of the most useful available information is the more recent research findings on how business benefits of highway spending (increasing the value of highway inventory) vary by state/region (Duffy-Deno and Eberts 1991; Dalenberg and Eberts 1992) and by business type (Nadiri 1996). These studies provide estimates of the marginal benefit to business per dollar of highway capital. In both cases, highway capital is defined as the depreciated value of accumulated highway investment, and marginal benefit is defined as the sum the private sector (businesses) would be willing to pay for an additional dollar of highway capital.

The two Eberts studies indicate substantial differences by metropolitan area, which is presumed to reflect differences in existing highway systems and business characteristics of the local economy. The Nadiri study indicates substantial differences by two-digit standard industrial classification group. In general, the marginal benefit is found to be greatest for manufacturing industries such as wood, chemical, and metal products as well as machinery and motor vehicles.

Findings on Aggregate Studies of Highway Investment and Productivity Benefits

In general, the consensus findings to date have been that there is a positive relationship of increasing business output levels to capital spending on transportation infrastructure. The relationship of (percent output)/(percent public capital) is generally found to be in the range of 0.2–0.4 at the national level, around 0.15 at regional and state levels, and as low as 0.04 at metropolitan area levels (Aschauer 1989; Munnel 1990; Dalenberg and Eberts 1992; Toen-Gout and Van Sinderen 1994). A related and more recent line of research, focusing on cost functions, has also confirmed that spending on highway infrastructure has led to reduced cost and hence greater productivity (Nadiri and Mamuneas 1996). The economic effect of transportation infrastructure spending appears to be lower for smaller geographic areas because many of the network interconnection benefits and broad area benefits to businesses are outside their study areas. These effects are captured in the analyses of larger, national studies of productivity effects.

Overall, Nadiri and Mamuneas (1996) report that the marginal value of benefits to industry over the 1950–1989 period has averaged $0.23 per year for each dollar of accumulated capital stock of highways. However, the benefit of highway spending in the past decade has been more modest than in the early decades, presumably because more recent projects have been aimed at enhancing connections for the national highway system and earlier-year expenditures were building the basic interstate system. As a result, the most recent data indicate that the marginal benefit from nonlocal highway capital has been slightly less than half the 40-year average.

Uses and Limitations of Aggregate Productivity Research

In theory, the measurement of aggregate productivity effects should reflect the net business benefit of all three of the previously noted types of productivity effects. However, there are also limitations associated with this line of research when used in isolation (Weisbrod and Grovak 1997). Most serious are the data limitations that have necessitated very aggregate-level analyses focusing on impacts of overall transportation or highway capital spending, without the ability to distinguish how productivity effects can differ depending on the type of highway system improvement, intensity of highway use, or level of congestion. As a result, it is uncertain whether the average benefits to productivity associated with past spending will necessarily be a good predictor of the marginal benefits to productivity from future spending to reduce congestion.

For purposes of estimating congestion impacts, such additional information on accessibility impacts can be important.

Alternative Approach of Linking Logistic and Access Factors to Overall Economic Growth

An alternative to the aggregate analysis approach to productivity estimation is a more micro-scale analysis, which examines how changes in logistic and scale/accessibility factors can also affect a region's cost competitiveness and comparative advantage of an area for attracting and retaining business (Evers et al. 1987). As a result, regional macro-economic simulation models have been applied to estimate the economic impact of transportation projects on regional competitiveness and shares of national economic growth. These include a regional model applied for areas within the Netherlands (Evers et al. 1987) and the REMI regional model for areas within the United States (Treyz 1992). In general, these models allow us to estimate effects on cost competitiveness of business, cost of living, and shift in business growth and location factors over time. The REMI economic model has been applied in many states, including Wisconsin, Indiana, and Iowa (Cambridge Systematics 1989, 1996b; Wilbur Smith Associates 1992).

As noted by Weisbrod and Grovak (1997), this type of analysis provides a means of accounting for transportation effects of cost savings, productivity enhancement, and market growth (scale economies) and their impacts on business expansion, competitiveness, and attraction of economic activity from elsewhere. That means that, with sufficient external analysis of spatial factors (such as logistic and market scale economies), this type of analysis can account for the business value of transportation system improvements. However, this type of analysis accounts for only private sector effects and places no value on activities of individuals that do not involve the exchange of money.

CHAPTER **4**

FRAMEWORK FOR MEASURING ECONOMIC COSTS OF CONGESTION

This chapter describes a framework and a methodology for estimating the changes in economic costs associated with congestion reductions or increases. The framework builds on findings from prior research (discussed in Chapters 2 and 3). It is based on a classification of five basic classes of trips, which are affected differently by congestion, and three general types of costs that are incurred because of congestion. The methodology builds on the characteristics of available data for metropolitan areas. It is based on a six-step process, with a statistical analysis to assess how businesses trade off labor and capital costs to adjust for congestion. The result is a measurement of the net cost impacts of congestion on business activity.

CLASSES OF TRIPS AFFECTED BY CONGESTION

It is first useful to identify five general classes of trips, which are differentially affected by congestion. The way each class of trips is affected by congestion is noted, based on findings from the Chapter 3 literature review.

Category 1: Commuting (Home-Work Car Trips)

Although the commuter absorbs the travel time and expense associated with congestion, the literature indicates that employers in competitive urban labor markets end up compensating workers for differentials in commuting costs. Thus, businesses (employers) end up absorbing excess congestion costs associated with commuting trips. Because essentially all commuting trips have origins and destinations within the region (metropolitan labor market), these trips are usually captured by regional travel data.

Category 2: Regional Freight Delivery (Work-to-Work Internal Truck Trips)

Associated with truck trips are vehicle operating costs, driver wages, and additional costs of travel time and variability associated with inventory, logistics, and just-in-time production processes. These are all components of total business product costs.

Category 3: Interregional Freight Delivery (Work-to-Work External Truck Trips)

A significant share of goods deliveries are truck movements with origins or destinations outside the region. Those trips are subject to the same classes of costs (for vehicle, driver, time variability, logistics, inventory, and production). However, trip lengths must be measured with data sets that extend beyond the region (for example, national commodity flow survey data) and must be adjusted for the fact that the relative impact of congestion on total travel cost is smaller for longer-distance trips.

Category 4: Regional Service Delivery (Work-to-Work Noncommodity Trips)

Some businesses depend on accessibility not only for workers and commodity shipments but also for delivery of services. The latter category covers business activities such as skilled professional services (lawyers, emergency medical care, accountants), construction and repair activities (plumbers, carpenters, electricians), and urban delivery activities (pizza delivery, couriers, parcel services). Typically, some time is spent traveling in a car or van to conduct these businesses and provide their services. Thus, businesses bear costs associated with time and expenses for such travel. However, trips taken by car are not covered by data on truck movements, and even those that do involve vans or small delivery vehicles typically are not covered by surveys of commodity flows.

Category 5: Personal Travel (Home-Based Nonwork Trips)

This includes trips for social, recreation, and shopping purposes. For such trips, any additional time spent traveling because of congestion has a negative effect on the quality of life of the driver and passengers but does not directly affect the flow of dollars in the economy. Any additional vehicle operating expense incurred because of congestion also represents a reallocation of spending patterns instead of necessarily changing overall income levels in the region. So, although congestion has bona fide costs for personal travel, it does not directly affect business operating costs, productivity, or generation of income. (Note that congestion effects on personal travel could indirectly affect business insofar as it could change the optimal location, size, and scale economies of retail and recreation business establishments, but this is a secondary effect that is beyond the scope of this study.)

This report separately analyzes the economic impacts of congestion for commuting trips (category 1) and for freight/service deliveries (categories 2–4). Costs for personal travel (category 5), including shopping trips, are not explicitly analyzed in this study because of the difficulty in identifying any associated business operating costs.

TYPES OF COSTS CAUSED BY CONGESTION

The literature review in Chapter 3 identifies three critical aspects of business operations that can be directly affected by congestion: accessibility of obtaining business inputs (supplies and workers), production costs of making business products and services, and delivery costs of providing products and services to buyers (either through sending deliveries to buyers or through attracting buyers to visit stores). To realistically portray the economic costs of congestion, there should be some recognition and the representation of all three types of business operation impacts. For the purposes of analysis, business operation impacts can be reclassified into three classes of costs:

1. Direct travel (user) cost, including vehicle operating costs and value of time for drivers and passengers, for all business-related travel;
2. Logistics and scheduling costs, including costs of stocking, perishability, and just-in-time processing; and
3. Market accessibility and scale, including loss of market-scale economies and reduced access to specialized labor and materials because of congestion.

Business costs of labor can be affected by type 1 and 3 costs, and business costs of product delivery can be affected by all three types of costs. Some businesses can also change operations and production processes to minimize those costs. For instance, they can substitute different types of differentiated supply inputs (for example, relying on more local suppliers), substitute different types of differentiated labor inputs (for example, relying on more local workers), or substitute between the two (for example, changing the labor or capital intensiveness of the operation).

To address these issues, the analysis in this report attempts to assess the magnitude of not only user costs of congestion but also the logistics/scheduling and accessibility costs to businesses. This is done with an economic model framework that also accounts for business substitution of labor and supplier inputs, and associated adjustments in trip making, in response to changes in the transportation cost of doing business in an area. The result of these business operating cost changes can be shifts in business profitability for various products and services in those areas. Ultimately, there can also be shifts in consumer prices and output levels, depending on the characteristics of customer demand and supplier competition in those areas. That effect, however, is beyond the scope of this study.

ANALYSIS STEPS

The process outlined here is designed to calculate the economic costs of allowing urban road congestion to increase or the economic savings associated with policies to reduce urban road congestion. Because prior research indicates that congestion is likely to vary widely among locations in a metropolitan area and is also likely to have costs that vary widely by industry, this analysis process builds on zonal data on trip patterns and delay patterns as well as industry and occupation breakdowns of business location and workforce location patterns. After a description of the steps involved, the study provides results for two metropolitan areas where this process was implemented.

There are six steps in this process. The first three steps represent calculation of traditional user impacts. These are excess time and expense costs incurred by users as a result of congestion, and reduction of those user costs is considered to be the primary transportation system efficiency benefit of transportation capacity improvement projects.

The latter three steps represent calculation of broader (nonuser) economic impacts. These are changes in business costs or income resulting from changes in logistics, scheduling, wage compensation, and market-scale economies as a result of changes in congestion levels. They are referred to as nonuser impacts in the sense that they can be incurred by a broad set of businesses and individuals who are not necessarily the travelers incurring the congestion delays. However, the broader economic impacts do occur as a result of the traveler delays caused by congestion and hence cannot be added to measure those direct effects.

The six steps are as follows:

- Part I: Measurement of traditional user impacts
    1. Trip data. It is first necessary to obtain zone-to-zone trip matrices to show the number of trips corresponding to each origin-destination pair of traffic analysis zones (TAZs). Separate matrices are needed for commuting trips (weighted average of car, commuter rail, bus, and nonmotorized modes) and delivery trips (reflecting truck movements). For both commuting and truck movements, the trip matrices should be further disaggregated by sectors of the economy, referred to as standard industrial classification (SIC) groups. These zonal traffic data can come from metropolitan planning organizations (MPOs). Breakdowns of the trip matrices by industry may be available from the MPO or may be estimated with census data on industry breakdowns of zonal employment also available from the MPO.

2. Travel time and distance data. Metropolitan transportation planning models typically include zone-to-zone matrices of travel distances, mean travel times, and variance in travel times applicable for commuting trips and for freight delivery trips. The matrices come from MPO model data at the TAZ level. These travel time and distance data, together with the trip data, allow us to calculate vehicle miles and vehicle hours of travel being incurred by businesses in different industries and commuters in different occupation groups.
3. User travel cost calculation. Once information on the components of commuting (car) and business delivery (truck) costs have been obtained, it is possible to calculate total travel costs by industry (in terms of SIC groups) for all zone-to-zone (TAZ) combinations. These travel costs include costs of driver time and vehicle operating expenses. Aggregate user costs are then calculated given current commuting and truck patterns. Unit cost factors are multiplied by the travel time, distance, and trip data (steps 1 and 2 above) to calculate aggregate user time and expense costs.

- Part II: Measurement of broader (nonuser) economic impacts

4. Total unadjusted business cost calculation. This step expands the user travel cost calculation (from step 3) to include a broader set of business costs by industry (in terms of SIC groups) for all zone-to-zone (TAZ) combinations. For product supplies and service inputs, these business costs will include not only user costs (vehicle operation expense and driver time) but also logistics/scheduling costs (including stocking, perishability, and just-in-time processing factors). For worker commuting, these business costs can also include business compensation to workers for a portion of their excess commuting time (based on differences in average wage levels by occupation and industry) and a portion of their excess commuting expense (vehicle and parking expense and time) to the extent that it affects wage compensation. Taking into account all these impacts, a total impact on business costs can then be calculated (given current commuting and truck patterns).
5. Activity data. The last element of data assembly is to obtain zonal data on business activity patterns (in terms of employment levels) and labor force patterns (workers by place of residence). Both can be disaggregated by industry sector and by occupation. These data, together with industry/occupation matrices, make it possible to calculate the proximity or availability of labor markets and supplier market alternatives for businesses.
6. Statistical estimation. The final step is application of maximum likelihood estimation methods to calculate business production functions, which indicate the relationship between calculated business cost of labor (given commuting patterns) and freight (given truck patterns) and observed business activity level in each zone. These functions also indicated the elasticity of substitution among various categories of workforce and supplies used in business processes. The analysis can be done separately by industry and occupation based on the unadjusted business costs (step 4 above) and patterns of workforce and supplier activities (step 5 above). The results indicate the total adjusted business cost and how it differs from the unadjusted cost calculation. (See the section *Approach and Contribution of This Study* in Chapter 1 for a discussion of how this type of business production function relates to the more aggregate form of production function used by Nadiri and others.)

These six steps were applied in two metropolitan areas. The next section provides an overview of the production function model that was used. The data collection process for those two areas is described in the following section, and the results are then described in Chapters 5 and 6.

GENERAL MODEL OF BUSINESS PRODUCTION COSTS

Objectives of the Economic Model

To understand the link between a particular change in congestion and its effect on productivity, it is necessary to have an economic model that explicitly recognizes how specific changes in congestion levels affect business costs in different locations in urban regions. This basic modeling approach relates location cost differences to variations in the level of access to specialized labor and supplier (intermediate) inputs. In this way, relative business costs in different locations reflect costs of congestion.

This approach views transactions between locations in terms of total transportation costs and the use of differentiated labor, goods, and services in the production process. Changes in transportation costs therefore result in two types of changes in business costs:

- Change in direct cost of production. A reduction of direct travel costs can directly translate into a reduction in the cost of obtaining workers and delivering products/services to customers and hence total cost of production.
- Additional change in accessibility to specialized inputs. Furthermore, lower transportation costs change the distribution of shipments and trips as more specialized workers and customer markets become accessible. Therefore, an additional reduction of costs occurs because firms are able to use labor that more specifically meets their production needs and serves broader customer markets.

> Effects on productivity may come from improved access to broader worker and customer markets as well as from logistic and scheduling efficiencies and scale economies.

To make this modeling framework appropriate for metropolitan congestion, it is necessary to obtain information on the business mix and location patterns of workers and businesses as well as network data on interzonal transportation costs. The applicable case for this study is a metropolitan transportation network that is subject to higher levels of congestion (and hence higher transportation costs) for some zones than for others. It is expected that businesses with specialized and time-sensitive inputs tend to prefer locating outside those areas. Because the spatial relation of economic activities is given a central role, this approach can incorporate various location costs including direct shipping costs, logistics costs, and costs associated with access to specialized labor and intermediate inputs.

Differentiation of Effects by Occupation and Industry

An important element of the economic model approach for this study is the concept of product differentiation. Product differentiation represents the preference that businesses have for a choice among inputs, including labor (workers) and capital (materials and equipment), used in production or provision of the products and services they provide. A higher degree of differentiation in the inputs a firm uses allows the firm to choose a combination of inputs that best suits their needs and maximizes their profits. When congestion causes a decrease in access, available inputs are less diverse and, on average, a firm must settle for an inferior substitute. When access increases, as when congestion decreases, a firm realizes a benefit in access to superior goods. The production function model captures this effect.

Another central concept in this approach is that businesses can adjust to changes in cost arising from greater or lesser access to diverse inputs. These potential adjustments are embodied in production functions and, in particular, a term called the technical elasticity of substitution. The technical elasticity of substitution refers to the importance of variety in goods and services supplied by various industries to all firms within a particular region. Firms that value differentiation more can realize a productivity gain by tapping into a larger market for their inputs. Those that do not are relatively indifferent to the larger market afforded by increased transportation access. Industries providing more variety tend to have a lower elasticity of substitution. This means that businesses seek inputs from a wide geographic area and are willing to pay for the higher transportation costs for those inputs. On the other hand, industries supplying less specialized inputs tend to have a higher elasticity of substitution. This means that firms get inputs from wherever it is convenient nearby and are less willing to pay additional transportation costs for their inputs.

Overview of the Production Function Analysis and Its Interpretation

Various types of businesses directly incur costs of freight and service deliveries associated with vehicle operation, driver time, logistics/inventory, and production scheduling. The literature review also showed that businesses in competitive urban labor markets do end up absorbing (in wage rates) a portion of the burden associated with higher commuting costs. However, it is known that businesses do not have to just absorb added costs of freight shipping or worker commuting caused by congestion. Instead, they have some ability to adjust to those cost changes. Thus, the introduction of realistic production functions can help to better calculate the true cost effects of congestion on business.

The production function recognizes that one employee is not a perfect substitute for another employee even if they are in the same occupation. It also recognizes that the product or service of one supplier may not be a perfect substitute for that offered by another potential supplier. Therefore, employers can enhance productivity by selecting the most appropriate possible suppliers and employees for their needs. It then follows that the larger the area from which businesses can draw suppliers and workers, the easier and less expensive is the task of selecting the optimal mix. Congestion then affects these decisions in the following ways:

- Workforce costs. Congestion serves to increase the business cost of obtaining employees and limits the effective size of the labor market. So changes in congestion can affect not only the cost of production but also the number and distance of commuting trips.
- Product and service delivery costs. Congestion increases the business cost of delivering products and services to customers and limits the effective size of the area from which a business serves on a competitive basis. So changes in congestion can affect not only the cost of production but also the number and distance of truck trips.

Labor Market Cost Issues

The total business cost of hiring employees incorporates two components: an acceptable wage for a worker if he or she did not have to commute and the additional compensation required to attract workers from any given zone to travel to a job in another given zone. For each industry and occupation, businesses may have a different elasticity of substitution among workers in the labor force. Jobs with specialized skills tend to have a lower elasticity of substitution, which indicates that businesses seek workers from a wide geographic area and are more willing to compensate for higher costs of commuting for those workers. On the other hand, jobs with more common skills tend to have a higher elasticity of substitution, which indicates that businesses get workers from wherever is convenient nearby and are less willing to pay additional costs to compensate workers for higher commuting costs.

Delivery Cost Issues

The total business cost of providing products/services incorporates two components: the cost of the goods or services if a delivery or commute were not involved and the additional compensation required to get supplies from any given zone to the customer site. For each industry, business customers may have a different elasticity of substitution among the various supplier choices. This elasticity reflects how sensitive businesses are to changes in those costs. Industries with more specialized products tend to have a lower elasticity of substitution. This indicates that their customers buy their products from a wide geographic area and are more willing to compensate for higher costs of delivery. On the other hand, there tends to be a higher elasticity of substitution for industries with more generic or common products. This indicates that business customers get supplies from wherever is convenient nearby and are less willing to pay additional costs for delivery of products or services from more distant suppliers.

Issues in Assigning Costs to Industries

There are some fundamental differences in how businesses incur congestion costs associated with worker commuting and goods/services delivery.

- Commuting costs affect the costs of obtaining workers—that is, an input to the business production process. (This can occur either through compensation of direct costs or through constraints on access to variety in the labor market.)
- Delivery costs of commodities and services, on the other hand, affect the net delivered price of products as seen by customers—that is, an output of the business production process. (This occurs insofar as shipping costs are added to final costs of delivered products or services.)

A distinguishing feature of the final model specification for freight movements is a reassignment of industry categories. Originally, the research team treated both workers and freight shipments as production inputs and assigned their costs to the industry category of their destination (which was purchasing the input). In the final analysis, freight costs were classified by the type of commodity and the producer (origin). This approach better corresponds to the way businesses set delivery prices for their goods, and it allows for more accurate assignment of freight value based on the commodity. It also recognizes that, although commodities are shipped to (and used by) businesses in all sectors of the economy, they are produced by essentially three sectors of the economy: agriculture, mining, and manufacturing.

Thus, for example, wholesalers and retailers may receive incoming shipments and make outgoing shipments of food, but the goods are still basically agricultural products. Similarly, a gardening center may receive lime for fertilizer treatment, and a gasoline retailer may receive fuel to sell, but in both cases the commodity is essentially a product of the mining/extraction sector. From this perspective, wholesale and retail activities are merely downstream elements of the supply chain, which ultimately provides manufactured, grown, or extracted goods to consumers.

The other sectors of the economy, including finance-insurance-real estate (FIRE), construction, services, and wholesale/retail activities, are combined in this study to represent a category referred to as service/other. The distinguishing characteristic of this category is that its businesses do not produce easily defined freight outputs. In the case of FIRE, construction, and repair services, company staff often do some traveling as part of their work, but their final product typically is not a shipped good. Most retail firms do not ship much of their product—more often, customers visit them. As a result, much of the travel conducted by these types of firms may involve people visits instead of freight shipments.

DEVELOPMENT OF CASE STUDIES: LOCATION AND DATA SOURCES

Locations: Choice of Case Studies

Because the research plan required highly detailed zonal data on patterns of business activity, labor force, travel volumes, distances, and travel times, it was necessary to focus on two case study areas. The research team sought large metropolitan areas with a diverse economy, measurable congestion, and good transportation data sets. A systematic process covered the following:

- Major metropolitan areas in the United States (with population over 1 million);
- Significant extent of congestion [based on a recent national study (Texas Transportation Institute 1996)];
- Diversified economy featuring a significant industrial base as well as office/service businesses;
- Availability of travel model data from the MPO; and
- Quality truck trip data (because every area had census journey-to-work data).

The research team also sought representation for both a coastal area and one located in the nation’s heartland. Based on those factors, the research team selected the Chicago metropolitan area and the Philadelphia metropolitan area. Both were rated in the national study as having significant congestion. As of the most recent available period (1993), the Chicago region had 788,000 person-hours of delay each day, with an annual congestion cost of $370 per capita. The Philadelphia region had 380,000 person-hours of delay each day, with an annual congestion cost of $250 per capita. Both the Chicago Metropolitan Area Transportation Study and the Delaware Valley Regional Planning Commission have very strong travel demand modeling capabilities and were extremely cooperative in providing the trip tables and network files necessary for this research. The data cover 1,669 zones in the Chicago metropolitan area and 1,510 zones in the Philadelphia metropolitan area. Figure 4.1 presents maps depicting the Chicago and Philadelphia study areas.

Data Sources

Types of Available Data

For commuting trips, the source of data was the U.S. census journey-to-work data set. For truck trips, the data came from MPO models (built from traffic observations and zonal economic data), special tabulations of the commodity flow survey, other trip generation, and trip distribution data by industry. The available information and its applicability is summarized as follows:

1. MPO commuting trip data. MPOs tend to have good commuting data, coming from the U.S. census journey-to-work files. This includes breakdowns of the numbers of trips with detail on industries and origin-destination zones. For this study, special breakdowns were also obtained from the U.S. census, providing commuting origin-destination patterns by occupation category.
2. MPO truck and business trip data. Most MPOs have limited data on truck and business car travel without a breakdown of industries or commodities. In particular, (*a*) there is a lack of detail on the industry of the shipper or the commodity being shipped, so those factors must be estimated by the analyst based on available employment data; and (*b*) there is a lack of information on truck travel to and from areas external to the metropolitan region. This leads to an underestimation of trip lengths.
3. Commodity flow survey (CFS) data. The CFS provides a promising means of obtaining data on freight flows by commodity, including external origin-destination patterns as well as within-region travel. However, special tabulations were needed to break out geographic detail at the subregional level. In addition, further analysis was necessary to convert shipment quantities to dollar valuations and to reconcile the county-to-county flows with finer zonal travel data.
4. Professional and service activity. A significant portion of business travel is conducted as part of professional services, repair services, FIRE, and courier services. Much of this travel involves cars or vans as well as small delivery vehicles and is not captured by the CFS but is, nonetheless, an important aspect of the business costs of congestion.
5. MPO travel time and variability data. Most major MPOs have data on interzonal travel distances and travel times. For this study, it was also necessary to obtain information from the MPOs to derive estimates of daily average travel times, commuting period travel times, and travel time variance.
6. Inventory and logistics costs. There are significant transportation-related costs associated with inventory and logistics for some types of business. Much of these costs are due to either perishability of the goods or just-in-time needs for stocking and manufacturing processes. These costs tend to be incurred when there is travel time variability (unpredictable delays caused by traffic incidents, which increase under congested conditions). These costs of travel time variation are in addition to the

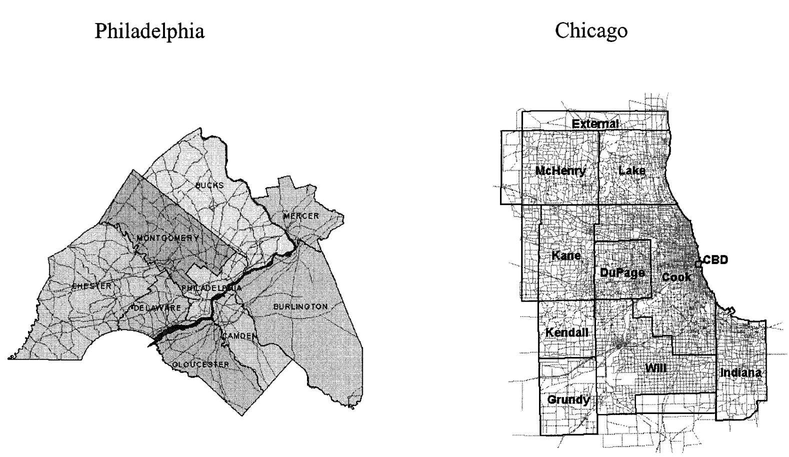


Figure 4.1. Philadelphia and Chicago study areas.

predictable costs of longer travel times due to road congestion.

Issues in Estimating Truck Trip Patterns by Industry

The research team had two sources of data on freight trips from which to estimate model coefficients.

1. MPO data. The first was the truck trip matrices supplied by the MPOs. This matrix was a product of the MPOs' own model processes, estimated from truck survey data collected in the metropolitan region. However, no information on the breakdown of trips by industry from the MPOs was available. To address this deficiency, average trip length and trip generation data by industry were obtained from the *FHWA Quick Response Freight Manual* and were used to disaggregate the truck trip matrices. The advantage of this approach is that the necessary information (on costs, travel time variability) is available for every zone in the regional matrix. The MPO data also cover nontruck work-related trips (including service delivery vehicles). There are two disadvantages of this approach: it requires industry allocations to be imposed on the available data, and the data are limited to the borders of the region so that information on trip lengths and travel times for long-distance travel is limited to that portion taking place within the region. Obviously, some information on truck costs is lost in making such an assumption.
2. CFS data. The second source of data that were made available to this project team under special arrangement through FHWA was tabulations of truck movements from the commodity flow survey (CFS). The CFS data set was enhanced by Reebie Associates and reports commodity flows within a metropolitan area at the county level, whereas flows from or to areas beyond the study region are reported at the census region level (which divides the nation into six distinct areas). The CFS data set classified trips based on the commodity that was moving instead of on the basis of the industry receiving the freight. Shipments also were reported for truck, less-than-truckload, and private carrier shipments as well as for air and water. The shipments were stratified by the four-digit Standard Transportation Classification Code. The benefit of using these data is that is the most valid representation of truck freight flows to and from metropolitan areas. The most significant drawback in using these data is the more coarse level of geographic detail.

After a critical review of the initial truck trip matrix with the MPO data, the project team reached two conclusions. First, it concluded that the assumption that there is a self-contained or closed system of regional productions and attractions is appropriate for modeling commute trips. Second, the team did not believe this was appropriate for goods movements, mainly because it ignored external travel and thus underestimated trip lengths for long-distance trips extending outside the region's boundaries.

In the final analysis, the special CFS tabulations were combined with MPO data detail on business origin and destination locations in the metropolitan area. That made it possible for the analysis to accurately account for long-distance (external origin or destination) trips. In addition, MPO data on work-to-work trips that were by car, van, and small delivery vehicle—which are not covered by the CFS data—were also used, thus covering service-related trips.

Methods for Calculating Total Shipment Costs

Because the CFS data are provided in terms of tons of freight shipped, the value and direct cost of shipments had to be estimated from the truck inventory and use survey. The mix of commodities produced and purchased by industries in the United States was then estimated based on the U.S. Bureau of Economic Analysis input-output technology matrix, which was reduced to the three commodity by eight sector level.

Total shipping costs were calculated to include direct shipping costs (vehicle depreciation, fuel, maintenance, and tire costs) plus travel time variability or reliability costs (associated with perishability or just-in-time processing factors). The perishability and just-in-time factors were developed to capture the level of business dependence on on-time deliveries and the average cost incurred when shipments are late. These factors were then applied to estimate costs of nonrecurring congestion—that is, changes in reliability. The derivation of these factors is described above, and key unit cost factors are also shown in the presentation of study findings on delivery costs, described in a later section.

Issues in Estimating Commuting Trip Patterns

The analysis of commuting patterns was carried out in two different ways. The first way was to use the MPO zonal data, which contained detailed information on travel times but only limited precision on industry and occupation breakdowns of trips. The second way was to use census STP154 detailed tract data—which contained detailed information on commuting productions and attractions (employment and labor force)—together with the U.S Census Bureau's new Land View III geographic information software, which showed interzonal distances and land areas for all tracts. These census data were combined with MPO data on average speeds by mode and region of the metropolitan area to calculate interzonal commuting costs. The census tract data were ultimately shown to produce reliable and useful results. The census data had the additional advantage of being uniformly available for all metropolitan areas, so the study methods and findings could be more easily extended for use elsewhere.

Additional studies were carried out to test the reliability of the U.S. census allocation of trips among census tracts and TAZs (the MPO's transportation activity zones). The concern was that the census allocates some trips where the exact destination location is not known, that these allocations are included in the census transportation planning package distributed to MPOs, and that the implications of such allocations are not known. To test this, the production functions were reestimated with and without the allocated trips. The results of these tests clearly indicated that the census allocations did not skew the analysis results.

CHAPTER 5

CASE STUDIES I: ESTIMATION OF BUSINESS DELIVERY COSTS

This chapter summarizes case study analysis findings concerning costs of congestion on business travel. Specifically, it covers the delivery of business products and services by truck as well as the delivery of some business services by car. Service trips are defined here to include all work-to-work trips. Home-based trips are excluded from our analysis. Other business costs relating to labor market access are covered in the following section of this report.

The analysis results indicate how congestion increases the direct costs of freight and service delivery, causes additional costs associated with travel time variability (unreliability), and causes firms to substitute among inputs to adjust to changes in accessibility to variety among differentiated suppliers. Separate models were estimated and calibrated for each major industry sector.

KEY FACTORS: DELIVERY TRIP PATTERNS

Importance

Trip distance and spatial distribution are important factors affecting the economic impact of congestion. This is because truck trip (and business car trip) lengths, costs, and flow patterns vary systematically by industry and commodity type. Systematic differences in delivery trip length were used in the case studies for calibration of production function and cost models, because they provide a basis for estimating the tradeoffs made between accessibility costs and business location/activity decisions by businesses in different industries. This also provides a basis for estimating the implied benefit that businesses in different industries assign to accessibility improvements and the implied cost they incur when congestion worsens.

Data Source Differences

Because of the importance of trip patterns, preliminary analysis of trip distances was conducted by using two approaches for the Chicago area.

The first approach used metropolitan planning organization (MPO) data on truck trips. These data contained only information on trip lengths occurring within the metropolitan area, which averaged 11.1 mi (17.76 km) for manufacturing trips and 9.6 mi (15.4 km) for service/other trips.

The second approach used a special tabulation of the commodity flow survey (CFS), which captured the length of all truck trips within the modeling region. The average truck trip lengths for manufacturing-related trips were 59.1 and 33 mi (94.5 and 52.8 km) for the Chicago and Philadelphia regions, respectively, reflecting the influence of trips with one trip end located external to the region. The CFS data do not cover business cars and small delivery vehicles used for local services. For that, MPO data were added covering work-to-work car travel. These service-related trips tend to be much shorter than the truck trips. The average trip length for service/other deliveries is 5.4 mi (8.6 km) in the Chicago data set. Because no service-related data were available for the Philadelphia region, these trips were estimated with the Chicago data. This procedure is described in Appendix B.

A full comparison of the average trip lengths and travel times associated with the two data approaches for Chicago, as well as corresponding data for Philadelphia, is presented in Table 5.1. The differences shown in that table indicate the danger of relying solely on MPO truck data (which undercount long-distance truck travel) and also the danger of relying just on CFS tabulations (which miss short-distance service delivery).

Industry Differences

Freight and service trips were classified into four categories based on their outputs: agricultural products, mining/extraction products, manufactured products, and service/other activities. As indicated in Table 5.1, trip lengths were found to be longest for the delivery of manufactured products, slightly less for the agricultural and mining products, and much shorter for the (largely local) service delivery category of trips.

Location Differences

Figure 5.1 shows how the relative length of incoming and outgoing truck (and business car trips) differs systematically by location. In this illustration, we see that the central area has the shortest trip lengths for outgoing truck deliveries but

TABLE 5.1 Number of truck trips and average trip lengths by industry

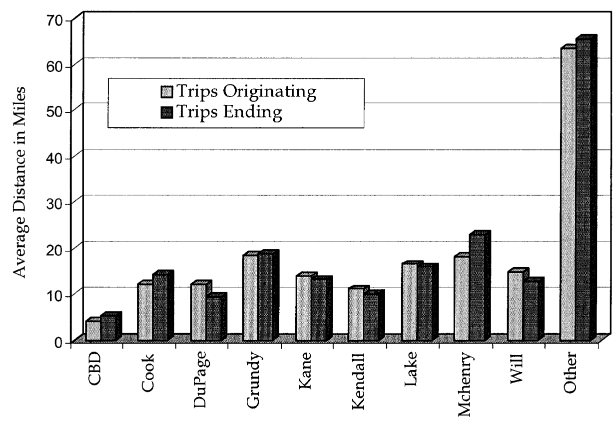
Delivered product	MPO truck data		CFS tabulation and MPO delivery data			
	Chicago		Chicago		Philadelphia	
	Miles /trip	Minutes /trip	Miles /trip	Minutes /trip	Miles /trip	Minutes /trip
Agriculture	8.90	18.46	50.22	95.61	29.57	40.36
Mining	5.43	11.97	50.63	108.16	35.10	50.50
Manufacturing	11.14	24.22	59.09	123.41	32.97	46.21
Service/other	9.57	22.09	5.43	14.60	5.97	10.01

one of the longest trip lengths for incoming truck deliveries. In this context, the relative impact of congestion costs on business depends critically on the magnitude or portion of the total trip over which the congestion impacts occur. This suggests that congestion in one urban center may have a more dramatic impact on a local, short-distance delivery business than on a coast-to-coast freight shipment.

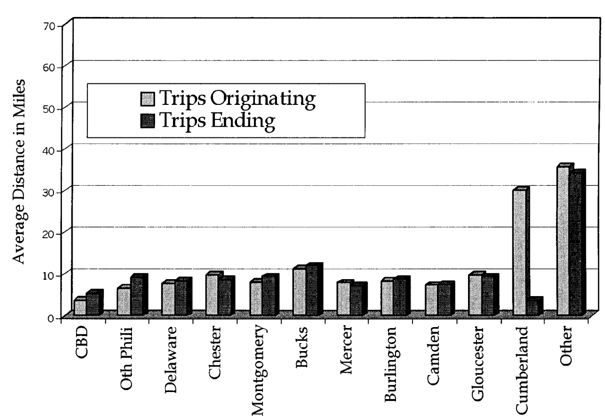
MODELING TRUCK SHIPPING COSTS

Table 5.2 indicates the calculated value of direct shipping cost, the additional increment associated with travel time variability, and the average commodity value per shipment for different types of deliveries. The value of direct shipping cost (traditional user cost measure) includes the value of vehicle

A. Chicago Region



B. Philadelphia Region



* Other includes trips from (or to) regions external to this study.

Figure 5.1. Truck trip length by location in metropolitan area.

TABLE 5.2 Shipping costs by industry

Delivered product	Direct user cost/h	Reliability cost (per min^2)	Value of shipment
Agriculture	$25.07	$7.00	$16,764.55
Mining	$25.04	$0.83	$5,469.32
Manufacturing	$25.66	$11.20	$34,681.55
Service/other	$0.00	$0.00	$135.00

operating expenses, safety-related expenses, and driver time costs. The additional increment associated with travel time variability includes logistics, scheduling, and just-in-time processing costs. It is important to note that these values are classified by commodity type instead of by recipient industry. Key findings are as follows:

- The unit cost of vehicle operation, safety, and driver time is in the range of $25/hour for all classes of freight delivery trips by truck but significantly lower for the service trips with cars and small delivery vehicles.
- The additional reliability cost incorporates an average level of delay and unit value associated with delay. The delay itself is associated with incidents that occur on freeways and expressways and is measured as the standard deviation of incident-related travel time delay. Estimates of this delay are based on a model derived from empirical measures incident impacts.
- The value of commodities carried per shipment is highest for manufactured products and agricultural products and much lower for mining/extraction products. It is minimal for service/other deliveries, as they carry little or no freight value, and largely represent the hourly cost of the service person being moved. Note that, for service trips, no single number truly representative of shipment value based on any past research was available.

There are additional elements of the total business cost of congestion delay associated with the delivery of products and services. These concern production functions, such as how businesses adjust production processes in response to changes in access costs for supplies. These are discussed below.

MODEL CALIBRATION

Interpretation of Business Response Elasticities

The economic model, summarized in Chapter 4 and more fully documented in Appendix B, yields coefficients reflecting the elasticity of substitution among product inputs. This reflects the extent to which firms purchase supplies that are specialized as opposed to basic commodities. In general, the more the materials purchased are not specialized, the more firms can substitute closer suppliers when costs of obtaining products from more distant suppliers increase, as occurs with increased congestion. These elasticities thus indicate the extent to which businesses can adjust to offset congestion costs.

- A high elasticity of substitution occurs when the supplier market is homogeneous (with little difference in quality or function of product), so that buyers are very willing to switch suppliers to save cost. For a purely homogeneous commodity in a market with competing suppliers, a 1 percent increase in product cost for one supplier leads to a 100 percent loss of sales to lower cost competitors.
- A low elasticity of substitution occurs when the supplier market is differentiated (in terms of product quality and specialized function), and buyers value access to that differentiated market. In that case, buyers are less willing to switch suppliers only because of a change in product cost. In a fully differentiated product market, every supplier is unique, so individual producers do not lose sales if the price of their product increases.
- In the context of this study, an elasticity of substitution of 12 means that a 1 percent increase in total product cost (due to congestion) leads to a 12 percent decrease in sales for the supplier of that product.

Values of Estimated Elasticities

Table 5.3 indicates the estimated elasticity of substitution (with respect to costs) among product inputs, for the four economic sectors, based on the case study analysis data. The technique used to estimate the elasticity of substitution parameters was maximum likelihood, which finds the parameters most likely to produce the observed number of trips in each zone and for each industry. It is notable that all these coefficient estimates have a very high degree of statistical accuracy and significance, as reflected by the very low standard deviations associated with each of them. Also, note that no service data were available from the Philadelphia data sets. For application of the model in the Philadelphia congestion scenarios, the service trip elasticity from the Chicago model was used. Service trips were derived from a trip generation and distribution model estimated from the Chicago data.

TABLE 5.3 Estimated elasticity of substitution

Delivered product	Elasticity of substitution	Standard deviation	*t*-statistic
Chicago			
Agriculture	14.51	0.41808	34.7*
Mining	4.62	0.27627	16.7*
Manufacturing	7.44	0.04913	151.8*
Service/other	10.61	0.01042	1018.2*
Philadelphia			
Agriculture	15.00	0.33072	45.4*
Mining	10.10	0.20607	49.0*
Manufacturing	6.81	0.00786	866.4*

*Statistically significant at the 99 percent confidence level.

Interpretation of Results

Key findings are as follows:

- The highest elasticity of substitution occurs for agricultural products. This result, which is consistent with prior expectations (and common sense), reflects the finding that there is a high degree of substitution among food product suppliers. Thus, buyers of food products are relatively price sensitive.
- A lower elasticity of substitution occurs for manufacturing. This reflects the greater degree of product differentiation among manufactured products compared with agricultural products, which makes some buyers more concerned with finding appropriate type and quality of manufactured products instead of just minimizing costs.
- The elasticity of substitution for the service industry lies between those for manufacturing and agriculture. The industry encompasses a broad range of skills and products, from highly specialized technical services (such as legal services) to relatively lower-skilled jobs (such as lawn services).
- In terms of rankings, the estimated elasticities are fairly consistent between the two cities for manufacturing and agriculture but not for mining. At least part of the difference can be attributed to the longer trip lengths of mining trips, relative to the other sectors, in the Philadelphia data set than in the Chicago data set.
- These maximum likelihood estimates of freight and service flow patterns support the finding that there is competition among product suppliers and some price elasticity of substitution in demand for competing suppliers. This elasticity explains why there are agglomeration economies and resulting productivity gains associated with city size. Increasing congestion, then, can be viewed as effectively reducing the market size (agglomeration economies) for business, whereas congestion reduction increases those productivity benefits.

Goodness of Fit

To calculate the goodness of fit of the estimated elasticities, the terms of the cost minimization equation were rearranged to solve for the number of trips by industry and by zone. Figure 5.2 presents the results of this effort in a histogram of estimated and observed truck trips grouped by travel distance. The goodness of fit is measured by the adjusted R^2 value, which represents the portion of variance explained by the equation. The overall R^2 values were 0.90 for Chicago and 0.82 for Philadelphia. They were higher for mining and services and lower for manufacturing and agriculture. Note that both models systematically underestimated the shortest distance trips, whereas both obtain a better fit to the longest distance trips.

MODEL RESULTS: ALTERNATIVE SCENARIOS

Definition of Scenarios and Impact Indicators

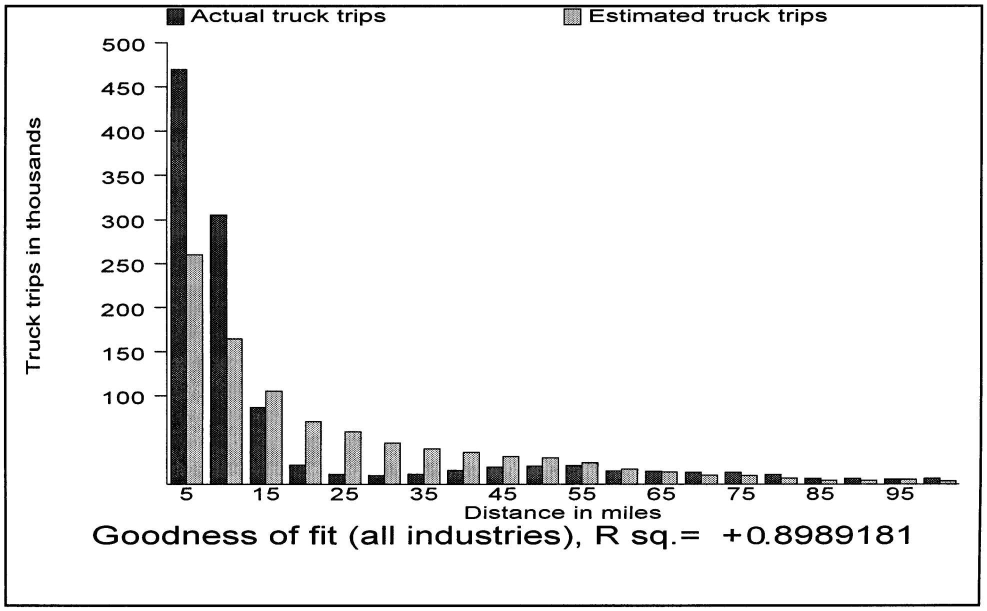
Scenarios

Once the production function model was estimated, its coefficients were reapplied to forecast how alternative congestion scenarios would affect business patterns in the Chicago and Philadelphia regions. These results indicate how delivery of commodities and services within each region would reorient to minimize the negative impact of an increase in congestion or maximize the positive impact of a decrease in congestion. The total demand or number of trips may change as well. Again, the degree to which this reorientation occurs is in part a function of each industry's elasticity parameter.

Three scenarios were tested for both Chicago and Philadelphia:

1. Regionwide congestion scenario,
2. Central business district (CBD) congestion scenario, and
3. Corridor congestion scenario.

(A) Chicago region



(B) Philadelphia region (excluding services)*

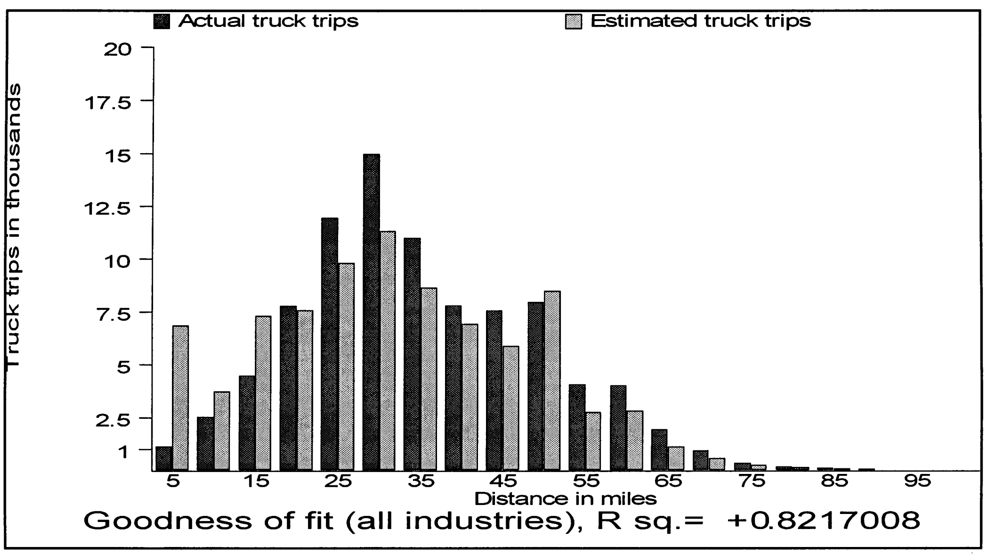


*Figure 5.2. Goodness of fit with observed trips. (*Philadelphia service trips estimated from a model derived from the Chicago data set and are not included in the goodness of fit statistic.)*

Impact Indicators

For each scenario, impact indicators were calculated reflecting how businesses' costs and trip patterns would change under fixed production functions, in which input suppliers are fixed, and flexible production functions, which allow businesses to respond with some substitution of input suppliers to minimize business operating costs with flexible production functions. These indicators were as follows:

- Change in total vehicle miles associated with adjustment in trips and trip lengths due to a change in business travel costs, with flexible production.
- Change in productivity associated with adjustment to a change in business travel costs, with flexible production.
- Change in total cost with flexible production functions, which reflects the above adjustments in trips, trip lengths, and associated mileage, as they respond to changes in congestion with some substitution of input suppliers. In

this model, adjustments in trips are synonymous with changes in productivity.

- Change in total cost with fixed inputs (no change from base case trip patterns) due to a change in business travel costs (without any flexibility in production inputs).

Scenario 1: Regionwide Congestion Reduction

Scenario Assumption

The first scenario was the regionwide congestion reduction scenario, which assumes that travel times are decreased uniformly by 10 percent throughout the region, while there is no change in vehicle operating costs or travel time variability costs. That is equivalent to raising average travel speeds from 33 to 36 mph (53 to 58 km/h) and results overall in just a 2.5 percent decrease in travel cost throughout the region. The resulting changes in miles traveled, trips (demand), and input costs for businesses were computed for each zone. These results are indicated for all industries in Figure 5.3 and Table 5.4, and their interpretation is summarized below.

Adjustment to Travel Patterns

The results indicate that, overall, businesses respond to a decrease in congestion by making longer distance trips (to access more specialized and varied labor markets and supplier markets). Vehicle miles traveled increase across the board in Philadelphia and through the inner ring of Chicago because of longer trips, while outer suburbs of Chicago indicate slightly reduced vehicle miles traveled caused by the slight reorientation of trips toward the inner ring.

Cost Impact

The results indicate that an across-the-board reduction in travel time for all zones leads to a decrease in business operating (input) costs for all areas. It is also notable that the percentage decrease in total input cost with flexible substitution of inputs is slightly greater than the percentage decrease in total input cost with fixed inputs. The difference between those two columns indicates that businesses can obtain productivity benefits from a reduction in congestion, which allow them to save more costs than would be expected if there were no allowance for substitution of inputs. (In effect, productivity is increased and costs are decreased, as firms tap into a larger market for inputs.) Although the relative difference in those business cost percentages appears to be small, the overall regional economic impact is still substantial. For Chicago the change with the flexible substitution of inputs is –0.385 percent compared with –0.0383 percent without substitution. Comparable figures for Philadelphia are –0.0328 and 0.0326 percent, respectively. These results (taking into account the substitution of inputs) translate to an annual business cost impact of $980 million in the Chicago area and $240 million in the Philadelphia area.

The results also show how firms can decide to use new combinations of inputs when it is cost-effective to do so. The productivity gain achieved from obtaining an input better suited to a firm’s needs comes at the cost of a longer shipping distance overall. A positive value for the percentage change in average trip length indicates that firms buy inputs from farther away to reach a larger supply (presumably one better suited to the firm’s needs).

Spatial Differences

In Chicago, the productivity benefits associated with regionwide congestion reduction are highest for the CBD, which is the area most highly affected by regionwide congestion because of its central position within the region. Indiana shows a relatively high cost reduction, as it is a source of a substantial amount of truck traffic bound for Chicago on congested interstates. In the Philadelphia region, the greatest productivity benefits accrue to Mercer County, New Jersey, which includes more heavily industrialized areas such as Trenton, and the CBD. For all scenarios, the results for Cumberland County, New Jersey, are inconclusive because of the small number of zones (three), which results in a very high sensitivity to small changes in travel times.

Scenario 2: CBD Congestion Reduction

Scenario Assumption

Under the second scenario, congestion reduction is focused on the CBD. It is represented as a 25 percent reduction in travel time for trips coming into and out from the CBD, with no change in travel times for other parts of the region. The scenario assumes no decrease in vehicle operating cost or travel time variability, so the overall impact is a 6.3 percent reduction in travel cost for CBD trips. The results are presented in Table 5.5 and are summarized below.

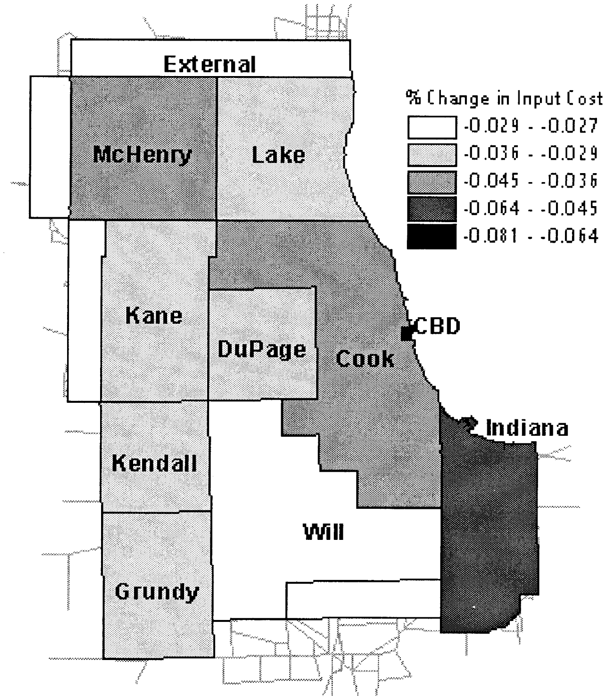
Cost Impact

As with the regionwide scenario, the reduction in CBD congestion leads to metropolitan-wide productivity increases. The cost savings for delivery of goods and services in Chicago are estimated to be $272 million annually. For Philadelphia, the cost savings are estimated to be $100 million annually.

Spatial Differences

Even though the direct impact is just on the CBD, most areas within the region save on business production (input)

(A) Chicago region



(B) Philadelphia region

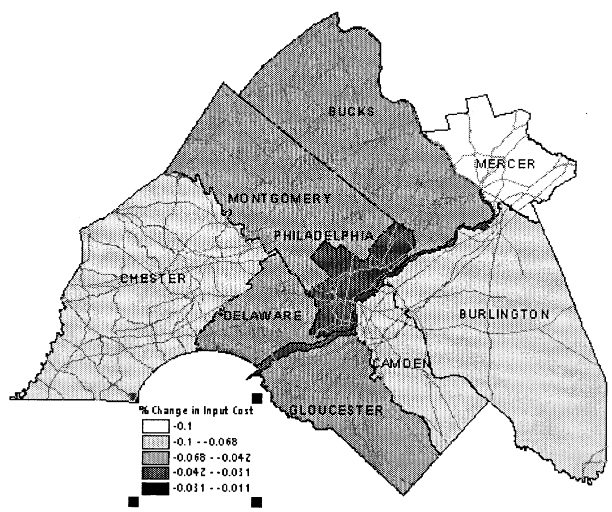


Figure 5.3. Percentage impact of a 2.5 percent regionwide reduction in travel cost for product and service deliveries.

costs. However, the additional productivity impacts are concentrated in the CBD and are relatively small elsewhere. That occurs because most goods shipments are coming into the CBD as opposed to producers in the CBD sending products out to other areas. (As a result, there is minimal effect on firms operating in other areas.) Businesses within the CBD are able to supply a broader market area, thus also increasing average trip lengths (and total miles) for trips from CBD businesses. In Philadelphia, decreases in vehicle miles traveled are correlated with decreases in productivity in areas just outside the CBD. This points to the redistributional effects of a targeted strategy to reduce congestion, as economic ties

TABLE 5.4 Percentage impact of a 2.5 percent regionwide reduction in travel cost for product and service deliveries

Chicago region Area	Change in vehicle miles (%)	Change in productivity (%)	Change in input cost (%) Flex inputs	Fixed inputs
Breakdown by area				
CBD	4.8643	0.4828	−0.0805	−0.0790
Chicago	1.3518	0.3839	−0.0446	−0.0444
North Cook	0.8662	0.4690	−0.0447	−0.0444
West Cook	1.3598	0.4347	−0.0446	−0.0444
South Cook	2.1239	0.7183	−0.0461	−0.0457
DuPage	−0.6436	0.3513	−0.0310	−0.0306
Kane	−0.6112	0.2698	−0.0332	−0.0330
Lake	−0.3815	0.2437	−0.0357	−0.0354
McHenry	−0.3516	0.1854	−0.0392	−0.0391
Will	−0.4919	0.2586	−0.0268	−0.0266
Kendall	−0.4211	0.2099	−0.0300	−0.0299
Grundy	−0.1575	0.1042	−0.0300	−0.0300
Indiana	−0.4248	0.2102	−0.0635	−0.0585
Other	0.0781	0.0020	−0.0292	−0.0292
Breakdown by industry				
Agriculture	0.1996	0.0039	−0.0516	−0.0515
Mining	0.0107	-0.0044	−0.1016	−0.1014
Manufacturing	0.0780	0.0011	−0.0279	−0.0279
Service/other	0.7252	0.4791	−0.6226	−0.6102
Overall	0.4226	0.3798	−0.0385	−0.0383

Philadelphia region Area	Change in vehicle miles (%)	Change in productivity (%)	Change in input cost (%) Flex inputs	Fixed inputs
Breakdown by area				
Philadelphia CBD, PA	2.6379	0.2382	−0.0308	−0.0305
Rest of Adams County, PA	1.4828	0.1774	−0.0287	−0.0285
Delaware, PA	1.3481	0.1975	−0.0497	−0.0494
Chester, PA	1.5716	0.3133	−0.0763	−0.0758
Montgomery, PA	1.2751	0.2095	−0.0507	−0.0505
Bucks, PA	1.1438	0.2241	−0.0423	−0.0422
Mercer, NJ	2.8250	0.5046	−0.0995	−0.0984
Burlington, NJ	1.3081	0.2484	−0.0684	−0.0680
Camden, NJ	1.5942	0.2262	−0.0747	−0.0742
Gloucester, NJ	1.2884	0.2470	−0.0437	−0.0435
Cumberland, NJ	NA	NA	NA	NA
Other	0.0274	0.0001	−0.0107	−0.0107
Breakdown by industry				
Agriculture	0.0127	0.0001	−0.0193	−0.0193
Mining	0.0186	−0.0002	−0.0800	−0.0800
Manufacturing	0.0172	0.0001	−0.0113	−0.0113
Service/other	1.9292	0.2605	−0.6545	−0.6600
Overall	1.4887	0.2283	−0.0328	−0.0326

between the CBD and Trenton (Mercer County) are strengthened, only partially at the expense of other areas.

Industry Differences

The results vary dramatically by industry and by city. In each city, however, most of the total cost savings benefit accrues to the nonmanufacturing (service/other) sector of the economy. That reflects the specialization of businesses within the CBD, which are predominantly services instead of manufacturing activities. However, even shipments of manufacturing and agricultural products have some net cost reductions in Chicago.

Scenario 3: Industrial Corridor Congestion Reduction

Scenario Assumption

Under the third scenario, congestion reduction is focused on one corridor affecting an industrial corridor outside the CBD. For Chicago, this corridor was defined as the portion of Cook County south of the CBD. This includes a heavily

TABLE 5.5 Percentage impact of a 6.3 percent reduction in travel cost for product and service deliveries: CBD only

Chicago region Area	Change in vehicle miles (%)	Change in productivity (%)	Change in input cost (%) Flex inputs	Fixed inputs
Breakdown by area				
CBD	13.2957	1.2503	−0.2075	−0.1975
Chicago	0.1464	0.1479	−0.0108	−0.0098
North Cook	0.5330	0.2922	−0.0048	−0.0040
West Cook	0.5891	0.3356	−0.0072	−0.0061
South Cook	1.3125	0.5636	−0.0078	−0.0063
DuPage	−0.0614	0.1331	−0.0025	−0.0021
Kane	−0.0330	0.0509	−0.0016	−0.0015
Lake	−0.0296	0.0748	−0.0017	−0.0016
McHenry	−0.0161	0.0251	−0.0017	−0.0017
Will	−0.0680	0.0760	−0.0016	−0.0014
Kendall	−0.0347	0.0439	−0.0015	−0.0014
Grundy	−0.0178	0.0200	−0.0015	−0.0014
Indiana	−0.1793	0.1265	−0.0310	−0.0230
Other	0.0005	0.0001	−0.0017	−0.0017
Breakdown by industry				
Agriculture	0.0026	0.0000	−0.0011	−0.0011
Mining	−0.0030	−0.0001	−0.0040	−0.0039
Manufacturing	0.0033	0.0001	−0.0029	−0.0029
Service/other	1.1076	0.4582	−0.4658	−0.4189
Overall	0.5932	0.3630	−0.0107	−0.0099

Philadelphia region Area	Change in vehicle miles (%)	Change in productivity (%)	Change in input cost (%) Flex inputs	Fixed inputs
Breakdown by area				
Philadelphia CBD, PA	6.8450	0.5940	−0.0780	−0.0761
Rest of Adams County, PA	−0.4190	−0.0626	−0.0061	−0.0059
Delaware, PA	−0.1595	−0.0614	−0.0174	−0.0162
Chester, PA	0.9134	0.0988	−0.0221	−0.0195
Montgomery, PA	0.4473	0.0313	−0.0133	−0.0121
Bucks, PA	0.6403	0.0763	−0.0092	−0.0082
Mercer, NJ	1.4944	0.2145	−0.0220	−0.0191
Burlington, NJ	0.3968	0.0702	−0.0191	−0.0169
Camden, NJ	−0.4430	−0.0394	−0.0275	−0.0254
Gloucester, NJ	−0.0060	−0.0189	−0.0147	−0.0133
Cumberland, NJ	NA	NA	NA	NA
Other	−0.0077	0.0000	−0.0021	−0.0021
Breakdown by industry				
Agriculture	−0.0176	−0.0001	−0.0116	−0.0115
Mining	0.0052	0.0000	−0.0259	−0.0259
Manufacturing	−0.0008	0.0000	−0.0027	−0.0027
Service/other	0.9454	0.1009	−0.3341	−0.3108
Overall	0.7274	0.0884	−0.0137	−0.0129

industrialized region. For Philadelphia, this corridor was defined as the area around Chester, Pennsylvania. In both cases, the scenario is represented as a 25 percent reduction in travel time for trips coming into and out from that area, with no change for other parts of the region. Like the prior scenario, it is assumed that there is no decrease in vehicle operating cost or travel time variability, so the overall impact is a 6.3 percent reduction in travel cost for trips associated with the specific county area. The results are presented in Table 5.6 and summarized below.

Cost Impact

As with the other two scenarios, the reduction in industrial corridor congestion leads to metropolitan-wide productivity increases. The cost savings for delivery of goods and services in Chicago are estimated to be $252 million annually. For Philadelphia, the cost savings are estimated to be $23 million annually.

Spatial Differences

Even though the direct impact is just one area of the CBD (southern Cook County in the Chicago case, and a small area to the north of Philadelphia in the second case), the benefits are broadly spread throughout the region. The breadth of these benefits is in contrast to the more concentrated benefits from the second scenario. Here, the effects are shown to extend to other areas that acquire a high portion of their inputs from the

TABLE 5.6 Percentage impact of a 6.3 percent reduction in travel time for product and service deliveries: industrial corridor only

Chicago region Area	Change in vehicle miles (%)	Change in productivity (%)	Change in input cost (%)	
			Flex inputs	Fixed inputs
Breakdown by area				
CBD	1.5997	0.1306	−0.0077	−0.0063
Chicago	0.5252	0.0957	−0.0048	−0.0043
North Cook	0.2247	0.0701	−0.0029	−0.0028
West Cook	0.4966	0.0871	−0.0052	−0.0046
South Cook	5.5533	1.7976	−0.1167	−0.1142
DuPage	−0.0062	0.0510	−0.0022	−0.0021
Kane	−0.0093	0.0189	−0.0024	−0.0024
Lake	0.0019	0.0125	−0.0027	−0.0026
McHenry	−0.0016	0.0056	−0.0032	−0.0032
Will	−0.2060	0.0838	−0.0021	−0.0019
Kendall	−0.0282	0.0297	−0.0020	−0.0020
Grundy	−0.0336	0.0259	−0.0018	−0.0017
Indiana	−0.2221	0.0914	−0.0306	−0.0248
Other	−0.0075	0.0001	−0.0028	−0.0028
Breakdown by industry				
Agriculture	0.0102	0.0002	−0.0037	−0.0037
Mining	−0.0560	−0.0001	−0.0317	−0.0315
Manufacturing	0.0033	0.0001	−0.0055	−0.0055
Service/other	0.7426	0.2204	−0.2548	−0.2340
Overall	0.3970	0.1746	−0.0099	−0.0095

Philadelphia region Area	Change in vehicle miles (%)	Change in productivity (%)	Change in input cost (%)	
			Flex inputs	Fixed inputs
Breakdown by area				
Philadelphia CBD, PA	−0.0995	−0.0092	−0.0009	−0.0009
Rest of Adams County, PA	0.3440	0.0384	−0.0068	−0.0066
Delaware, PA	−0.0116	−0.0076	−0.0030	−0.0027
Chester, PA	0.1287	0.0087	−0.0041	−0.0036
Montgomery, PA	0.0446	−0.0019	−0.0026	−0.0024
Bucks, PA	0.0898	0.0066	−0.0018	−0.0016
Mercer, NJ	0.2129	0.0242	−0.0047	−0.0042
Burlington, NJ	0.0345	0.0026	−0.0037	−0.0033
Camden, NJ	−0.0940	−0.0093	−0.0049	−0.0045
Gloucester, NJ	−0.0117	−0.0033	−0.0025	−0.0023
Cumberland, NJ	NA	NA	NA	NA
Other	−0.0075	−0.0001	−0.0015	−0.0015
Breakdown by industry				
Agriculture	−0.0026	0.0000	−0.0024	−0.0024
Mining	0.0002	0.0000	−0.0016	−0.0016
Manufacturing	−0.0021	0.0000	−0.0010	−0.0010
Service/other	0.1209	0.0100	−0.0635	−0.0591
Overall	0.0926	0.0088	−0.0031	−0.0029

industrial corridor area, including the CBD, rest of the city, and other counties including western Cook County in the Chicago case. In the case of Philadelphia, impacts are spread among the rest of Philadelphia (rest of Adams County), Chester County, and Mercer County, New Jersey.

Industry Differences

The results vary dramatically by industry. Consistent with the CBD scenario, most benefits accrue to the service industry in both cities. In Chicago, services are followed by mining, whereas in Philadelphia, agriculture follows services.

OVERALL IMPLICATIONS

The analysis results in this chapter indicate that industries with higher levels of truck shipping absorb higher costs associated with congestion and thus benefit more from congestion reduction. The statistical analysis also shows that firms with nonspecialized (commodity) input requirements tend to be hurt relatively less by congestion (and benefit relatively less from congestion reduction) than those with requirements for highly specialized material inputs, because the former can more easily adjust to congestion by substituting closer suppliers.

The case studies also indicate how congestion impacts can differ depending on the nature of the congestion scenario.

For instance, when congestion was assumed to be centered in the CBD, the economic benefit was largely concentrated on those businesses located in the CBD. That is because many of those CBD businesses are service oriented, relying on incoming deliveries of supplies but with relatively modest movements of outgoing truck deliveries to other parts of the metropolitan area. When congestion was assumed to occur equally throughout the region, the analysis models indicated that economic impacts would be most pronounced in the CBD and in the most densely industrialized areas, which are particularly dependent on incoming trucks for deliveries of supplies. Finally, when congestion was assumed to be centered around an older industrial area outside the CBD, the economic benefits were widely distributed among industries and business locations throughout the metropolitan area. That is because the directly affected businesses had a high level of outgoing truck shipments, serving broad industries and locations from the CBD to outlying fringe areas.

These examples indicate how congestion impacts can vary among both types of businesses and locations within a metropolitan area. More importantly, they demonstrate that the economic impacts of congestion are experienced not only in the congested areas but also in other areas that are economically linked by product delivery patterns. This highlights the importance of understanding truck movements within metropolitan areas.