WHITE PAPER 4

ECONOMIC EVALUATION OF IMPROVED RELIABILITY

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Executive Summary

Over the past several years, the Oregon Transportation Commission (OTC) has initiated a review and assessment of the potential implications of highway tolling and pricing. This assessment produced a discussion about tolling and pricing options for Oregon and the ways these options might be put into practice. These ideas were documented in a report prepared for the Oregon Department of Transportation (ODOT) titled *The Future of Tolling in Oregon: Understanding How Varied Objectives Relate to Potential Applications* (Cambridge Systematics 2007). Several important questions about how tolling might be implemented and its potential effects arose from this report. This paper is one of a series of papers commissioned by ODOT to highlight specific topics required to develop a *". . . comprehensive and analytically sound set of policies regarding the potential use of tolling in Oregon."*

Properly applied, either fixed or dynamic pricing can reduce traffic volumes, especially during peak travel periods when congestion bogs down large parts of the highway system. Reduced traffic volume helps to maintain free flow conditions and, in so doing, may assure the motorist both a faster and a more "time certain" trip over tolled portions of the highway system. The ODOT Future of Tolling `report identified improved reliability – i.e., reduction in the variability and uncertainty of travel times – as one of the most important results of using pricing and tolling for traffic management. This increase in reliability has an economic value for motorists.

There have been no systematic attempts either to quantify the value of improved reliability or to factor it into economic evaluations of priced and non-priced highway corridor alternatives in Oregon. This white paper:

1. examines ways to measure reliability,
2. reviews the ways reliability can be included in an economic analysis of pricing and tolling policy, and
3. discusses some of the practical implications of measuring and evaluating reliability for the pricing and tolling applications identified in the Future of Tolling report.

Measuring Reliability

Measuring reliability has proved difficult in the past because it requires more than just estimating the average travel time between two points. Instead, reliability measures have to account for the entire range of travel times that motorists are likely to experience between two points. This means the time needed to make each individual trip has to be measured and recorded. Recent advances in technology and vehicle detection have made it possible to measure reliability for limited access highways where vehicles entering and exiting the highway can be monitored.[1] The most significant issue in measuring reliability is that there are no current techniques for accurately determining reliability for major arterials or primary and secondary roads. Reliability measurement technologies have only been applied to limited-access highways. This is a fundamental problem in assessing the economic impacts of tolling and pricing policy, because there are inevitably motorists who cannot or

[1] Such a system is in place in the Portland metropolitan area. It measures reliability on several – but not all – of the region's Interstate Highways and a few of the limited-access state highways that connect to the Interstates.

will not pay the toll and choose other, untolled routes. These "diverted" motorists increase the congestion on untolled routes, which are invariably local roads and arterials connecting points otherwise accessible via the tolled roadways. Because we cannot measure the effects of reduced reliability on such roads, we cannot determine the effects of reduced reliability on roads that receive diverted traffic. As a result, we can only address the benefits of improved reliability, not the detrimental effects of diverted traffic for travelers on these associated, untolled roads.

Economic Analysis of Improved Reliability

Economic effects depend on how reliability is valued by each trip-maker and how the consequences of improved reliability are reflected in decision-making and commercial cost management. The most important distinction is between personal and commercial travel. For *personal* travel, there is extensive research on the value of travel time (including the value of variation in travel time – which is a key element of reliability), personal trip-making decisions, and the relationships between travel activity and trip/tour-making characteristics. Most of the more recent survey-based information on personal travel choices and behaviors captures the *direct* effects of improved reliability on personal travel choices. It is a relatively straightforward exercise to determine the overall value of reliability improvements, but *only* if appropriate measures of reliability are available for all affected roadways.

In contrast, there is substantially less information available about the *indirect* effects of changes in reliability on personal travel. How the overall amount of travel is constrained or expanded by improved (or reduced) reliability remains largely unaddressed in the research and associated data collection activities. For tolling projects of limited scope, such as tolling a single freeway or building a new freeway, these indirect effects are usually negligible. But for projects of a larger scope, such as system-wide pricing or cordon pricing, indirect effects may be substantial.

The effects of reliability on the *costs* of commercial (business) travel are well understood and have been extensively studied and documented in the business logistics literature. However, the *economic* consequences of improving reliability of highway systems have not been systematically included in highway planning and project evaluation. One of the most difficult aspects of such an evaluation is that each sector of the commercial economy or business "cluster" has very different ways of responding to and managing transportation costs. This is because the transportation cost component of production varies greatly, depending on how each industry has organized its logistics support and production processes.

A major misconception about economic evaluation of reliability on business travel is that the true costs of improving reliability can be assessed simply by valuing the combined effects of reliability on over-the-road travel time savings and the reduction of travel time variation. While these are important elements of commercial transportation, there are often behind-the-scenes operations that are highly dependent on the reliability of deliveries and shipments. These dependent operations – whether related to inventory control, production scheduling, warehouse systems management or the number of vehicles and drivers to employ – vary greatly depending on the type of business and how it uses the transportation system.

Emerging research on the effects of reliability on commercial travel highlights the relationship between transportation system reliability and business productivity. Productivity of commercial transportation influences the ways businesses can access new markets or respond to challenges in serving existing markets. However, very little attention has been paid to gathering the kind of business and operations data needed to assess the effects of reliability on commercial operating costs, or to incorporate these costs into traditional travel demand modeling. Thus, there is a serious gap in our knowledge about how tolling and pricing policy influences business productivity.

Reliability and Tolling Applications

Tolling and pricing options range from adding one or two new toll roads to tolling all or part of existing freeways (toll managed lanes or HOT lanes) to charging tolls to operate vehicles within designated areas (cordon pricing). As the size and complexity of tolling applications increase, measuring the effects of tolling on the reliability of both tolled and untolled roads becomes more difficult. Even for the most straightforward of tolling options – tolling a new highway – measurement of changes in reliability requires taking diversions to arterial and secondary roadways into account. It may be possible to estimate some localized effects of reduced reliability due to congestion of local roads. But converting a large number of existing freeways to tolled roads or imposing area-wide or cordon pricing will require inventing ways to measure reliability that are far more extensive than current methods. This is a major hurdle in developing the information needed to evaluate the economic effects of changes in reliability.

Even if these measurement issues are overcome, there is a substantial gap in our ability to evaluate the economic consequences of improved reliability on personal and commercial travel. The *direct* effects of improved reliability can be reasonably evaluated for personal travel for most of the single-project pricing applications envisioned in the Future of Tolling report. However, as the complexity of pricing applications is extended to more comprehensive pricing schemes like multiple freeways or cordon pricing, assessing the offsetting reductions in reliability on untolled highways that receive diverted traffic will be central to determining the net economic impacts of these proposals. The *indirect* effects of reduced reliability on personal travel also become a significant component of an economic evaluation. Estimating indirect effects depends a great deal on measuring the ways that diverted traffic affects local roads, neighborhoods, and travel patterns.

Evaluating the effects of tolling applications on commercial operations will require significant advances in available information and research before the economic effects of reliability can be assessed with even a reasonable degree of confidence. Although the business logistics literature covers the effects of reliability on process design and logistics costs, little if any of this information has been synthesized to support the kind of analysis needed to assess the economic effects of changes in reliability on highway systems. Changes in highway system reliability can have major economic impacts on business operations, productivity, and market access. These factors can influence the economic competitiveness of a region or a state. Therefore, the economic impacts of tolling and pricing on commercial operations should be carefully evaluated, especially if system-wide pricing is considered (such as for a large number of major freeways or for area-wide pricing). Even in situations where single facility pricing is an option, changes in operations in response to the direct and indirect effects of pricing can affect the competitiveness of businesses that routinely use the priced facility or the roads that receive diverted vehicles. The primary concern is not so much for the effects of improved reliability on long-distance and high-speed commercial travel, but for the economic effects of diversions on local streets and the impacts such diversions will have on the reliability of the "last mile" moves required for all commercial travel.

Chapter 1: Introduction

Oregon's ability to ensure a reliable, effective highway transportation system is an important element in achieving the state's land use, growth management, and economic development goals. Building, operating and maintaining a reliable highway system requires a continuing series of capital investments that must address a wide range of needs, from replacing worn-out or deteriorated infrastructure, to expanding capacity to meet increased demand, to managing the system to use new and existing capacity effectively.

This last need—managing the State's highway infrastructure—has been the focus of a series of planning and policy initiatives by the Oregon Department of Transportation (ODOT). One alternative receiving attention is to use tolling and pricing to manage existing highway capacity, help pay for new investments, and improve future highway operations.

Introducing tolling and pricing options, however, requires examination of a number of issues. In particular, methods are needed to evaluate the relative effectiveness of alternative tolling proposals. Historically, the effectiveness of congestion relief has been measured by reductions in travel times. But recently, interest has turned to other measures of effectiveness, and the need to address both direct and indirect benefits of transportation improvements.

Reliability

The federal government defines transportation reliability as *"consistency or dependability in travel times, as measured from day-to-day and/or across different times of the day*."

In particular, increasing the *reliability* of a roadway or segment of a roadway—that is, decreasing the *variation* in travel times associated with that roadway or segment—has been the subject of much recent research and debate. Of course, using increased reliability as a basis for managing and pricing highways means we must be able to evaluate the *effects* of reliability. This paper examines the issues associated with measuring reliability and the effects of changes in reliability on both personal and commercial travel decisions under various tolling and pricing options.

The Problem with Using Travel Time to Evaluate Congestion

One of the most popular indicators of congestion is published every year by the Texas Transportation Institute (TTI) in its *Urban Mobility Report*. Using a composite measure of the time spent in congested conditions, TTI has documented how congestion has increased every year since 1982. According to the most recent TTI data, the amount of time drivers in Portland, Oregon spend in congested conditions during peak hours has risen from about 12 hours per year in 1982 to 37 hours per year in 2005!

For the 25 cities with populations between 1 and 3 million (Portland's "peer group"), the hours of delay per peak hour traveler has been above the national average. Many cities in this group have added highway capacity at rates much higher than Portland, yet have seen little appreciable difference in the effects of peak hour congestion. This suggests that travel time and the number of hours spent in congested conditions may not be the best way to gauge the effects of congestion or to measure the ways we have traditionally sought to reduce it.

Adding highway capacity to reduce congestion is still an important part of the solution to increased congestion, especially where there are bottlenecks or where land use activities have intensified. However, adding capacity is not the only solution to congestion in urban areas, and may not always be the most effective one. The dilemma of adding highway capacity in urban areas was summarized well in Anthony Downs' seminal work on this subject, *Stuck in Traffic* (Downs 1992). Downs described how difficult it is to eliminate congestion and the delays associated with it. In fact, he believes that congestion and delay, when associated with population growth and increased economic activity, are positive signs of a healthy economy and should be expected. Using the *principle of triple convergence*, Downs described the dilemma metropolitan highway planners face when trying to solve congestion problems with capacity enhancements:

> *". . . any large initial reduction of peak-hour travel times on a major limited-access roadway will soon be offset by the subsequent convergence on that roadway of drivers who formerly (1) used alternative routes, (2) traveled at other times, or (3) used public transit."*

In *Still Stuck in Traffic* (2004), Downs suggests that *selective* tolling and traffic management strategies (such as rapid incident response and real-time information dissemination to drivers) are likely to be among the most successful ways of dealing with congestion in metropolitan areas. However, Downs also has argued forcefully that congestion will be a fact of life as long as population and incomes are growing and the economics of successful metropolitan regions requires large numbers of people to work together in time and space (Downs 2006).

Research and experience demonstrate that people come to expect, plan on, and cope with delays associated with congestion. Peak hour drivers *expect* traffic to move more slowly and are willing to accept longer travel times. They usually anticipate delays during peak hours, and adjust trip plans accordingly. But what people find most frustrating and costly are *unexpected* delays in congested periods. Leaving half an hour early for the airport is futile in the face of an *unexpected* additional hour's delay that results in a missed flight.

Why Reliability Provides a Good Measure of Congestion's Effects

So, if congestion is a fact of life and we need to learn to live with and manage it better, how can we tell if our efforts to manage it are making a difference? Using travel time reduction as measure of effectiveness provides limited insight into the effects of congestion reduction because of Downs' principle of triple convergence. As time saved by drivers on an improved highway increases, others who had previously given up using that part of the highway system, those who may have shifted to transit, or those who have chosen to travel at another time will tend to move back into their prior patterns until the travel times again become intolerable. This is what TTI has been so successful in measuring, and why congestion seems to be getting worse if we measure only increasing travel times.

The limitations of using travel time savings to measure congestion reduction explain why *reliability* has become such an important indicator of the effects of congestion. Reliability captures a fundamental aspect of congestion and traffic flow essential to users of the highway system—the *predictability* of travel time, regardless of the trip length or travel time required.

Recent research on the value of travel time for both automobile users and commercial freight operations has demonstrated that both the average time required to make a trip and the *variability* of travel time are measurable and significant. We are beginning to understand that the most successful approach to managing congestion requires balancing capacity enhancements at key bottlenecks and choke points with better overall traffic management and monitoring for the entire system. Capacity improvements can reduce the total travel time it takes to get from place to place, while reliability improvements reduce the *uncertainty* associated with our trip decisions. Thus, both capacity and reliability have important roles to play in evaluating the economic effects of transportation system investments.

These three concepts—predictability, variability, uncertainty—are keys to defining and managing reliability. Determining the economic value of reliability is crucial to understanding people's willingness to pay for highway system improvements, either through congestion pricing/tolling or by more traditional means such as fuel taxes and auto-based fees. Reliability also is becoming more relevant for managing and monitoring the efficient use of existing capacity, especially as the technology required for measuring it improves.

This white paper discusses several key considerations that must be weighed when deciding how to use measures of reliability in evaluating the economic effects of managing congestion. The paper covers the following topics:

- Defining Reliability – a discussion of what reliability is and why travel market segmentation is important;
- Measuring Reliability – a discussion about how reliability can be measured and how direct and indirect effects should be addressed; and
- Analyzing the Economic Effects of Improved Reliability – a review of the economic impacts of improved reliability on personal and commercial highway users.

The paper also includes technical appendices with information for readers who want to know more. Topics include current research into the relationships between reliability and economic evaluation, technical aspects of collecting and analyzing reliability data, and ways that reliability measurement and evaluation can be integrated into decision-making.

Reliability and Tolling Applications

Interest in congestion pricing and tolling in Oregon has resulted in a review of the various approaches that might be used for one or more forms of highway tolling (Cambridge Systematics 2007). This review outlined several approaches to pricing, each with implications for how reliability will need to be measured, monitored and evaluated.

When considering the effects of tolling on reliability, it is important to understand that *how* tolls are imposed on any new or existing highway facility is just as important as *how much* tolls cost. *Fixed tolls* manage congestion by using people's unwillingness to pay for travel time savings to reduce the number of vehicles on a highway, thereby improving travel times enough to compensate for the cost of the toll. Reducing traffic volume usually results in a more reliable trip. However, although fixed tolls may discourage travelers from using the facility at first, over time, travelers tend to adapt to tolls and adjust their travel choices accordingly. If, over time, enough additional travelers choose to pay the fixed tolls, congestion may increase and reliability may decline, raising the issue of whether tolls should be increased. Raising a fixed toll is usually a difficult decision unless there is consensus on the purpose for imposing them in the first place and unless users of the roadway recognize clearly the relationship between the toll and highway performance.

Dynamic tolls are tolls that are adjusted by time of day (e.g., higher in peak hours and lower in off-peak hours) or are based on traffic volume on the tolled facility at the time of use. Dynamic tolling is often able to provide higher reliability because the variability of demand on the facility is closely monitored, and tolls are adjusted to manage demand and maintain a pre-determined operating standard.

Each type of tolled facility described below could use either fixed or dynamic tolls. In most cases, reliability should be higher with dynamic tolls than with fixed tolls. For tolled facilities of any type, performance may be adversely affected by connecting, untolled facilities. With the exception of cordon area pricing, overall reliability of the entire trip will be only as good as the least reliable part of the highway network used by the traveler.

Tolling New Facilities

Constructing a new tolled facility—highway, bridge, tunnel, etc.—creates new capacity but also imposes an additional, direct cost on users. If tolls are fixed, reliability may improve in the short run. However, over time, the principle of triple convergence may reduce reliability improvements if the tolls are not adjusted upwards as needed. Dynamic tolls may deliver more consistent reliability on a new facility, but if roadways feeding or fed by the facility are congested and operating in an unreliable manner, the overall reliability of affected trips will be compromised.

Creating Toll Managed Lanes

Toll managed lanes include a variety of options. One option is to convert high-occupancy vehicle (HOV) lanes to high-occupancy tolled (HOT) lanes. Another is to convert an existing general purpose (GP) lane to a HOT lane or express toll lane (ETL). In each case, the decision to use fixed or dynamic tolling will influence the reliability of travel on the facility. However, as with new tolled facilities, the overall reliability of the entire trip will only be as good as the reliability of the rest of the system.

When GP or HOV lanes are converted to HOT lanes, travel reliability of the GP lanes may or may not be affected. In the short term, reliability should improve as some former GP users now choose to pay to use the tolled lanes. However, in the long run, as drivers who had chosen other routes or modes become aware of the improved conditions, volumes and reliability of the GP lanes are likely to return to pre-toll levels.

Converting an Existing Freeway to a Tollway

Converting an existing freeway to a tollway can result in many of the same reliability problems as tolling a new facility. Certainly, drivers who use the tolled facility should see some improvement in reliability (provided the tolls are set sufficiently high to divert some drivers to other routes). But in light of the principle of triple convergence, if improving reliability is the goal, then the performance of the tolled facility should be reviewed periodically to ensure that the tolls are accomplishing their intended purpose.

Drivers who choose not to pay tolls will need to find other routes. If less congested routes are available but diverting to these routes increases overall travel time, the predictability and variability of travel for these drivers may remain the same. However, uncongested alternative routes that provide comparable overall travel time and reliability will often not be available. Therefore, drivers who are priced off an existing freeway may face both greater overall travel times *and* lower reliability.

Traffic on highways that receive diverted traffic from a tolled freeway may be adversely affected for several reasons. The first is simply due to the volume of diversions from the tolled facility, as discussed above. Another reason is that a properly priced freeway will tend to generate higher peak traffic volumes, and some of this traffic will eventually need to use the non-priced portions of the system to complete trips.

Experimentation with freeway conversion has been limited. Most demonstration programs and tolled highways are relatively isolated. Whether increasing the number of tolled highways will improve overall system reliability or just the reliability of the tolled facility is yet to be determined. As more highways in metropolitan areas are converted to tolled facilities, it will be important to monitor the reliability of *both* tolled and untolled facilities. One of the unintended consequences of tolling is the possibility that improved operating performance of the freeway system may be offset by congestion and reliability problems on untolled roadways.

Convert an Entire Freeway System to Tollways

Conversion of an entire freeway system to tollways is appealing from the standpoint of overall system operational efficiency. Under either a fixed or dynamic tolling system, performance of highways included in the tolled network would be significantly improved. However, as noted above, monitoring the reliability and overall performance of the entire highway system—not just tolled segments—would be extremely important.

Diversions from the existing freeway system would likely increase congestion and reduce reliability on local roads and untolled highways. Drivers using the tolled highways would eventually have to use these same local roads to complete their journeys. If the reliability on the "last mile" segment of local roads, truck routes, and major arterials deteriorates due to diversions from tolled highways, many of the benefits of tolling as a means to improve traffic flow and system reliability would vanish. [2]

Cordon/Area Pricing

In a cordon pricing system, drivers pay to enter or operate their vehicles in a predefined area, typically a city center or well-defined geographic area like the central business district (CBD) or, conceivably, the Urban Growth Boundary (UGB). Limited access highways can be used to define a cordon as long as they provide a continuous and identifiable boundary for the area to be tolled. Regardless of the scale, the effects of cordon pricing on reliability of the highway system would be difficult to determine without careful monitoring of all roadways.

If the cordon is properly priced, current practice shows that traffic volumes within the cordon decline and both speed and reliability of travel increase, at least in the short run. However, immediately outside of the cordon area congestion may increase and reliability may be reduced as travelers move around the periphery to avoid the cordon charge. Thus, the problem of monitoring cordon pricing is similar to that of monitoring multiple freeway conversions. Periodic, network-wide monitoring of the system's performance and reliability would be needed to ensure the system is

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[2] As shown in Appendix D, there are a number of local roads whose functions are vital to freeway drivers in the Portland region.

functioning properly and that congestion and bottlenecks on untolled roads at or near the periphery do not undermine the performance of the entire system.

Conclusion

This set of possible tolling applications frames the range of possible approaches that can be used for implementing tolling in Oregon. By examining these examples, we can more easily understand how the scale of tolling affects its overall impact. Single-corridor tolling projects have limited, localized effects, while area-wide or cordon pricing will produce broader, regional effects. Our ability to analyze the economic impacts of tolling and pricing depends on our ability to measure the effects of improved reliability for each of the applications, and to characterize the economic value associated with improved reliability for both personal and commercial travelers. As the geographic scale increases, measuring and analyzing economic impacts of improved reliability will become more complex and more difficult.

Reliability in Tolling and Pricing Policy

This discussion of the economic evaluation of improved reliability is part of a broader series of eight White Papers developed for ODOT. These White Papers cover a range of topics dealing with economic, environmental, and implementation issues that affect the future of highway tolling and pricing in Oregon (see Appendix A).

These White Papers are organized around three topics designed to help focus public discussion on tolling and pricing in Oregon:

A. Refining ODOT's tolling and pricing policy objectives with respect to current environmental concerns;

B. Describing methods of analysis to assess the effects of tolling and pricing policies; and

C. Assessing how tolling and pricing should be implemented and how the relevant policies should be communicated to the public.

This paper addresses one of the four methodological issues included in topic B—economic evaluation of improved reliability. The other issues under topic B are estimating traffic demand on tolled facilities (White Paper 3), the economic effects of congestion pricing (White Paper 5), and the economic comparison of tolled and non-tolled highway improvement alternatives (White Paper 6).

Chapter 2: Reliability of Transportation Systems: What it is and Why it is Important

Although there are many ways to define reliability, a consensus among transportation professionals has emerged on the basic requirements of a reliable transportation system. These technical definitions of highway system reliability focus on the *measurement of variation* in observable travel patterns and the degree to which these variations exceed the expectation of "normal" or "design" conditions. Measures of reliability are different than the typical design measures for which most planning and travel demand modeling has been developed. Typical planning and engineering metrics focus on reducing travel time, assessing the relationships between the capacity of a segment of highway and the number of vehicles using that segment, and determining if the system is providing the desired level of service. In contrast, reliability focuses on the *variation* in these measures and the degree to which this variability is greater than what might normally be expected to occur.

Defining Highway Reliability

The federal government has offered a definition of reliability that focuses on users' expectations for predictable travel: ". . . *consistency or dependability in travel times, as measured from day-to-day and/or across different times of the day*" (FHWA 2008). Using this view of reliability, the FHWA suggests that one of the objectives of improving reliability is to reduce the variability (i.e., improve the predictability) of travel. The concept applies equally to a particular roadway or to an entire highway system. Recent research into the factors that affect both individual roadway operations and overall system performance defines travel time reliability as: *". . . the percent of trips that reach a destination over a designated facility within a given travel time (or equivalently, at a given travel speed or higher)"* (Elefteriadou and Cui 2007).

Federally-sponsored research under the Strategic Highway Research Program (SHRP2) highlights an important aspect of reliability—the ability to distinguish between recurrent and non-recurrent congestion. The definition of travel time reliability recognized by SHRP2 links the operational and physical characteristics of a highway system into a more "inclusive" definition of the factors that influence reliability:

> "*Travel time reliability refers to how travel time varies over time and the impacts of this variance on highway users. In other words, for repeated travel or vehicles making similar trips, there is an underlying distribution of travel time for a particular type of trip within a specific time period between two points."*
> (SHRP2 Program Web Site)

SHRP2 organizes the factors that influence reliability into seven broad categories:

1. traffic incidents
2. work zones
3. weather
4. special events
5. traffic control devices
6. fluctuations in demand
7. inadequate base capacity

Each of these factors can affect reliability by influencing the severity and uncertainty associated with both recurring and non-recurring congestion and related delays (NCHRP 2003). There is a fundamental, inverse relationship between reliability and variability associated with highway travel that needs to be captured in any definition of reliability:

Reliability = 1/Variability

Thus, the more *variability* there is in the time it takes to make a trip, the less reliable the system seems. We usually think of variability as resulting from a combination of fluctuating demand (such as peak versus off-peak traffic) and inadequate capacity. Variability increases when demand is greatest because traffic moves more slowly and sporadically when highways are congested. Although we attempt to design highway systems with adequate capacity (*supply*) for typical and foreseeable volumes (*demand*), it has not been possible to provide the capacity needed to handle peak hour traffic.

Determining the reliability of travel time would be relatively straightforward if highway users could anticipate variability with some degree of certainty. But as demand grows, the effects of congestion on reliability become less predictable. If travelers understand that predictable delays or congestion will add to the time for a particular trip, they can build that expectation of delay into their travel plans. But three of the seven factors that influence reliability—traffic incidents, weather and fluctuations in demand—are inherently *unpredictable*. These situations create *uncertainty*, leaving travelers less able to plan effectively. It is not so much the variability of travel time, but the *uncertainty* associated with this variability, that leads to perceptions of the system as unreliable.

Factors in Reliability

The concept of reliability includes three primary factors:

- *Variability* – how much variation is there in travel times between two points?
- *Predictability* – how well can users predict travel times?
- *Uncertainty* – how effectively can users plan their trips?

Uncertainty is increasingly recognized as a factor in reliability, for highways and for entire highway systems. As a result, more sophisticated assessments of reliability have introduced variability, predictability and uncertainty into the assessment of reliability, changing the "equation":

Reliability = 1 / (Variability, Predictability, Uncertainty)

Each of these concepts—variability of travel time, predictability of variation, and uncertainty associated with trip-making—needs to be incorporated into a formal definition of reliability. These factors are discussed in Chapter 3, along with discussions of how they are used and the ways in which the information needed to create these measures is collected and applied to estimating reliability.

Reliability and Travel Market Segmentation

Households, businesses, public institutions, and a wide range of service providers need a reliable, safe and predictable highway system to manage their lives and run their businesses. Each of these constituencies uses the same highway system, yet each demands performance from the system based on different abilities to absorb the costs and effects of deteriorating reliability. Therefore, each constituency has a different tolerance for reduced reliability. These differences are directly associated with the value of travel time and reliability for each user, and as discussed below, the costs of reliability can produce very different responses for each.

Given this segmentation of responses to system reliability, we can view each of these user groups as a distinct "market" for highway services. Their responses to changes in the way highways deliver reliable services can range from forgoing or substituting trips (in the case of households and businesses) to forgoing expansion or moving operations out of a region or even out of the state entirely (in the case of businesses.)

Household Highway System Use

Households use highways for a wide range of purposes, including getting to and from work, shopping and recreation, managing a range of daily activities (such as child care), and a host of other personal and cultural needs. Their ideas of what constitutes a reliable transportation system are based on the need for predictability. This need varies in importance, depending on the purpose and urgency of a trip. Some trips require advanced planning and have an important consequence attached to a late arrival, such as missing an airline flight. These kinds of trips require travelers to anticipate accurately the extra time they may need based on their prior experience with delays or congestion en route.

Other household trips are more urgent but offer less opportunity for advanced planning or adjusting departure time. These may include picking up a child at day care after work or keeping a doctor's appointment, activities for which departure times are constrained by other activities and arrival times are inflexible. Still other trips—shopping, recreation, or other discretionary travel—may be neither urgent nor time-sensitive. However, delays or unexpected congestion may still be frustrating and, if chronic, may cause travelers to alter their travel choices.

If household members know they can count on a trip taking a certain amount of time, they will generally adjust their schedules to accommodate this requirement. When system reliability deteriorates, they respond either by building the extra time into their schedule (occasionally foregoing other trips) or, if the deterioration in reliability persists, by changing travel patterns.

Most people understand how their own travel patterns and use of the highway system are affected by system reliability. In analyzing the use of transportation systems, planners and engineers have traditionally associated trip purpose and frequency with household income, location, family size and household composition. This has resulted in a large literature on the travel demand for several household market segments defined by these characteristics. Considerable attention has been paid to household travel behavior, because the vehicular volumes and aggregate amount of travel time used by home-based travelers is relatively large. Neither the public nor, to some extent, transportation planners are as familiar with the consequences of the erosion of reliability on business uses of the highway system.

Business Highway System Use

Business use of the highway system is based on a more complex set of considerations with a wider range of possible consequences than those associated with household use. Businesses tend to be:

- Highly differentiated in terms of transport requirements, especially within key sectors or clusters.
- Dependent on specific links to suppliers and markets provided by the highway system.
- Sensitive to costs of reliability on the highways over which they operate.
- Less able to re-structure of their logistics support for receiving and shipping goods and services in the short-run.
- Very sensitive to transportation costs as they affect overall supply chain management.

Every business depends on the highway system to some degree. Each values time differently, and each bases the design and operation of its transportation support systems on past experience and the requirements of the particular business. Larger industries often have extensive supply chains needed to keep their manufacturing, warehousing and distribution system operating smoothly and efficiently. Most of these larger businesses manage logistics costs closely, and have integrated logistics operations into overall production and inventory control systems. They depend on the transportation system to provide reliable service in order to manage costs.

Over time, businesses also may adjust logistical operations to reflect reduced reliability of the highway system.[3] However, such changes, and the attendant costs and efficiency losses, are often overlooked in assessing the impacts of reliability on regional or state economies. From an economic analysis standpoint, the un-measured and under-valued effects on businesses of deterioration in highway system performance are significant and can potentially overwhelm similar effects on the household sector (Portland Business Alliance et al. 2005).

Much has been made of changes in the economy of metropolitan areas as they move away from activities concentrated in 20th century manufacturing and extractive industries toward more service- and technology-oriented businesses. The assumption has been that because the 21st century economy is less dependent on transportation-reliant manufacturing and extractive industries, the need for reliable commercial transportation has been reduced. In fact, many of the logistics and commercial transportation services that support technology- and service-intensive industries are even more dependent on highway system reliability than traditional industries. This is because:

- Inventory management is often more complex, involving the rapid flow of a more diverse mix of intermediate and finished goods.
- Profit and operating margins are smaller because of highly competitive global markets.
- Effective internal cost management requires keeping less inventory and produces greater cost impacts for late deliveries of intermediate goods.

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[3] Certain highway dependent industrial sectors, such as warehousing and distribution, have seen efficiencies in automated warehouse management and control eroded reduced highway system reliability.

- The value of cargoes are greater per ton because components are more technologically complex and have more added value, thereby placing greater emphasis on transportation reliability.

Thus, for most technology-driven and high value-added manufacturing industries remaining in the U.S., the transportation system has become an integral part of inventory management systems, and many service and technology-oriented industries require even greater emphasis on high levels of logistics service. Sustaining these industries will require greater—not lower—reliability of the surface transportation systems.

Reliability has become an important consideration as decisions about transportation investments have been subject to more financial scrutiny and as capacity expansion has been limited by concerns about environmental and land use impacts. The focus on household travel and costs has not been balanced with a similar depth and rigor in assessing the costs of travel time and reliability improvements for commercial users of the highway system. As both international and domestic markets for goods and services traditionally produced in Oregon become more competitive, transportation costs and the cost-effectiveness of using the highway system has become a more noticeable and significant factor in attracting, retaining and preserving the competitiveness of both service and manufacturing businesses. Reliability is one of the most important and least understood elements in transportation planning and investment decision-making.

Pricing and the Economic Importance of System Reliability

Although transportation services for both personal and commercial highway users are measured in similar terms (e.g., travel time, reliability), the economic consequences for each class of user will be quite different. Each class or class subgroup constitutes a distinct "market segment" with different ways of balancing the cost of transportation services against other investment factors. (In this sense, a household creates "product" in the form of both financial and social value for various members of the household.) Thus, each segment of the market is likely to value reliability differently and will have a different willingness to pay for these services.

With the exception of a limited number of toll bridges, highway users in Oregon pay for transportation services through fuel taxes and various registration fees. Certain classes of commercial vehicles pay mileage-based fees instead of fuel taxes. Any of the pricing or tolling applications currently under consideration would involve an increase in out-of-pocket costs to users, thus changing the basic underlying cost structure.[4] Even if tolls are fixed and similar for all vehicle types, the advent of tolling in Oregon would fundamentally change how highway system users think about and use Oregon's highways. Households and businesses using tolled facilities would have to absorb the resulting costs into their budgets or business expenses. If reliability of the tolled facilities (or some combination of travel time and reliability) were to improve sufficiently to completely offset the costs of tolls, the net cost would be zero. To determine if there is a net increase or decrease in overall costs to users, reliability would have to be measured for both tolled highways and untolled highways receiving diverted traffic. The effects of changes in reliability on the costs of highway travel would have to be assessed for each market segment affected by the tolling system put in place.

[4] This assessment assumes that there is no "offset" in user fees designed to reduce or neutralize the effects of tolling on commercial travelers.

These kinds of considerations highlight the fact that evaluation of the economic impacts of implementing one or more types of tolling or pricing involves analysis and measurement of reliability that are potentially complex and that have rarely been done before. The next two chapters explore issues in the measurement and economic evaluation of changes in reliability with these considerations in mind.

Chapter 3: Reliability Issues and Measurement

Direct Measures of Reliability

The ability to directly assess reliability requires devising ways to measure it. Such measures must be able to relate information about differences between *expected* and *actual* travel times and operating conditions. They also must be able to establish some monetary value for differences between actual experience and users' expectations.

It is clear from the various definitions of reliability that planning practices focused on average point-to-point travel time (measured in minutes) or the relationships between the observed usage of a highway and highway capacity (Level of Service) are not sufficient. Reliability should not be measured by average time required to make a trip, but by the *difference* between average travel time (expectations) and some measure of the range of times likely to be encountered. More sophisticated measures of reliability also estimate reliability by time of day, because variations between expected and actual travel times can be different during peak hours than off-peak hours.

Suggested Methods of Measurement

There is no single measure of reliability (Elefteriadou and Cui 2007). However, several have recently been developed (FHWA 2008). Because these measures are relatively new, they have not generally been used in project evaluation or for metropolitan and statewide planning.[5]

Direct measures of reliability can be classified under three general headings:

- Travel Time Dispersion
- Congestion/Reliability Indices
- Threshold/Exceedance Measures

Travel Time Dispersion

There are two measures of travel time dispersion:

1. Standard deviation of observed travel times between two points.
2. Percentile measures.

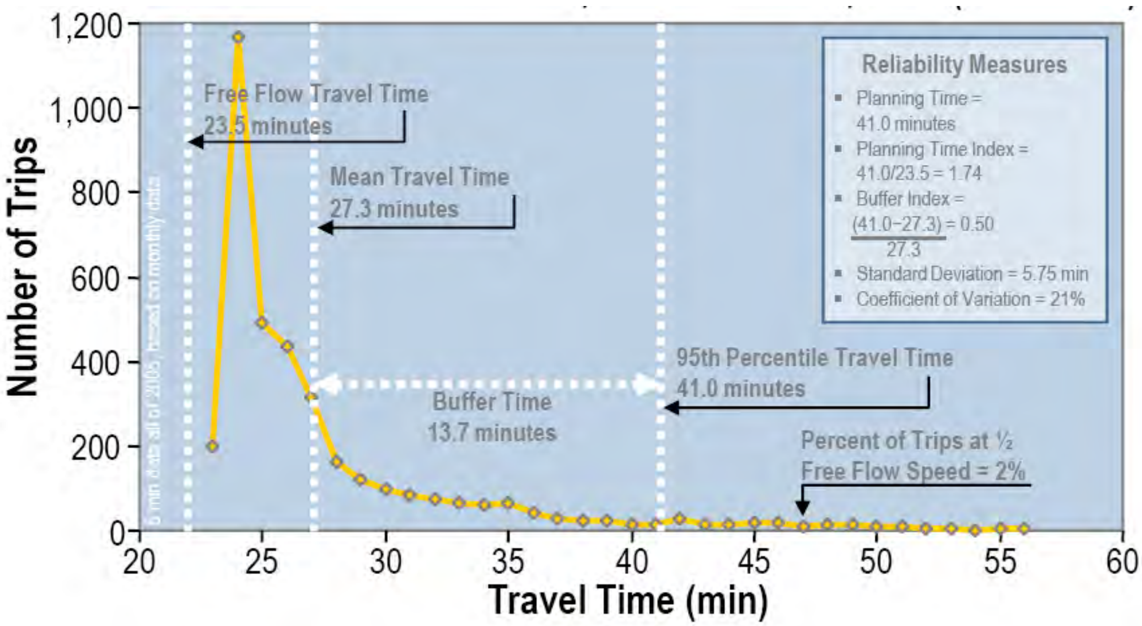
Standard deviation measures the distribution of observed travel times for all vehicles (or a random sample) for a particular section of highway. It is a straightforward measure of dispersion about a mean value and is easily computed. It can be used in statistical analysis of reliability by time of day and can help to determine if reliability is changing over time. The major drawback in using standard deviation as a measure of reliability is the implicit assumption that the distribution about the mean is symmetrical – that is it is equally likely that traffic will be faster or slower than the mean travel time. Traffic patterns are not usually distributed uniformly around a mean time (see Figure 1).

[5] A recent survey of 382 Regional Transportation Plans (RTPs) found that none of them used reliability as a basis for project evaluation, although a few RTPs used reliability measures to set future performance goals for their plans (Lyman and Bertini 2008).

As with standard deviation, when using percentiles, individually observed travel times between two points are measured and analyzed. There is no implicit assumption about the shape of the distribution. The analyst simply selects a level (percentile) that represents the desired degree of reliability (e.g., the percentage value for "expected" travel time assumed to be tolerable for most travelers). For example, if the 50th percentile of all measured travel times between two points is 32 minutes (see Figure 1), then 50 percent of all trips between these two points take 32 minutes or less. The other half take longer than 32 minutes. If we want to know how long it will take 9 out of 10 vehicles to travel between these two points, we would use the 90th percentile travel time. If we want to know how long it takes 19 out of 20 vehicles to make this same trip, we would use the 95th percentile (in Figure 1, 41 minutes).

While quite good for comparing the reliability of the same parts of a highway network over time (or before and after improvements designed to increase reliability), both standard deviation and percentile measures of travel time distribution are not very good for comparing different portions of the highway system, unless the length and operating conditions of the roadways to be compared are the same.

Distribution of 2005 Travel Times on Portland I-5 Northbound



Source: Lyman and Bertini (2008)

Figure 1 – The relationship between reliability time measurements and index computation

Congestion/Reliability Indices

Indices have been suggested as a means to make meaningful comparisons between the reliability of different highway segments. The larger the value of the index, the less reliable the expected travel between two points will be. The same index can be computed for different highway segments and used to compare the relative performance of each segment.

Three indices have been defined and suggested for use by FHWA:

1. the travel time index,
2. the buffer time index, and
3. the planning time index.

The *travel time index* is the average time required to travel between two points divided by the free flow time – the travel time when there is nothing to interfere with travel. So, on a section of highway 20 miles long with a posted speed limit of 60 miles per hour, the free flow travel time is 20 minutes. If the average travel time measured, say, during the morning rush hours of 6AM to 9AM is 30 minutes, then the travel time index for the morning rush hour is 1.5. Another way of looking at this is that someone making this trip during the morning rush hour should allow 50% more time to complete their trip than during free flow conditions.

The *buffer time index* uses the difference between the mean travel time and some travel time percentile to measure the extra time individual trip-makers should allow to complete their trip under a specific set of expectations. Let's say, for instance, a traveler wanted to know how long it would take to complete a particular trip 19 times out of 20 for the roadway in Figure 1. To compute the buffer time index, one finds the difference between the 95th percentile travel time and the mean travel time (in Figure 1, 41 minutes and 27.3 minutes, respectively), then divides this difference by the mean travel time (27.3 minutes). The result is a buffer time index of 0.501. So if the average time during rush hour is 30 minutes, allowing an extra 15 minutes should ensure that 19 times out of 20 the trip can be made within 45 minutes.

The *planning time index* measures the entire amount of time a traveler should allow to make a trip with some assurance of meeting specific time requirements (e.g., making the entire trip within their expected travel time) with a certain likelihood of success (e.g., 19 times out of 20). Unlike the buffer time index, the planning time index includes time for the entire trip, compared to free flow conditions. By using free-flow time as a basis, planning time includes both expected delay time (the difference between the free-flow time and the mean time) and unexpected delay time (the buffer time between the mean and – in this example – the 95th percentile travel time). The planning time index is computed by dividing the total time required to make a trip under the likelihood assumptions by the free-flow travel time. In our example, using Figure 1, dividing the 95th percentile travel time (41.0 minutes) by the mean free flow travel time (23.5 minutes) gives a planning time index of 1.745. So, if the free-flow time for a length of roadway is 20 minutes, then the planning time would be about 1.74 times 20 or about 35 minutes. Note that the planning time index uses free-flow conditions as the basis of comparison, while the buffer index uses mean travel time, giving total allowed times of 35 and 45 minutes, respectively.

Congestion/Reliability Indices

Using *indices* of congestion or reliability enables comparisons of highway segments that have differing characteristics. Three commonly used indices are:

- *Travel time index* – measures the additional time required for a trip over free flow conditions.
- *Buffer time index* – measures how much extra time is needed to assure trip completion to a given percentile, compared to the mean travel time.
- *Planning time index* – measures the amount of time needed to assure trip completion within a specific time, to a given percentile (not dependent on mean travel time).

Threshold/Exceedance Measures

Threshold or *exceedance measures* describe congested conditions that exceed some expected level of performance (e.g., average speeds or average travel times). Measures of threshold or exceedance are usually expressed as the percentage of the time a trip would exceed a predetermined travel time. If we set our threshold at twice the free-flow travel time, then instead of measuring travel performance as some percentile or likelihood of making a trip within a certain length of time, we use total travel time as a measure of performance. In Figure 1, our free-flow travel time is 23.5 minutes. So, to know how many trips are made at twice the free-flow travel time, we look up the number of trips made in 23.5 times 2, or 47 minutes. From the graphic (or from a cumulative data distribution), we can see that roughly 2% of all trips require 47 minutes or more to travel between the two points.

Both congestion/reliability indices and threshold/exceedance measures are data-intensive, relying on direct measurements of traffic volumes, speeds, and point-to-point times. Moreover, these need to be collected by day-of-week and hour-of-day (to the nearest minute, if possible). With the introduction of Intelligent Transportation System (ITS) architecture and real-time monitoring of travel patterns in many metropolitan areas, it is becoming more realistic to collect, store, and analyze this kind of information.[6]

Indirect Measures of Reliability

Indirect measures of reliability describe the opportunity and structural costs that changes in reliability can produce for both personal and commercial travel. Studies of the effects of the amount of time devoted to *personal travel* have begun to focus on activity-based assessments that help to define indirect effects. These assessments require measuring all activities in which members of a household engage – both travel and non-travel. The reasoning is that as the time needed to accommodate reduced reliability increases, there may be less time for other household activities. For *commercial travel*, these considerations often have significant effects on both the organization of labor and the allocation of capital and equipment. For example, if a shipping company saves 40 minutes on a particular route, it might be able to increase the number of deliveries or use fewer trucks.

Thus, for indirect measures of reliability, there are three classes of measurement that should be considered:

- Lost utility of activity participation (personal and commercial travel);
- Schedule delay costs (personal and commercial travel); and
- Operational analysis (commercial travel)

Lost Utility of Activity Participation

This approach to reliability measurement, developed for use in activity-based models, explicitly captures losses attributable to time spent traveling that might have been spent on other, more preferred activities. Measures of the value of reliability are imputed through interviews and responses to hypothetical questions about how people might substitute time devoted to non-travel

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[6] Reliability monitoring in the Portland region and issues involving measuring travel and reliability information at the state level are discussed in Appendix D.

activity for time spent traveling. Then, using the estimated values that household members derive from non-travel activity, the value of improved reliability (measured using the direct measurement techniques described above) is calculated. This calculation is based on the cumulative time spent in travel in excess of a pre-established measure of desired performance or, in the case of a proposed improvement to a highway, the time saved based on improved reliability.[7]

For commercial travel, measuring the indirect effects of reliability is more complex. The basic issue is the same as for personal travel: determining the value of time spent traveling that might be used for other, more productive activities. Valuing this time is highly dependent on how businesses are organized, the substitutability of the skills of those involved in transportation related activities for other transportation/logistics operations, and the potential for increased productivity from transportation resources affected by changes in reliability. These vary from sector to sector. Thus, indirect reliability measures of commercial travel require careful investigation into all affected business sectors in a region. For single corridors, this may limit the number of businesses involved. But for area-wide tolling, all business sectors and commercial clusters would need to be evaluated.

Schedule Delay Costs

Explicit estimates of schedule delay costs can be developed through interviews or information developed using industry data. For households, this information can be gathered from activity surveys. For commercial operations, industry-specific operations research data or information from direct interviews can be used. Using this approach, actual costs of late and early arrivals are estimated, with "late" and "early" typically defined in terms of deviations from the 50th percentile arrival time. Often, these costs may be asymmetric, with late arrivals typically more costly than early arrivals. There are different mathematical models for predicting these costs. The most useful ones provide ways to incorporate the notion that extremely late arrivals bear disproportional costs. For households, schedule delay costs can be incorporated into travelers' utility functions in the mode choice, time-of-day choice, and traffic assignment modules of travel demand models.

Operational Analysis

For commercial travel, measures of reliability must be specified in terms of costs incurred by businesses to avoid or cope with increased over-the-road times. These times are set using planning methods similar to those described in the direct measurement section. Recent research has highlighted how these costs affect operations of various kinds of industries (Portland Business Alliance et al. 2005; Holguin-Veras 2006). Operations-oriented studies of reliability demonstrate the economic consequences of reliability are often quite large and businesses often struggle to manage costs associated with changing reliability. Businesses may:

- Offset increased over-the-road costs or changes in buffer or planning times by incurring increased inventory costs.
- Add drivers and vehicles to shifts.
- Forego cost-saving improvements in operations (e.g., cross-docking or warehouse consolidation).

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[7] Several studies have explored the methods needed to measure and estimate these effects. For more information, see White Paper 3, Supernak (1992), Kitamura and Supernak (1997), Kim et al. (2006), and Lam and Yin (2001).

For industries with the pricing power to do so, the costs of reduced reliability are passed on to customers. Measuring these costs requires some knowledge of the pricing structure and multiplier effects of particular industries. Industry structure, capital and labor intensity of specific operations, industry practice, and intra-industry response to changes in transportation reliability must be measured on a case-by-case basis. Such issues as factor productivity, cost allocation, and service standards (e.g., the ability to set delivery parameters) must be considered.

This operational approach to measuring and assessing the reliability of a transportation system has been used extensively in operations research and logistics planning, but almost entirely to develop efficient ways to manage deteriorating reliability of transportation service delivery. It has rarely been used in public sector transportation planning. Including the costs of reliability to business and industry within a region provides a much broader perspective on the impacts of transportation performance on commercial activities and the competitiveness of metropolitan areas and regions (Weisbrod and Fitzroy 2008).

Conclusions

Measurement of reliability is essential to understanding its economic impacts. Both direct and indirect measures of reliability require new, more technology- and time-intensive approaches to measuring the responses of transportation system users. For personal travel, activity-based surveys that measure both transportation and non-transportation activities are being developed to measure how reliability influences travel decisions and costs. For commercial travel, the impacts of reliability are only beginning to be measured. Many of the hidden costs imposed by declining reliability have not been assessed or included in decision-making because the effects (both direct and indirect) have been neither adequately described nor measured as part of the planning process.

Chapter 4: Methods of Evaluating the Economics of Improved Reliability

Introduction

Appropriate methods for evaluating the economic impacts of improved reliability are grounded in current approaches to economic analysis of transportation systems. Evaluating the economics of any proposed project requires comparing current and future expected conditions, absent any major project funding (the "base case"), with one or more alternatives.

When assessing the economic impacts of reliability, economic evaluation methods need to assess the consequences of highway improvements using one or more measures of reliability discussed in the previous chapter. Then, the effect of these improvements on the value of travel time reliability (for both personal and commercial travel), on productivity, and in the case of commercial travel, on market access all need to be evaluated.

The methods for analyzing the effects of reliability on the *costs* of commercial travel are well understood and have been extensively studied and documented in the business logistics literature. However, the *economic* consequences of improving reliability of highway systems and analyses based on these understandings have not been systematically included in highway planning and project evaluation.

Commercial operations tend to be very diverse, and are segmented by the requirements of the wide variety of markets they serve and required logistics operations. This is especially true of Oregon, because commercial operations support a range of products and commodities that are traded throughout the United States and Canada, and internationally. The economic vitality of the entire Pacific Northwest depends on moving goods to, from and through the greater Portland region. The economic competitiveness of the region depends on the productivity – and therefore the reliability – of highways that support this commercial activity.

Structural and competitive economic evaluations are complex undertakings, and require a more diverse set of analytic methods than has characteristically been used to assess the economic impacts of highway investments. Therefore, several key points need to be covered in this chapter with respect to the economic evaluation of improved reliability:

1. What are the key questions that need to be addressed?
2. How can we link our ability to measure improvements in reliability with our methods of economic analysis?
3. What are the uncertainties and issues associated with these methods of economic evaluation?
4. How do our current methods of analysis need to be changed to meet the challenge that improving reliability poses?

This chapter presents economic evaluation methods for personal travel and commercial travel in separate sections. Each section covers the issues of evaluating the direct and indirect economic effects of reliability, the uncertainties involved in reliability assessment for each type of travel, and recommendations for addressing the evaluation issues identified in the discussion.

Reliability and Personal Travel

The key questions in assessing the economic impacts of reliability on personal travel concern (1) how to estimate the value of the variations in travel time and (2) how to assess the economic impacts of reducing these variations. Travel time savings and improved reliability for personal travel traditionally have been examined using benefit-cost analysis (BCA). This is appropriate, as the predominant effect of improved reliability at the household level accrues to the users (all those in the household who rely on the highway system to deliver "transportation services"). Thus, one of the key requirements for the economic evaluation of personal travel is to establish the monetary relationships between the ways reliability is measured and the way individuals value reliability. (See Appendix C.)

The value of time saved is the principal *direct effect* attributed to improving reliability. However, *indirect effects* need to be considered as well. As noted in Chapter 3, indirect effects on personal travel include changes in trip-making efficiencies and improvements in the quality of life that may result from improved reliability. Personal travel often includes *tours* – multi-stop trips generally characterized as "running errands." Although this implies a home-based trip (i.e., the trip-maker leaves from and returns to a single point, typically their residence), it can be used to describe any multi-stop trip wherever it begins or ends. Travel surveys show that evening commuters often make multiple stops for such things as child care, groceries, school pick-ups, and after-school activities (referred to as trip chaining). The more segments in a trip, the more the decision to combine small trips into a larger tour or trip chain will be influenced by travel time reliability.

Benefit-Cost Analysis (BCA)

An analytic technique used in determining the economic value of a project or plan. Costs and benefits are typically denominated in dollars and include the money, time, resources, and consequences associated with a project or activity.

Economic Impact Analysis (EIA)

A comprehensive assessment of direct, indirect and induced economic impacts that takes into account the system-wide, sectoral effects of productivity improvements, expanded access to jobs and markets, and effects of improved reliability on business operations.

Improved reliability can lead to more efficient personal trip-making. In theory, this should reduce the amount of time a household "budgets" for travel. Travel demand modelers increasingly have been able to document and develop these kinds of travel patterns by collecting travel data in the form of "diaries." Such diaries list all travel as it is being made, describing each element of the tour by time of day, day of week, and purpose. The result has been a much richer appreciation for the complexity of travel and trip-making decisions at the household level, along with new theories of trip-making that consider travel as one of many daily household activities. As with those effects attributable to actual savings in monetized travel, efficiencies accruing to tours are usually considered as direct effects of improved reliability.

Indirect effects have received much less attention than direct effects. Improving reliability for personal travel can increase the geographic range of activities reasonably accessible to trip-makers, such as employment opportunities, consumption activities, and recreational opportunities.

Access to employment opportunities, for example, is primarily a function of average travel time. But if reliability of travel to existing employment deteriorates, or if the expected time to access new employment opportunities is too great, practical choices of employment – including better-paying opportunities – can be effectively limited. This is especially true for households that must accommodate travel for multiple workers.

These considerations also apply to shopping and recreational travel. As transportation reliability declines, options for where to shop and, to a lesser extent, recreate are reduced. Although it can be argued that the net change in overall economic activity in a region should be close to zero (e.g., shoppers will simply substitute service providers more easily accessed), high levels of congestion at specific locations coupled with reduced ability to access customary markets may change individual household shopping patterns and effectively reduce choices.

The important question from a personal travel perspective is whether an increase or reduction in travel reliability will have a net impact on the overall income and expenditure patterns of households. Some care must be taken in defining and evaluating these effects, as it is possible to double count the economic impacts of reduced market access for households if the same effects are being assessed for employers and retailers (see the discussion on commercial travel, below).

Uncertainties in Data and Methods – Personal Travel

The greatest uncertainty in evaluating the economic impacts of reliability is how to attribute or impute a value of time to reliability. Although there are very good and improving methods of measuring travel delays and travel time variability (see Chapter 3 and Appendix D), and although there is a growing consensus on the methods that should be used to estimate the value of reliability, deriving reliable empirical data from surveys and developing models that adequately reflect these measures have proven difficult, although not intractable.

The claim that improved reliability will increase the efficiency of travel and travel choices is controversial. The efficiency argument rests on the idea that multi-segmented trips (tours) by certain segments of the traveling public will take advantage of improved reliability to combine trips. However, there is little or no evidence to support this in the absence of other motivating factors (such as the cost of vehicle operations). There is some evidence that, for travel involving routine daily activities, households operate within a "travel time budget" (Schafer 2000; Downs 2004). This suggests that improved reliability may induce people to make more trips or to add activities to their existing routines, within the constraints of the portion of a household's travel time budget. However, no individual travel surveys have managed to confirm this theory of a travel time budget or the substitution effects for reliability improvements.

There is substantially less certainty about, and very little investigation into, the indirect effects of changes in reliability on personal travel and choices. How changes in reliability affect choices of employment and, to a lesser extent, of shopping and recreation remains largely unknown.

Including the *direct* costs associated with changes in reliability is becoming a standard part of BCA practice. This is particularly true of projects where reliability improvement is a basic objective of the project. However the lack of attention to the indirect effects of reliability on access to employment, the effects of reliability in limiting or constraining access to non-employment opportunities, and the opportunities for improved access to more diverse recreational or cultural opportunities have been largely omitted from economic analyses.

While some of the reasons for this lack of attention are based on limitations of analytic methods used for project evaluation (see White Paper 6), there is a clear need to properly consider at least those indirect economic effects of changes in reliability that are most pertinent to a specific tolling proposal (e.g., the effects of improved reliability on jobs access for projects that affect low-income neighborhoods). Because these effects are not currently included in typical BCA-based economic assessments, such studies typically under-estimate the indirect economic benefits of reliability improvements associated with highway investments. For personal travel, these effects appear to be somewhat limited and may be confined to specific geographic subregions or socioeconomic groups. However, as more emphasis is placed on the equity of tolling applications, the direct and indirect effects of these revenue and traffic management concepts relative to low-income households or populations that are underserved by transit will become more apparent. And, as discussed below, failure to consider the direct and, especially, the indirect effects of reliability on commercial activity leaves a major gap in both understanding and communicating the full economic effects of reliability improvements on projects and on programmatic, system-level planning.

Reliability and Commercial Travel

The effects of reliability improvements on commercial freight movements are almost always underestimated when considering highway investments. Typical analyses overly rely on travel time values as a proxy for the economic costs of reliability. This assumes the full costs of reliability are somehow fully capitalized in the observed values of travel time for drivers, and that the value of travel time adequately captures the opportunity costs for equipment use and cargo delay. Compounding this problem is the omission of attempts to assess the costs of reliability improvements to businesses that rely on the highway system as an integral part of their logistics and supply chain management. The overall consequence of under-valuing or omitting important elements of the cost structure of commercial transportation leads to under-estimating the value of highway reliability improvements attributable to commercial transportation (Wigan and Rockliffe 2000). It is possible to improve estimates of the economic effects of reliability improvements, but analysis based on economic impact assessment methods must be introduced into the planning and project evaluation process.

Valuing Commercial Time-Based Reliability Measures

We noted earlier how the concept of the value of travel time reliability is used to assess the impact of reliability on personal travel. As a measure of direct and indirect impacts on individuals and households, travel time value is, for all practical purposes, an adequate descriptor. The methods by which these costs are measured and valued for commercial travel reliability are similar in that the value of reliability must be established either through a survey process or by directly measuring driver response to tolling systems that reduce variability of travel. Research along these lines is being done at international border crossings and on tolled highways and bridges (Taylor et al. 2003; Holguin-Veras 2006).

As more research is developed, it is becoming evident that the value of reliability must be developed separately for individual business sectors. This is because the costs associated with variations in expected arrivals tied to reliability have potentially different consequences for each sector (Weisbrod 2003). These differences are primarily attributable to the ways in which costs are either absorbed within commercial operations (as in private carriers) or passed through to shippers (as in for-hire carriers). Both contractual requirements and industry practice influence the overall ability to pass through costs. But market competition and operating decisions allowing carriers to internalize costs can also have a bearing on how such costs influence commercial travel patterns.

Research in Australia indicates the monetized value of reliability for commercial travel may be much greater that the monetized value of average in-transit time. Based on this research, a 1% improvement in reliability is about 5 times as valuable as an hour saved in shipping for time-sensitive industries such as auto parts, and as much as twice the value of an hour saved in over-the-road time for other industries (Fuller et al. 2003). This is significantly larger than estimates of the value of reliability for personal travel (Brownstone and Small 2005). Considering the ways in which reliability changes can influence both sector operation costs and cost allocation, it is evident that a careful and thorough assessment of the value of reliability of the over-the-road component of commercial travel is an important aspect of the economic evaluation of system reliability.

Valuing Commercial Operations and Market Access

There are added dimensions of market access and regional competitiveness that must be considered in evaluating the importance of highway reliability. As in any economic analysis, the linkages between the ways reliability is measured and monetized must be clearly and convincingly established. Within the various commercial and business sectors, the ability to absorb or pass on the cost of delay and the decisions made regarding how reliability can be managed or absorbed into on-going operations can vary substantially.

The effects of improved reliability differ by industrial sector because each sector allocates and recovers transportation costs differently. Businesses that base their logistics operations on private truck fleets – such as Walmart or Target – operate their own warehousing and distribution centers, while smaller-scale retailers depend on for-hire services or distributors. These organizational differences influence how costs are managed, allocated and recovered.

Operationally, manufacturers reliant on timely delivery depend on minimizing inventory to keep overall production costs low. Their operations may be much more sensitive to reliability issues than retailers or wholesalers who routinely keep inventory on-hand or have integrated inventory and management costs into their overall cost structure.

The key issue to keep in mind is that operational requirements of commercial transportation are quite varied. Operational and logistics responses to improved reliability reflect the direct effects of improved productivity of labor and equipment dedicated to the over-the-road portion of commercial transportation operations, and any operational improvements that can be realized in inventory or logistics system management. Businesses that can achieve better productivity due to improved reliability are often able to expand their markets by increasing the territory they serve, lower their costs to achieve a more cost-competitive position in their business sector, and even transform entire industries.

Reduced reliability can produce negative market impacts. Businesses that are unable to provide consistent services or stable costs, or that are otherwise uncompetitive due to unreliable transportation and logistics operations, can lose market share or access to markets. Any change in market access can result in a change in business output and employment.

Uncertainties in Data and Methods – Commercial Travel

There is a broad range of uncertainty in data collection and methods for assessing the economic impacts of improved reliability on commercial transportation. These can be grouped into three major areas:

1. Establishing the monetary value of improved reliability for over-the-road operations.
2. Determining the effects of improved reliability in logistics practices and costs.
3. Allocating costs to shippers and carriers.

Monetary Value of Improved Reliability. Determining the monetary value of improved reliability for over-the-road operations requires rethinking the ways reliability has been monetized for personal travel, and adapting those methods to the unique characteristics of commercial travel. Survey methods for assessing the value of time and reliability for personal travel need to be adapted to the diversity of commercial operating environments and the ways that commercial transportation operates for different sectors. Surveys of driver/operators have been attempted in various locations, but with a wide range of results.

The most productive surveys of the costs associated with reliability involve surveying companies rather than drivers or vehicles. Structuring questions and sampling designs that control for the industrial structure of a region and the size of the companies in each sector provide the basis for gathering meaningful survey data. Participation rates have been historically low, and costs of administration have been high. However, when business groups have been actively involved or have co-sponsored these surveys, the results have been more encouraging. The advantage of establishment-oriented surveys is that more realistic cost data can be developed because imputation of average wage, equipment and cargo costs is not required.

Logistics Practices and Costs. Determining the expected cost savings associated with improved reliability is dependent on how businesses have structured their logistics operations. While the theory and practice of logistics management are highly developed, the costs to implement various logistics practices are usually dependent on local factors (labor and equipment costs, land availability, and the business environments) and on the quality of freight services.

Cost Allocation. Changes in the reliability of commercial travel are experienced directly by over-the-road operators and receiving parties. However, the costs of changes in reliability can be felt by companies along the entire supply chain.

Savings to shippers depend to a great degree on specific industry sectors, because each sector's use and mix of modes and other production factors can vary significantly. Modal composition of logistics support is also highly dependent on the mix of commodities used as inputs to production. Each commodity/industry combination has a specific way of absorbing, allocating, or passing through costs. Primary metals, manufacturing, and warehousing/distribution sectors are the most intensive freight shippers by volume (weight). Transportation sectors, on the other hand, are more likely to invest in certain capital improvements and pass other savings, such as fuel and labor costs, on to shippers. Finally, service sectors and selected high-value manufacturing industries may use reliability-based cost savings to supplement R&D investments, increase hiring, invest in productivity improvements, or increase market share.

Thus, it is very important to understand the structure of freight costs in a region and within various industry sectors, as the different types of carriers have different economic pressures to absorb costs or pass them on to shippers, and respond differently to travel time variability. Each industrial sector has a cost structure sensitive to the mix of inputs and outputs, and to pricing pressures to remain competitive.

Additional Methodological Considerations for Evaluating Improved Reliability

From the discussion above, it is apparent that even if the analysis for commercial travel was limited to time-dependent measures and values related to travel time reliability, the segmentation of commercial transportation markets would make the assessment of the economic effects of reliability much more complex than for personal travel. A full specification of the entire range of direct and indirect costs of travel generally associated with BCA methods should include carrier and shipper costs. Some allocation between the two would be necessary to assess the "incidence" or cost burden to be allocated to various parties, as would a more in-depth assessment of the benefits derived from improved reliability. If the full impacts of improved reliability were limited to the over-the-road and logistics benefits, this enhancement of BCA would likely be sufficient to characterize the impacts of proposed reliability improvements on commercial travel.

However, there are a number of other effects related to productivity, expanded access to markets, and modifications to logistics operations that may create opportunities for commercial highway users to offer better or different classes of service. There are also a variety of other non-logistics responses by one or more industry sectors that could change the way businesses operate and compete. Likewise, as reliability deteriorates, these processes can produce negative consequences, with businesses internalizing increased costs due to declining reliability (thus reducing profits and taxable revenues), eroding productivity, or losing market share, access to markets, and competitiveness.

These kinds of economic effects cannot be captured with BCA methods. Instead, a more comprehensive assessment of economic impacts is needed, one that takes into account the system-wide, sectoral effects of changing markets and productivity. Economic impact analysis (EIA) is increasingly being used to assess the effects of reliability improvements on the broader economy of a metropolitan area or region. It provides another way of examining the effects of reliability improvements to projects, investment programs or system-wide plans, and can supplement project-specific assessments of alternative projects or alternative project development scenarios commonly analyzed with BCA (see White Paper 6). There is an established approach to project evaluation based on BCA, extensively reviewed by the Government Accountability Office (GAO) in the past few years. These independent reviews support the issues identified in this discussion relative to the limitations of BCA (GAO 2004).

Recent studies in Oregon and other locations in the US and Canada illustrate how the effects of improved reliability on commercial operations can be addressed as part of a comprehensive economic impact assessment (Portland Business Alliance 2005; Weisbrod and Fitzroy 2008). Although it requires a broader and more complex approach to analyzing the economic effects of reliability, accounting for the effects of changes in reliability on commercial travel is important – especially when pricing applications are being considered. Current methods for economic evaluation of pricing tend to focus more on its effects on personal travel than on commercial travel. As noted above, the actual economic impacts of pricing may produce more of an impact on commercial operations than on personal travel – especially when indirect economic impacts are considered. Thus, more of an effort needs to be made to include analyses of the economic impacts of pricing and tolling alternatives on commercial travel when considering tolling applications.

Chapter 5: Evaluating Improved Reliability – Conclusions and Recommendations

This white paper has explored one of the primary questions that must be answered to formulate an informed, effective tolling/pricing policy—how to evaluate the economic consequences of enhanced highway system reliability achieved by tolling. This requires several questions to be addressed:

- How do we measure highway system reliability?
- How do we determine the effects of improved reliability on personal and commercial travel?
- How do we use the information we have about reliability to assess the economic impacts of a wide range of possible tolling applications?

These questions must be addressed regardless of the particular tolling or pricing systems under consideration. In addition, there are other policy questions that concern particular types of tolling/pricing systems. These are discussed under "Recommendations for Evaluating Tolling Applications," later in this chapter.

General Tolling/Pricing Conclusions

No matter what kind of tolling or congestion pricing plans are being considered, the following issues need to be addressed to determine the full economic effects of improved transportation system reliability.

1. Methods for measuring reliability comparable to those presently being used on limited access highways need to be developed for secondary and arterial roadways.
2. Estimates of the value of reliability on the indirect effects of personal travel need to be refined. Improved reliability may change the ways that people travel, their access to employment, shopping and cultural activities, and their choices of transportation modes.
3. The effects of improved reliability differ by business sector because of the ways that each sector allocates and recovers its transportation costs. Responses by commercial operations to more reliable over-the-road travel are not well understood. Substantial effort is needed to understand the relationship between improved reliability and the potential for improving the efficiency of commercial operations.
4. Improved reliability can increase productivity of logistics operations, thereby increasing the ability of businesses to serve existing markets more efficiently and to extend their market reach. These effects need to be better understood so that they can be included in economic impact evaluations of proposed tolling applications.
5. Improved reliability may provide businesses in certain industrial clusters or within a sector of the economy with the ability to increase their overall competitiveness relative to businesses in other regions of the country. As decisions are made about tolling and infrastructure investments, the relationships between improved reliability achieved through tolling and

increased competitiveness that accrues to key business sectors needs to be better understood.

Recommendations for Evaluating Tolling Applications

The geographic scale of a proposed tolling project has an important influence on the type and quantity of information needed to evaluate reliability improvements attributable to tolling. Each of the applications discussed in the *Future of Tolling in Oregon* report (Cambridge Systematics 2007) requires consideration of the economic effects of reliability improvements that reflect:

- Travel patterns of all vehicles using tolled and untolled facilities,
- Decision-making (price response) of commercial and personal travel, and
- Logistics and operational considerations of commercial users.

The recommendations that follow highlight some of the general issues identified in the overall conclusions concerning problems with evaluating the economic impacts of reliability improvements, and also identify issues specific to assessing each of the pricing typologies.

Tolling New Facilities

Evaluating the effects of a new tolled facility is probably the most straightforward of all tolling assessments. No traffic will be required to divert from existing facilities, and reliability should improve (or at least remain relatively constant) for existing highways and secondary roadways in the general area. However, a careful analysis of potential traffic flow will be required to determine if the new, relatively free-flowing, high-speed, high-capacity roadway will induce traffic into the corridor and onto secondary access roads. If this induced traffic is expected to influence the reliability of secondary roads, the same data collection and analysis needed for conversion to tollways will be required.

Recommendations. *Consider ways to measure reliability of current travel patterns on existing roadways in the proposed corridors, and to identify both potential personal and commercial users.* Develop a survey of potential users that questions both their willingness to pay and how they envision improved reliability will contribute to increased productivity (personal and commercial).

Creating Toll Managed Lanes

Toll managed lanes developed from existing facilities will affect the reliability of both the remaining general purpose (GP) lanes and any other roadways that receive traffic diverted from the GP lanes. Certain types of toll managed lanes, such as HOT lanes or ETLs, may not permit use by commercial vehicles, depending on the policy being implemented. Other tolling projects may be exclusively for trucks, such as truck-only toll (TOT) lanes.

Recommendations. *Systems to gather data and measure the reliability of all potentially affected highways, arterials, and secondary streets that feed or accept diverted traffic to the proposed tolled facility should be put in place* before a tolling project is introduced, so that baseline conditions can be properly assessed. Information about both personal and commercial travel patterns along the tolled corridor should be developed. This will enable the socioeconomic profiles of passenger traffic and the operational characteristics of businesses using the corridor (directly affected highways and those likely to receive diverted traffic) to be analyzed and the response to alternative proposed tolling regimes to be assessed.

No matter which tolling application is being considered, *assess the logistics and operational requirements of commercial users to determine how changes in reliability for both tolled and GP lanes may affect their business practices, access to markets, and competitiveness.* For single-corridor projects, the potential for disproportionate or potential competitive advantages accruing to businesses using both tolled and untolled highways should be assessed. Care should be taken to determine if there will be costs due to tolling that are not offset by savings attributable to improved reliability.

Converting Existing Freeways to Tollways

Conversion of existing facilities to tollways requires the same measurement, price response, and commercial operation investigations as those for toll managed lanes. The difference is that the system-wide effects of diversion for non-toll paying users are likely to be more geographically extensive. Therefore, measuring reliability on all affected secondary roads will be very important if the full economic impacts of freeway conversion are to be determined.

Diversions that increase congestion and reduce the reliability of secondary highways could negatively affect both personal and commercial travel on these facilities. Therefore a careful assessment of both positive and negative economic effects of changes in reliability is important. Positive effects will accrue to those willing and able to use the tolled freeway.

Negative effects may be more complicated to assess. Travelers who choose not to use the tolled roads are likely to face increased congestion and reductions in reliability because of increased traffic on untolled arterials and secondary roads. However, increased congestion and reduced reliability on these roadways also will affect those who pay tolls, because they inevitably must exit the tolled highways and use these roads to complete their trips. Thus, the negative effects of converting existing freeways to tollways will involve a more complex evaluation than is typically undertaken.

Recommendations. Diversion of traffic unwilling or unable to pay tolls will be an important issue for these kinds of tolling projects. *A system for measuring reliability on secondary roadways will need to be developed.* This may pose some difficulties, as most of the current technology used to measure reliability has been applied only to high-speed, limited access highways.

Developing information about how both increased and decreased reliability affects households and businesses with potential to use the tolled freeways and those who rely either partially or entirely on affected secondary and arterial roadways will be vital to a proper assessment of the economic impacts of these kinds of projects. Depending on travel patterns in the affected corridor(s), there may be a substantial number of "winners or losers" in terms of economic impacts. This requires additional emphasis on evaluating the sensitivity of both households and businesses to changes in costs. For households, income effects and socioeconomic impacts will be important factors in assessing the equity issues raised by implementing such a tolling system. For businesses, competitive issues relative to similar businesses within the market areas they serve will be important to assess, as affected businesses will either have to absorb toll costs or find ways of coping with the costs of reduced reliability on alternative roadways.

Convert Entire Freeway System to Tollways

Converting an entire system of freeways to tollways poses interesting possibilities for large-scale traffic management, but would require a substantial investment in research and analysis. Each of the three elements of economic evaluation (data, price response, and operational analysis) would need to be carefully considered, and each has serious hurdles to overcome.

Information on baseline reliability would be needed for all existing freeways and for most of the arterial and secondary highway system, in order to a) assess the economic consequences of area-wide tolling, and b) monitor and manage the tolled system (whether using fixed or dynamic pricing).

Information on response to pricing decisions would have to be assessed for personal and commercial users of the system. For single lane or single freeway conversions, it is usually possible to identify specific population subgroups and business sectors that would be directly affected. For a system-wide conversion, an extensive assessment of all population subgroups and business sectors would be needed.

The ability to evaluate the economic effects of improved reliability for system-wide tolling would rest on an assessment of the operational and logistics requirements of all commercial activity in the region. The assessment would have to encompass both transportation-intensive industries such as trucking and warehousing, and service and professional businesses with different delivery and distribution requirements. Such an undertaking would pose significant challenges in both measurement and analysis.

Recommendations. As indicated in the conclusions, one of the most challenging requirements for implementing system-wide monitoring will be to establish baseline reliability measures for all major roadways, including secondary and arterials receiving diverted traffic. *Measurement of reliability will be required both before and after tolling on a system-wide basis is implemented, because it may be necessary to adjust toll levels to both manage traffic on the tolled facilities and to address potential degradation of reliability on local streets that absorb diverted traffic.*

Developing the information needed to assess the economic impacts of system-wide tolling would be extremely complicated. For freeway conversions, as noted above, there are important equity impacts that have profound economic consequences for low-income groups. The issues of "winners and losers" would be somewhat mitigated, as a system-wide implementation policy will not necessarily burden one geographic area over another. However, the effects of more congested, less reliable arterial and secondary roads, and the increased costs of vehicle operations would require significant attention to providing alternatives, especially for low-income auto users, and to the impacts of reduced reliability on local businesses.

For commercial operations, intra-regional competitiveness issues may be reduced. However, *gaining a practical understanding of the full economic consequences of pricing an entire region will require an extensive and in-depth assessment of the structure and operational characteristics of every business sector and industrial cluster in a region.* Information about the effects of changing transportation costs on logistics and other operations will have to be developed for each sector, and a careful assessment of the impacts on competitiveness and productivity will need to be developed.

Cordon/Area Pricing

Although cordon area pricing will require a network of reliability baseline data collection and monitoring, similar to that for system-wide conversions, key economic impact assessment issues will need to be approached differently. These differences will depend on the extent of the cordon, that is, whether it includes just the central business district (CBD) or a more extensive area.

Within the cordon or priced area, it is likely that reliability will improve. Economic benefits from this increased reliability will depend on users' cost-sensitivity and the degree to which their travel is confined within the cordon or requires moving across a cordon boundary. The issue with movement across the boundary has to do with the effects of travel behavior, the delays that take place in the immediate area of the boundary, and the degree to which reliability outside of the cordon area is affected.

With cordon pricing, more so than with complete freeway conversion, the effects of changing traffic patterns at the periphery of the cordon will be difficult to assess. Traffic control measures may be required to manage traffic flow across the cordon boundary to avoid reductions in reliability. To some degree, this will be a function of the kinds of toll collection (e.g., managing a mix of electronic in-vehicle and manual toll collections) and pricing policies (e.g., avoiding burdening residents and businesses located inside the cordon, violation enforcement, etc.) that are instituted for cordon pricing.

Travelers who pass into the cordoned area will experience both the positive and negative effects of congestion and the resulting changes in reliability. Positive effects will accrue to travelers who make all or part of their trip inside the cordoned area, because they will likely experience greater reliability. However, drivers approaching the cordon boundary could experience significantly reduced reliability unless traffic flow is carefully managed and monitored at the boundary. Drivers who must travel near the cordon for all or a portion of their travels may be the most negatively affected because of the traffic patterns that may develop as a consequence of diversions and potential queuing at the cordon boundary.

Impacts on personal travel into a cordon area might be mitigated by providing transit alternatives. But commercial operations will have to bear the costs of any reduction in reliability at or near the cordon boundary, even though those businesses that operate in or serve the cordoned area may receive some economic benefit. As with freeway conversion, determining the overall economic effects of cordon pricing will require a comprehensive assessment of the business operations and logistics dependencies of the business mix inside and outside of the cordoned area. This may be especially important for those businesses located within the cordon that rely on suppliers or customers outside of the cordon area, and vice versa.

Recommendations. As with the freeway system conversion option, establishing baseline measures of reliability and monitoring them will require substantial planning and effort. It will be important to determine how changes in operation and reliability will influence reliability before implementing a cordon pricing scheme so that potential economic impacts can be determined. This sort of assessment will depend heavily on the ability of planners to simulate the decisions of drivers and the ways that the entire highway network will respond to these decisions. As noted above, it is currently not possible to measure reliability on other than limited-access roadways. *So, the twin complexities of measurement and simulation of the impacts of a cordon area pricing system will have to be addressed before other issues of evaluation can be successfully addressed.*

Assuming reasonably sufficient methods of measuring and simulating changes in highway network reliability are available, economic evaluation of the effects of changes in reliability will need to be developed. For personal travel, careful assessment of the economic benefits of reliability improvements for activities that require movement within or across the cordon boundary will need to be assessed, as will social equity issues. The magnitude of the issues involved will be a function of the size of the area enclosed by the cordon. *A careful assessment of the price response to cordon pricing – recognizing that many travelers will not have the option to avoid paying to cross the cordon boundary – will have to be undertaken. Special consideration will need to be given to equity issues and to the availability of alternatives to automobile travel.*

For commercial activity, a number of complex inter-relationships between suppliers and customers will have to be evaluated. These will include understanding how costs associated with pricing are allocated within the production processes of each business sector and industrial cluster in the cordon area. Commercial travel will need to be evaluated based on the geographic extent of the designated cordon. As an example, for cordon areas larger than the CBD, *it will be important to understand how or if commercial travel formerly moving through the cordon will be diverted, the extent of this diversion, and the degree to which any additional costs of diversion may be potentially offset by the net cost savings that may accrue to paying a cordon fee.* Many businesses, especially those highly sensitive to changes in marginal transportation costs, may be faced with relocation or process restructuring decisions, depending on the kinds of tolls imposed at the cordon.

Finally, imposing cordon costs for businesses will very likely change their access to markets and potentially their competitiveness relative to businesses in other market areas not faced with cordon charges. *Evaluating the economic impacts of cordon pricing will require a careful assessment of the impacts of a changed transportation cost structure on logistics decisions and on potential market access, and competitiveness –* especially for key strategic business clusters and businesses for which managing transportation costs is essential.

Reliability and Pricing Applications – General Recommendations and Conclusions

The complexity of moving from a relatively simple, single-corridor pricing application (toll managed lanes and freeway conversions) to more comprehensive applications like conversions of freeway systems and cordon pricing requires adaptations of new and untested reliability measurement technologies and development of data that can help to describe the direct and indirect effects of pricing on commercial travel. Although information and methods of assessing the economic impacts of pricing on personal travel are reasonably well developed, more attention should be devoted to assessing the indirect effects of pricing and tolling applications, especially if tolling is considered for large-scale applications on multiple freeways or area/cordon pricing.

Measurement

Moving from single-corridor applications to conversion of entire systems of freeways or cordon pricing poses significant reliability measurement problems. For the high-speed, limited-access elements of highway networks, reliability measurement is possible, but this is potentially a very expensive and complex undertaking with current technology. As discussed in Appendix D, the issues involved in measuring the reliability and performance of roadways that receive vehicles diverted from the tolled highways is just beginning to be addressed, and adequate coverage is not currently available. In-vehicle tracking technologies are just beginning to replace loop detectors and camera-based systems, and will require more extensive validation and better coverage of local and arterial streets before information from these sources can be used to measure and monitor reliability. Serious questions remain about whether the density of coverage that might theoretically be available from large numbers of in-vehicle sensors can be assembled and processed to provide the information required to measure reliability at such a fine-grained level. Clearly, more applied research needs to be done in this area. In the long run, it will be important to find ways to collect and assess reliability data for roadways affected by diverted traffic, and to monitor reliability on them as traffic patterns adjust to new tolling regimes.

Recommendation. Consider new methods of measuring reliability focused on secondary and local roads. Investigate emerging technologies that are vehicle-based rather than sensor-based, and establish baseline measures of reliability using these new technologies that can provide coverage for all areas that may be affected by diverted traffic well in advance of implementing either corridor or area-wide tolling applications.

Economic Data Collection

We are just beginning to understand the impacts of improved (and degraded) reliability on commercial travel. Without knowing what these effects are and how they influence commercial operations at all points along particular logistics supply chains, it is difficult to accurately determine either the basic benefit-cost relationships needed to assess the impacts of small-scale, corridor-level tolling applications or the larger, and potentially more important, economic impacts of freeway conversion or cordon pricing on the economy of the region. Addressing the direct and indirect economic impacts of tolling on commercial operations will require a significant investment in collecting, organizing and analyzing data focused on business operations. Such efforts should be seriously considered, as the potential impacts on the economic health and competitiveness of a region or state may be seriously affected if tolling and pricing applications are not properly evaluated in light of their impacts on affected businesses.

Although personal travel patterns and decision-making are well understood, there are several potential indirect impacts that may be attributable to toll-diverted traffic. Some of these impacts, such as those attributable to delays, are well understood. But others, such as the loss of access to employment, shopping or other social and cultural outlets, may require additional examination. As noted above, these indirect effects on personal travel are likely to be negligible for limited tolling applications like new facilities or toll managed lanes that affect only one or two corridors. However, as the scale of tolling increases, these indirect effects may produce much more noticeable and unavoidable impacts on personal travel choices.

Recommendation. Consider developing and integrating commercial operational and logistics data collection and surveys into the overall planning process. Using studies and methods cited in this paper and available from other freight-oriented planning documents, develop ways to efficiently and effectively collect data that address the cost structure of commercial travel. Assess the information available for evaluating indirect personal travel impacts due to localized reductions in reliability, and identify the kinds of information that will be required to adequately address these issues for large-scale tolling applications.

Analytic Methods

Measurement issues aside, economic evaluation of tolling applications also requires a better balance between personal and commercial economic impact assessments. Evaluation of indirect effects of changes in reliability on personal travel and assessment of both direct and indirect economic effects on commercial travel will add important new dimensions to the economic evaluation of tolling applications. Ignoring these impacts has been possible in the past, because individual project investments and even corridor-wide investments have not held the potential to create the kind of broad impacts or the range of indirect impacts on personal travel and commercial operations that tolling applications may produce.

Recommendation. As tolling applications are introduced – even at the corridor level – analysis of commercial economic impacts and evaluation of the indirect effects of tolling on personal travel should be undertaken, using reliability information and the commercial operations and indirect personal data and methods listed in prior recommendations. Analytic methods developed for smaller-scale tolling applications should be tested, refined, and verified so that as tolling applications become more wide-spread and comprehensive, the methods of analysis will be readily available, understood, and agreed upon.

Conclusion

Based on the review of measurement and analytic methods presented in this paper, it is apparent that more work is needed, especially for large-scale tolling applications. Important progress has been made in identifying and developing the methods and the range of data needed to support these analyses. However, these methods have received only limited application. If broad applications of tolling are considered, then serious consideration should be given to developing a program of data collection and applied analysis that supports an in-depth assessment of an economic evaluation of reliability and pricing. Sufficient information exists to say with certainty that large-scale tolling applications have the potential to result in major economic impacts, especially on commercial operations. Therefore it is important that the kinds of economic impacts identified in this paper be addressed, so that decision-makers can be confident that they understand the implications of implementing the various tolling applications.

Appendix A: Tolling and Pricing Policy Development White Papers

Advances in electronic technology enable the tolling of highways to be done in a variety of ways and for a variety of public policy objectives. To date, tolling in Oregon has been limited to a few Columbia River bridges. In response to new opportunities for tolling, the Oregon Transportation Commission established several strategies in the 2006 *Oregon Transportation Plan* for examining the applicability of tolling in Oregon.

As part of this effort, a series of White Papers has been commissioned to explore a variety of policy and methodological issues unique to tolling or congestion pricing. These White Papers are intended to provide discussions of particular issues that are accessible to both policy-makers and the general public. Because of the relative unfamiliarity with tolling and pricing, coupled with the immediacy of our current transportation challenges, discussions about putting tolling and pricing policies in place can be confusing to the public. Because public attitudes and acceptance of tolling are also evolving, ODOT policy development needs to be sensitive to the potential effects of tolling on public attitudes. The white papers are intended as a mechanism for soliciting public comment and not as statements of OTC policy.

White Paper #1 – Air quality/greenhouse emissions

In order to improve air quality or to reduce greenhouse emissions, tolling/pricing must induce changes in the use of motor vehicles, such as fewer "cold starts," reductions in vehicle miles traveled (VMT), or decreases in vehicles hours of delay (VHD). The white paper discusses the relative efficiency of various tolling applications as a strategy for reducing greenhouse gas emissions.

White Paper #2 – Geographic & Situational Limits

Highway tolling or pricing may have limited applicability in parts of Oregon. Much of the state is rural and possesses highways with neither the traffic volume nor levels of congestion typically required for successful tolling/pricing applications. Further, Oregon has little experience with tolling, a fact reflected in the relative lack of consideration of the topic seen to date in transportation planning throughout the state.

It is ODOT's desire that the planning process be better equipped to consider tolling/pricing applications, when appropriate, while being relieved of the need to consider tolling in circumstances with little or no chance for success. Additionally, the relatively low traffic volume on many state highways implies that most potential toll projects are unlikely to be financially self-sustaining. The resulting requirement for state or local financial contributions raises, in turn, a series of finance and project programming issues.

White Paper #3 – Demand Projection Sufficiency

Technological enhancements enable highways to be tolled or variable-priced in a number of ways. The evaluation of tolling applications is dependent upon accurate projections of resultant travel behavior that predict not only facility usage but also the level of expected toll receipts, the amount of traffic diversion around the tolled facility, and changes in relative levels of accessibility to different locales in the area served.

This white paper assesses current modeling practices in Oregon. It explains how new methods of travel demand modeling address the analytic requirements of tolling and dynamic pricing, evaluates the effectiveness of existing models across a range of tolling applications and offers a set of general recommendations for improving model performance.

White Paper #4 – Economic Evaluation of Improved Reliability

A major benefit of some highway pricing applications is improved reliability for motorists. The application of variable prices, dynamically in certain cases, can reduce traffic volumes sufficiently to ensure free flow conditions and to guarantee the motorist a "time certain" trip over the affected roadway. Beyond the travel time savings a tolled facility provides, the guarantee of reliability can be expected to have an economic value in and of itself. This is a new consideration in transportation planning. The paper discusses the challenges to quantifying the economic benefits of improved reliability.

White Paper #5 – Assessing the Economic Effects of Congestion Pricing

Congestion pricing is being considered in some locales for entire parts of an urban area. Pricing schemes cannot be expected to affect all motorists or locales evenly; there will be winners and losers and a unique set of economic consequences for each potential application.

Given the indeterminate nature of broad congestion pricing schemes coupled with expected analytical challenges, it may be necessary to develop one or more methodologies for determining expected economic outcomes. This white paper is intended as a first step in this process, and provides a general discussion of the potential economic effects of system-wide congestion pricing that frames the problem in terms of its theoretical, analytical, and institutional parameters.

White Paper #6 – Economic Comparison of Alternatives

Since most potential tolling are new to Oregon, attention may need to be paid to the analytical methods for assessing the relative economic efficiency of tolled and non tolled highway improvement alternatives.

Tolling presents some unique challenges to traditional methods for evaluating alternate transportation improvements, such as benefit/cost analysis or cost effectiveness comparisons. Constant value-of-time assumptions have been challenged by observed motorist behavior in toll managed lanes. There is also the need to consider the "consumer surplus" a motorist enjoys in a tolled lane rather than simply straight time savings. Freight movements demonstrate variable elasticity to tolls, which could alter analytical conclusions.

The analytical challenges and lack of public familiarity with some of these issues suggests the need for increased analytical rigor and transparency for potential tolling projects. This white paper is intended as an initial consideration of how this can best be done.

White Paper #7 – Truck Only Toll Lanes

There has been a recent surge in national interest in truck only toll lanes (TOT lanes), and a variety of proposals are in some stage of consideration. In varying degrees this reflects the growing economic cost of congestion, lagging investment in highway capacity, and a desire by some to privatize portions of the highway system. This growth in national interest implies a need for ODOT to consider the utility of TOT lanes before embarking on future freeway corridor studies. This white paper provides an introduction to the subject intended for enhancing state policies and the transportation planning process.

Appendix B: Glossary of Terms, Abbreviations, and Acronyms

Amortization – A financial term referring to terms of a loan where the provision is made in advance for the gradual reduction of an amount owed over time.

Area pricing – A tolling approach where vehicles are charged a fee to travel within a high activity center, such as a downtown or business district. Prices may vary by time of day to encourage motorists to enter the zone during less busy times or to use transit. An example is Fareless Square in Portland, where transit is available for free to discourage short-term and short-distance auto travel within the business district.

Bus rapid transit (BRT) – High-frequency bus service on dedicated lanes that are separate from general travel. BRT combines the advantages of rail transit – exclusive right-of-way to improve punctuality and frequency – with the advantages of a bus system – low implementation costs and flexibility to serve lower density areas.

Congestion pricing – An overarching term used to describe measures that reduce congestion by charging drivers tolls that vary by time of day or traffic volumes.

Consumer surplus – In economics, the difference between the price a consumer pays for an item and the price she would be willing to pay rather than do without it.

Cordon pricing – A pricing scheme whereby vehicles entering a high activity area are charged a fee when they cross the boundary line into the activity center. Motorists are charged each time they cross the cordon line. Prices could vary by time of day, to encourage motorists to enter the cordon zone during non-peak periods or to make peak trips using transit. This is similar to area pricing, distinguished by the toll being charged for crossing the cordon line rather than for driving within the cordon zone.

Cost-benefit analysis (CBA) – An analytic technique used in determining the economic value of a project or plan. Costs and benefits are typically denominated in dollars and include the money, time, resources, and consequences associated with a project or activity.

Distance-based tolls – Fixed toll rates based on distance traveled and vehicle type.

Diversion – The result of people making different travel choices, in this case as a result of a toll. Diversion can refer to taking different routes, or changing modes, travel time or destination.

Dynamic congestion pricing – Tolls that change based on real-time travel conditions. For example, when traffic volumes go up, so do the tolls. Rates are lowered as demand eases.

Economic impact analysis (EIA) – A comprehensive assessment of direct, indirect and induced economic impacts that takes into account the system-wide, sectoral effects of productivity improvements, expanded access to jobs and markets, and effects of improved reliability on business operations.

Elasticity – The price elasticity of demand measures the nature and degree of the relationship between changes in quantity demanded of a good and changes in its price. High elasticity implies high sensitivity to changes in price while low elasticity, often referred to as inelasticity, means low sensitivity to price changes.

Electronic toll collection (ETC) – Using technology to collect tolls from drivers without requiring them to stop and make cash payments.

Equity – The idea that all travelers are of equal standing, and should be considered in the development of toll policy. Social, geographic and income equity are examples of equity issues that arise in toll policy development and implementation.

Express toll lanes – Limited access, normally barrier-separated highway lanes requiring drivers of all vehicles to pay toll in order to use the facility. All tolls are collected electronically.

Fixed tolls – Toll rates that don't change. They are typically used to pay for the bridge or road on which they are charged. Trucks pay more than cars.

Fixed-schedule congestion pricing – Tolls charged at predetermined rates reflective of demand levels at different times of day; rates can be based on hour of the day, day of the week, direction of travel and vehicle type.

Gas tax – A state levied tax on the consumption of gasoline. Currently the primary means of financing highways in Oregon.

Greenhouse gas emissions – The generation and emission of gases, such as carbon dioxide, methane, nitrous oxide and halocarbons, which accumulate in the atmosphere and have a long residence time, leading to a surface warming of the land and oceans.

High occupancy vehicle (HOV) – A vehicle containing more than one person.

High occupancy vehicle (HOV) lane – A travel lane restricted to transit and carpool vehicles meeting occupancy requirements of two or three people per car. HOV lanes are meant to carry more people in less space than general purpose lanes.

High occupancy toll (HOT) lanes – Travel lanes restricted to either qualifying HOVs or solo drivers willing to pay a toll. The toll typically varies by time of day or traffic levels and is collected electronically.

Investment grade – The top four rating categories for bonds. Important to tolling, as special, independent analysis of the revenue generating capacity of a particular toll project may be required for bond issuance.

Managed toll lanes – Any toll lane that uses variably priced tolls to maintain superior, less congested travel conditions.

Mileage-based fee or mileage tax – A tax on vehicle use based upon miles driven rather than fuel consumption.

Non-recurrent delay – A type of travel delay that occurs because of incidents, and is therefore not as predictable as recurrent delay caused by traffic exceeding capacity, bottlenecks, or other infrastructure problems.

Open road tolling – Use of electronic toll collection methods to keep traffic moving, as opposed to making people stop at toll booths to pay the toll.

Opportunity cost – In economics, the value of the next-highest-valued alternative use of a given resource.

Parking policies – Adopted means of managing access to a particular locale by changes in the price of parking.

Peak period – The busiest travel time of the day, also known as commute time or rush hour. There are typical two peak periods each weekday – the morning and afternoon commute times.

Public-Private Partnerships (PPPs) – Contractual agreements formed between a public agency and private sector entity, which expand on the traditional private sector role in the delivery of transportation projects. PPPs are particularly prevalent for tolling projects.

Pricing – A tolling concept where the level of toll (price) is used to change travel behavior.

Public good – In economics, a good that is non-rival and non-excludable. This means consumption of the good by one individual does not reduce the amount of the good available for consumption by others, and no one can be effectively excluded. A non-congested public highway can be considered a public good.

Recurrent delay – A type of highway delay that occurs regularly due to too much traffic and/or geometric constraints.

Single occupancy vehicle (SOV) – A vehicle containing only one occupant.

State Infrastructure Bank (SIB) – An ODOT-managed revolving loan fund available for transportation projects.

System-wide tolling – Implementing tolls on highways and major arterials to reduce congestion, minimize route diversion and increase transportation revenues.

Theory of the Second Best – In economics, a theory of what happens when one or more optimality conditions are not satisfied in an economic model. It implies the need to study the details of a situation prior to assuming theory-based conclusions, because improvements in market performance in one area may not mean an overall improvement. This is significant in congestion pricing schemes where theoretically optimal conditions are likely to be unachievable.

Time-of-day pricing – A tolling approach that varies by the time-of-day in order reduce congestion at peak hours; rates are higher at peak hours than at off-peak.

Tolling – Charging a price to use a road, bridge or tunnel.

Toll Revenue Bonds – A type of municipal bond where the principal and interest are secured by tolls paid by the users of the facility that is built with the proceeds of the bond issue.

Travel-demand forecasting – The analytical estimation of future travel volumes and patterns, typically performed with computer models. There are four basic components: (1) trip generation – predicting the number of trips that will be made; (2) trip distribution – determining where the trips will go; (3) mode usage – how the trips will be divided among available modes of travel; and (4) trip assignment

– predicting which routes the trips will take, resulting in highway system and transit ridership forecasts.

Travel demand management – The application of techniques that affect when, how, where, and how much we travel, done in a purposeful manner by government or other organizations. The techniques include education, policies, regulations, or other combinations of incentives and disincentives.

Truck only toll (TOT) lanes – Limited access, normally barrier-separated toll lanes available only to trucks for a variably priced toll. All tolls are collected electronically.

Value of time (VOT) – One of the most important benefits of road pricing, as well as other transportation projects, is travel time savings. What these savings are worth to motorists can vary by income, gender, age, trip purpose, mode used, length of trip, uncertainty of travel time, and other factors. This in turn implies analytical difficulties in applying values to given situations.

Value pricing – Toll rates that vary in direct proportion to travel demand or congestion on alternative free routes.

Variable toll – A toll that changes by time of day, traffic volumes or other factor.

Appendix C: Review of Current Research on Reliability and Economic Evaluation

Because most investigations of travel reliability have focused on personal travel, the trend has been to measure the economic effects of reliability in terms of the value of personal time, particularly as measured by users' willingness to pay for improved reliability through tolls. Although there are regions of the country where tolling and pricing are currently in place or where demonstration projects are under way, most attempts to assess the economic value of reliability need to begin by establishing some basis for valuing travel time. Usually this is done through stated preference surveys that ask prospective questions about the value of time. There has been limited field experimentation with systems to collect information about choices made under conditions that simulate time value (e.g., revealed preference studies) and real-time monitoring of travel and route choices (e.g., Puget Sound Regional Council 2008).

Variability of trip time is viewed as an added dimension of travel time; this variability includes both the deviation from expected travel time users anticipate and the uncertainty surrounding the measurement of this variability. The value of time associated with the differences between expected (average) travel time, the costs of allowing additional time over what a route or a system may have required in the past, and the costs attached to uncertainty relative to estimating this variability – all contribute to the economic value associated with reliability.

Although the literature related to the economic value of reliability is broad, there are few published works that provide a comprehensive overall view of the subject and the issues involved. This is partially due to the fact that linking reliability with congestion management and the role of variation in expected trip length have been recognized only relatively recently (Small et al. 1999). Most investigations into the value of travel time have focused on the effects of congestion and the cost imposed on others by choices people make to travel under congested conditions.

These "externalities" were recognized by economists early on as a basis for a price structure that might force users of congested systems to "internalize" the costs they impose on others. The noted economist Arthur C. Pigou was among the earliest to investigate the use of pricing to internalize these external costs (Pigou 1920). However, his focus on government price-setting was challenged by a school of thought that came to be known as Public Choice Theory, the most prominent proponent of which was the Nobel economist Ronald Coase. Coase's fundamental insight was that real transaction costs established through market forces (e.g., based on supply, demand, and prices set by willing buyers and sellers) should be the basis of price-setting (Coase 1960). His theory (known as the "Coase Theorem") essentially states that the most efficient way to allocate (trade) externalities is to employ transactions costs (pricing) that are established dynamically. Public choice theorists applied these principles to a variety of governmental resource allocation problems, from auctioning the transmission spectrum by the FCC, to mineral lease auctions, to contemporary efforts to allocate environmental mitigation and remediation costs, and recent attempts to price carbon emissions. Coase revisited the implications of applying his theory to congestion pricing in subsequent discussions of how pricing should be applied and who should bear the costs (Coase 1992).

Most contemporary reviews of research on the effects of reliability and its relation to congestion begin by identifying the role of pricing in transportation investment, as described by William Vickery

(1969). As Vickery noted, without a mechanism to allow trip makers to displace others who may place a lesser value on their time, the operation of roadway systems are inherently inefficient. Vickery and others built on the allocative efficiency of pricing under public choice theory to establish a theory of road pricing used by most contemporary authors as a basis for investigating both the value and the reliability of travel time (Taplin 2000).

The technology needed to support contemporary implementation of pricing emerged in the mid-1990s, using techniques that eliminated toll booths that had characterized highway pricing in the U.S. since the pre-colonial era. Once these new methods came into use (primarily in overseas venues, like Singapore), federal and state research agencies began to give serious attention to the possibility of using congestion pricing and to examine ways to provide users with real "value" for their investment in optimizing travel time. As information from highway pricing projects accumulated, researchers began developing more sophisticated analyses of the differences in the ways that trip-makers value reliability. They noted that stated preference surveys tended to understate the true value of reliability. Initial inquiry into the possible value of reliability led to inconclusive results, although clear guidance on valuing both personal and commercial travel times was established (Small et al. 1999). However, based on the difficulty of estimating the value of reliability in this study, additional efforts were made to examine both the importance of reliability and the different ways that reliability was regarded by various users of the highway system.

Lam and Small (2001) were among the first to develop a structural model for distinguishing between the value of time (VOT) and the value of reliability (VOR). They developed a method to estimate these two separate properties of the value that trip-makers attach to the willingness to pay for highway use. Using new information from the California SR-91 project, they were able to move from an abstract discussion of the theory of pricing to more empirically based evaluations of the timing and expectations involved in valuing travel decisions. Using repeated survey data for SR-91 and I-15 in California, Brownstone and Small (2005) showed that people valued their time at nearly twice the level that they said they would when asked on surveys and questionnaires.

The realization that reliability is an important element for trip-makers was also supported by research into the response of highway networks to congestion. In defining the congestion problem, the issue of reliability was frequently mentioned in the context of its economic effects (USDOT 2006). However, the most recent research on reliability and economic measures continues to focus on personal travel and the value of time to people faced with choices between priced and unpriced roadway lanes. Evidence from these studies strongly suggests that earlier studies may have understated the value of reliability, but the general thrust of the research remains focused on valuing time (Tilahun and Levinson 2008).

Increasing interest is being directed toward the effects of highway system reliability on commercial traffic, especially as concepts for truck-only tolling are considered. (See White Paper 7 for a more detailed discussion of truck-only tolling.) There is also a growing base of research on freight logistics and time-sensitive delivery that indicates there is a substantial premium placed on travel time reliability and the avoidance of delay for commercial highway operations (Rao and Grenoble 1991; Small et al. 1999; Cohen and Southworth 1999; Grant-Muller and Laird 2006).

An important issue from a commercial perspective is the relationship between reliability (the variability of arrival and the uncertainties associated with unpredictable arrival times for scheduled services) and the ripple effects of reliability on the logistics supply chain. Logistics managers often define their jobs in terms of managing the uncertainties associated with various elements of the supply chain – highway, rail or marine components. These transport factors are complicated further by the simultaneous changes in how industrial supply chains are managed (Lenz and Menge 2008).

Much of this literature and a large volume of business logistics research have focused on just-in-time (JIT) delivery. However, some of the efficiencies in logistics operations accruing to JIT have suffered from the increasing variability and unpredictability of arrival times associated with greater congestion. Recent studies in a number of metropolitan regions suggest that declining reliability has imposed increased inventory and operating costs on a number of businesses, with the result that reduced reliability, including the closing of "near" off-peak options for freight operations, has affected implementation of JIT-dependent strategies for operational efficiencies such as cross-docking, and has reduced the potential efficiencies associated with backhaul operations (Weisbrod and Fitzroy 2008; Portland Business Alliance et al. 2005).

From a commercial perspective, congestion and reliability are viewed not as systemic capacity problems, but as a combination of localized capacity and reliability issues coupled with institutional and decision-making structures that need to balance the changing requirements of emerging patterns of commerce (TRB 2003). These observations were echoed in a contemporary report to Congress by the GAO concerning congestion and reliability on the nation's freight transportation system (GAO 2003). Substantial work has been completed recently identifying choke points (metropolitan areas with recurring congestion and delay) and capacity and reliability issues related to choke points and freight bottlenecks (metropolitan areas with annualized truck hours of delay greater than 25,000) (AASHTO 2007). The Portland metropolitan area was among those nationwide exhibiting significant bottlenecks and choke points with consequences to national and international commerce.

Contributing to this complex view of commercial transportation's role in broader economic activity, two recent studies of the Portland, Chicago, Vancouver, BC, and New York metropolitan areas demonstrate how a focus on the costs of over-the-road time can mask larger system-wide effects on businesses and industries (Holguin-Veras et al. 2006; Weisbrod and Fitzroy 2008). Through extensive interviews and observed travel behavior in both tolled and free-flow highway networks, both studies show the economics of highway-dependent commercial operations to be seriously affected by highway system reliability, and that these effects are transmitted throughout the cost structure of industry in varying ways that depend on the structure of the industry, the design of the logistics systems, and the ability of the organizations to pass on or absorb costs within their existing cost structure.

Potentially significant economic factors such as productivity increases/losses, usage and expansion of warehousing and distribution facilities, and transfer costs within an organization or between suppliers and producers can vary significantly. Moreover, because of intermodal schedules, service contracts, industry practice, and competitive factors, many commercial highway users – especially those in metropolitan areas – have little flexibility in changing usage patterns due to the inability of receiving companies (consignees) to make significant modifications to their operations. Although acknowledged at the highest policy levels (USDOT 2006), surprisingly little information about the effects of deteriorating highway system reliability on the economics of commercial operations are included in the economic analysis of reliability.

Economic Evaluation

Research on and analysis of the economic effects of reliability have been conducted in three distinct but related areas: the value of travel time, project- or corridor-level analysis, and analysis of metropolitan or regional impacts. The first two research efforts generally support the kinds of analysis needed for benefit-cost analysis (BCA). In these studies, time savings, vehicle operating costs, effects of safety improvements, and environmental issues are evaluated for projects or programs under consideration. The third area, analysis of metropolitan or regional impacts, is covered by Economic Impact Analysis (EIA). The details of these economic analysis methods are described briefly in this White Paper, but are covered in more depth in White Paper #6.

The effects measured by BCA are directly related to the project, and do not include all of the indirect effects a project may produce. Indirect effects include such things as changes in employment or business opportunities because the project makes new markets or sources of labor available to businesses in the areas affected by the project. BCA does not capture the multiplier effects of improved business operations, spending induced by access to more or better employment opportunities, or other consequences of personal or business operations arising from better transportation system operations. Instead, these effects are covered in EIAs, and therefore, reliability measures and impacts can and should play a greater role in economic impact analysis.

Most of the work on assessing the economic effects of reliability on both personal and commercial travel has focused on assessing pricing options for improving reliability by either (1) allowing drivers/operators to choose between travel on priced or congested, unpriced roadways, or (2) allowing them to use special purpose lanes in existing corridors (usually with unpriced, parallel alternatives). Thus, the focus has been on the direct trade-offs highway users will face when confronted with a decision to either pay a toll or to use a more congested but untolled alternative. Value of travel time is imputed to users' willingness to pay for a predictable amount of time savings. More specifically, recent research suggests that the real focus of the value attributed to reliability attaches to the arrival time at the destination. Also, the value of time has been shown to vary based on the purpose of the trip and on the amount of time saved. The majority of research on the value of travel time savings, therefore, has failed to recognize that separately valuing reliability provides a more complete assessment of the trade-offs involved in monetizing the value of these facilities.

However, several important elements of an overall assessment of the full economic costs of reliability are missing. First, most research has been devoted to assessing the value of reducing uncertainty related to travel time for a single trip on a single facility. Travel behavior has become more complex, and as travel demand studies have shown, a large and growing percentage of travel – even at peak hours – consists of "tours" involving multiple trip segments, each of which may have a different purpose and destination. Although this phenomenon has been revealed through better data collection for personal travel, commercial travel has always faced these issues in managing routes and delivery systems. Thus, even if one were to assume that current research could provide the means to estimate a valid value of time, the concatenation of multiple trips – each with different possible purposes and restrictions on arrival times – makes valuing the travel time for each a major undertaking.

Most existing literature on economic impacts of urban traffic focuses on congestion at a very broad-brush level, demonstrating that congestion can affect business productivity through changes in travel time costs and the size of market areas serviceable from a given location. However, there is little information to explain the ways in which congestion affects different types of freight movement, different types of businesses, or the ways in which businesses can respond to those conditions. Likewise, very little public research has been devoted to the direct and indirect effects of reliability on commercial travel, other than to assume that the emphasis on measuring the value of time and the premiums associated with reliability developed for personal travel also fully describes the importance of reliability to commercial travel costs. While this may be true to a certain extent, specifically for the over-the-road time costs for drivers, it fails to address other issues related to business operations. A seemingly logical extension of in-vehicle time variation has been applied to the cost of delay on cargo, equipment and inventory. In addition, some limited acknowledgement of the cost of delay and its system-wide expectation has begun to be addressed in recent investigations into decisions by businesses about how to address costs of highway delay and reliability and how to balance these costs (and risks) against other costs of operations. These costs have proven elusive for transportation planners and engineers, so far, because of their focus on over-the-road costs.

A framework for defining congestion and viewing the ways in which it can affect the economic feasibility, competitiveness and growth of economies was established by the National Cooperative Highway Research Program (Weisbrod et al. 2001). Congestion was defined as "a condition of traffic delay (i.e., when traffic flow is slowed below reasonable speeds) because the number of vehicles trying to use a road exceeds the design capacity of the traffic network to handle it." The NCHRP study examined how congestion affects producers of economic goods and services through three general avenues of impact: (1) availability of skilled labor, (2) cost of acquiring specialized material inputs, and (3) size of customer delivery markets. It demonstrated that the severity of these impacts varied systematically by industry, with greater impacts accruing to industries with greater requirements for skilled workers and higher levels of service requirements for truck shipping. It also showed that traffic congestion can nullify some of the agglomeration benefits (economies of scale) associated with operating a business in larger urban markets.

Studies by NCHRP followed a pattern of investigations conducted in the late 1990s that addressed the relationship of productivity to employment density and accessibility (Ciccone and Hall 1996; Weisbrod and Treyz 1998), as well as a study of how urban traffic congestion can reduce the effective size of an urban area's markets (Prud'homme and Lee 1999). Recent research also has shown how, by constraining the benefits of agglomeration, urban road traffic congestion can serve to reduce achievable levels of productivity in congested urban areas (Graham 2007).

However, these studies discussed productivity and accessibility only at a general level, and none of them investigated the "micro-level" mechanisms by which businesses actually see their productivity eroded by traffic congestion. Furthermore, studies have seldom distinguished congestion effects on freight movement from other effects on commuting travel. Such information is necessary if transportation models are to appropriately capture the full impact of congestion and its economic effects and to examine policies that could minimize those effects. This is why emerging research on business operations that can be directly applied to planning and evaluation from a public planning perspective is so important (Holguin-Veras 2006).

Summary

Even with increased emphasis on examining the economic relationships between reliability, congestion and business operations, questions remain about the extent to which business decisions about location, scheduling, and deployment of vehicles and labor resources can be changed to offset or minimize the effects of rising traffic congestion. These issues and their economic consequences can only be addressed through more detailed micro-level analysis of business processes and decision-making. These analyses need to be done at the metropolitan level for a number of reasons. While there are generalized approaches to managing productivity and operations within industries, each metropolitan area is configured differently. Location, access to major highways, and local demand all factor into the day-to-day decisions and strategic planning undertaken by businesses. These local factors need to be addressed by developing insight into logistics operations by industry and by region. Thus, understanding local business operations and research on the structure of logistics support industries are essential first steps in understanding the economic impact of highway system reliability on commercial traffic.

The assumption that methods developed for economic evaluation of reliability for personal travel costs can be mimicked for commercial travel has led to various studies of the value of time for freight transportation. These studies have focused primarily on the willingness of freight haulers to pay for improved system performance through shorter travel times, improved reliability (reduction of travel time variance), or reduced uncertainty about the response of highway operations to congestion. These aspects of economic evaluation only address the over-the-road component of the economics of commercial travel and are focused on supporting project-related BCA. The elements most often missing are those related to economic impact assessment. Economic impacts – both operational considerations for businesses and the overall economic consequences for regional and state economies – are thus overlooked by decision-makers in the overall assessment of strategic investments in transportation infrastructure.

Appendix D: Implementing Reliability Measurement, Monitoring and Data Collection Methods

Introduction

Deciding how much and where to invest in reliability improvements requires understanding how personal and commercial highway users value and benefit from greater reliability. Because these investments require public funds, it is also important to understand how the value of reliability improvements affects the economy of the region. This white paper has discussed the kinds reliability measures and methods that should be considered to evaluate the economic impacts of investments in improved reliability. Gathering and analyzing this data will require addressing four key issues:

1. Measuring traffic flow, variability and response to congestion
2. Determining the response of highway users to travel time variation
3. Monetizing the value of reliability in ways that can be used in economic impact analysis
4. Assessing the consequences of changes in reliability to personal travel and commercial logistics decisions

This appendix describes each of these issues and how they fit into the framework of economic evaluation of reliability. The usefulness of data and evaluation methods depends on how well they depict the effect of improvements to the highway system on operating conditions for highway users and how more reliable personal and commercial travel will benefit the economy.

Measuring Traffic Flow

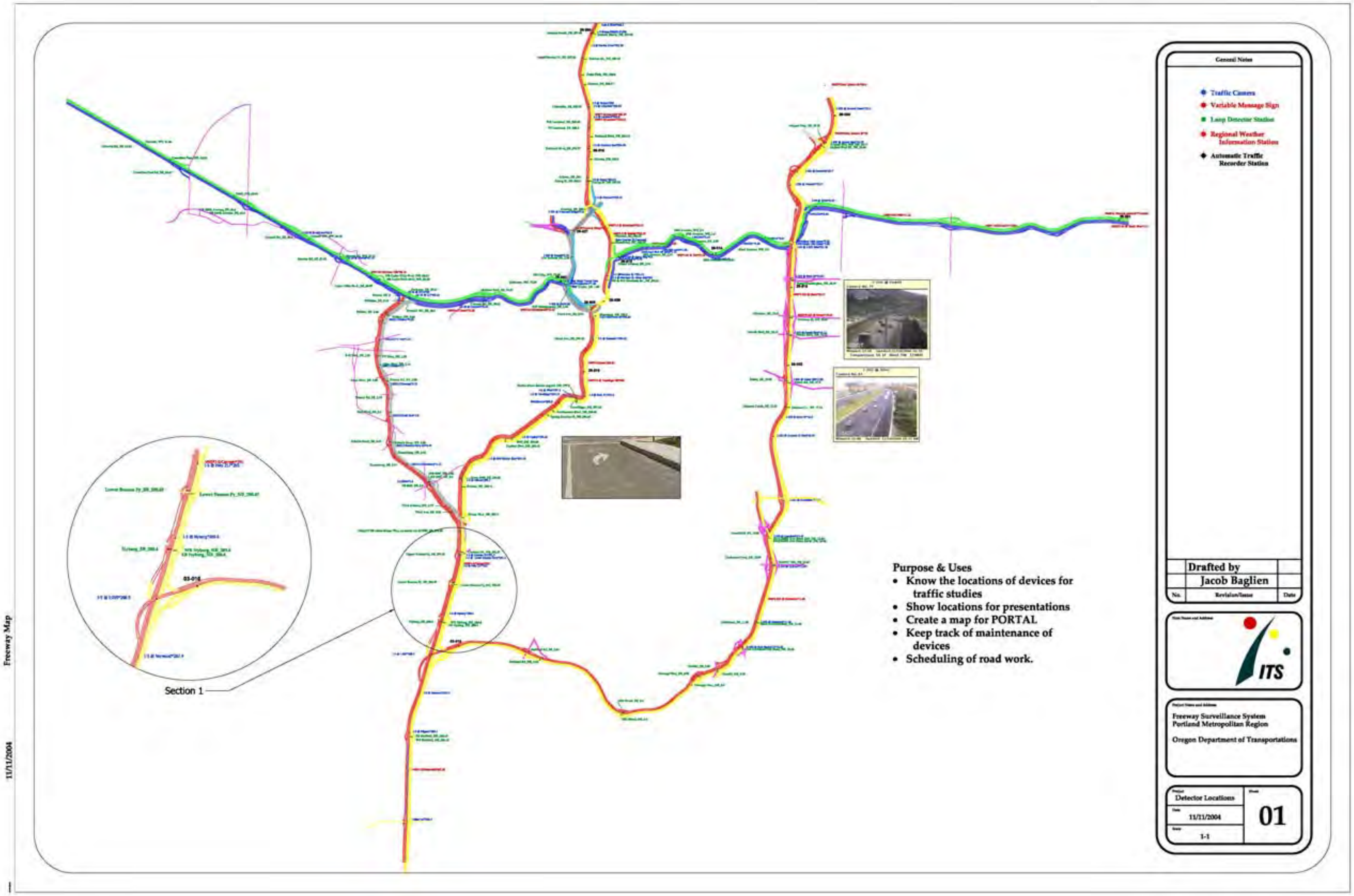
Measuring reliability requires developing information to determine average (or expected) travel times between fixed points throughout the entire highway network and the observed distribution of travel times between these fixed points. Since these measures vary by time of day, day of the week, or even seasonally, large amounts of data must be collected, stored and available for analysis. Continuous collection of data is required. For large metropolitan areas with complex highway networks, the data collection process can appear daunting.

Traffic flow measurements needed to estimate travel time variation require the ability to accurately determine point-to-point travel times and speeds, and then to aggregate and tabulate this data in a way that provides reliability measures described in Chapter 4. Historically, only tolled highway facilities came close to meeting these requirements. Mechanical traffic counters and periodic manual surveys were introduced as transportation planning and engineering became more systematized. With the introduction of computer-based travel demand modeling, it was possible to simulate conditions approximating travel time variation, but results derived from simulations have not proven to be as reliable or useful as data collected in "real-time." The demands of computerized modeling systems for physical surveys and traffic flow data (for calibration and verification of simulated results) have proven expensive. Primarily because of the expense of physical surveys and traffic counts, continuous manual collection of highway operations data has become progressively more difficult to sustain.

With the advent of electronic monitoring systems that can indirectly measure the number, speed, travel time and location of individual vehicles, much more sophisticated and less obtrusive ways of monitoring traffic flow and collecting individual vehicle travel data have been introduced. These data collection techniques have been developed as part of a nation-wide initiative that was initially proposed and funded through the Intelligent Transportation Systems (ITS) Program under the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). Under federal sponsorship and with the cooperation of DOTs and MPOs, a system "architecture" and standardized design for both the technologies and methods for collecting electronic traffic data have been developed. By 1998, the federal government recognized both the value of and need for storing, retrieving, and archiving such electronic data. Guidelines and methods to include an archived data user service (ADUS) for maintaining and accessing archived data were included in a revised National ITS Architecture (Joint Program Office for Intelligent Transportation Systems 1998). Subsequent revisions have updated these methods to incorporate advanced technologies for collecting, transmitting (telemetry), storing and retrieving this information (Texas Transportation Institute 2001).

Based on guidance and initiatives by ODOT and Portland Metro, a system of loop detectors and communications called the Portland Regional Transportation Archive Listing (PORTAL) was set up in the Portland region in 2004. This system, operated by Portland State University, collects and archives real-time data (Bertini et al. 2005). Data archived by PORTAL has been used in a variety of traffic analysis studies and has recently been used to develop empirical data analysis of reliability measures on selected corridors in the Portland Metro region (Monsere et al. 2005; Horowitz and Bertini 2007). The PORTAL system supports analysis of reliability pursuant to FHWA measurement guidelines, and has been shown to provide the kinds of data needed to assess a full range of reliability measures (FHWA 2008; Lyman and Bertini 2008).

This data collection and archiving system provides a firm basis for collecting the basic data needed to assess reliability and changes in reliability of major portions of the Portland metropolitan highway system. Current coverage consists of approximately 500 loop detectors supplemented by video cameras, variable message signs and automated traffic recorder stations. The present system covers all of the Interstate system in the Portland Metro region (I-5, I-205, I-405 and I-84), and portions of two of the highest volume state routes (OR 217 and US 26) west of the I-5 corridor (see Figure 2).



Source: PORTAL On-Line Resource (http://portal.its.pdx.edu/info/links.php) Accessed September 15, 2008.

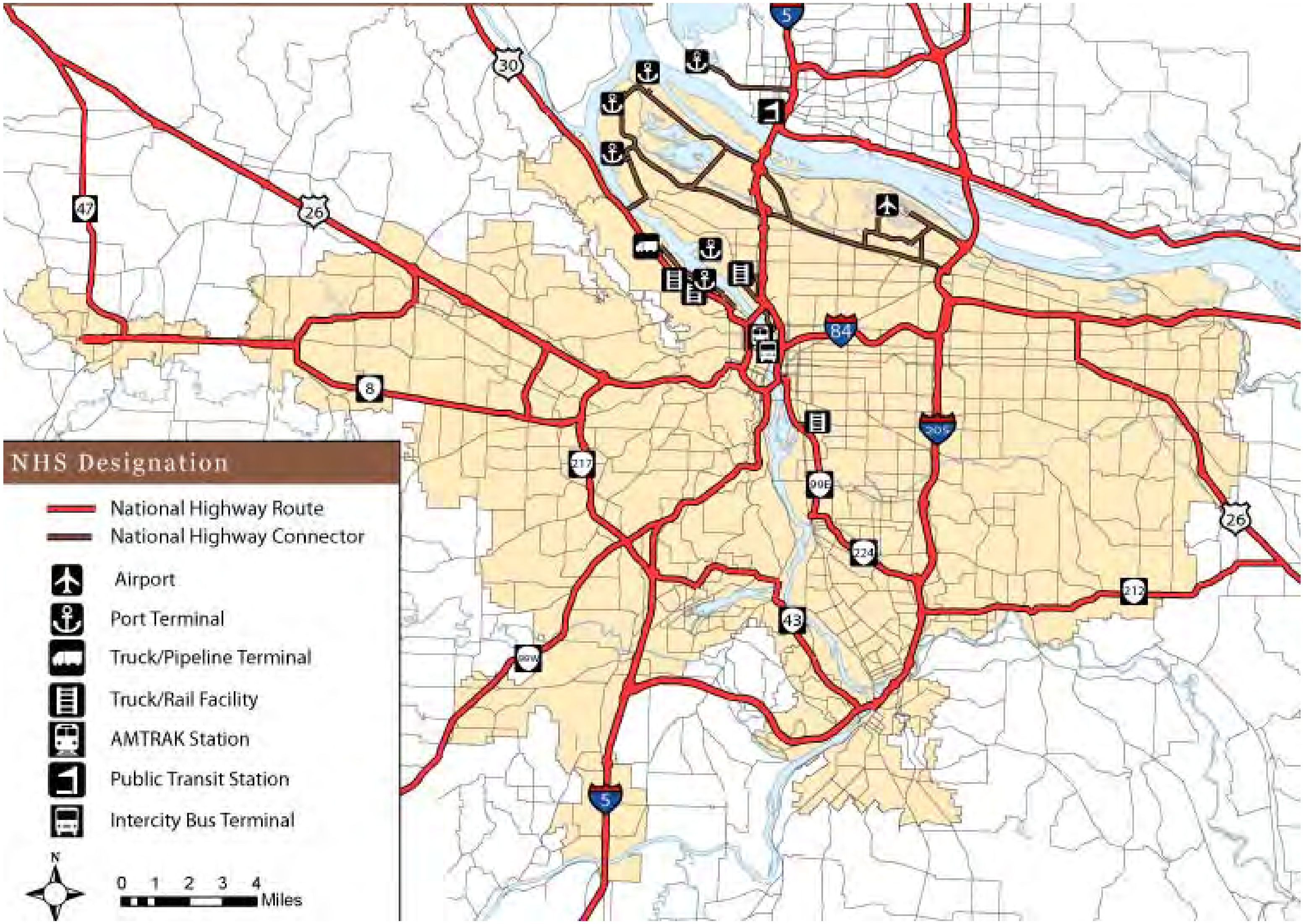
Figure 2 – PORTAL System Traffic System Coverage and Sensors

While these Interstates and major state routes are important to the mobility and economy of the region, there are a number of other highways that are part of the National Highway System (NHS) (see Figure 3).[§§] In the Portland region, the NHS-designated roadways provide key connections between the Interstate system and many of the key urban centers, industrial centers and employment centers in the region. As shown on Figure 3, the NHS includes all of the highways in the PORTAL system, as well as US 30, US 26 east of the I-5 corridor, and OR 8, OR 43, OR 47, OR 99E, OR 99W, OR 212 and OR 224. The NHS connectors also serve the areas of Portland vital to port operations. Although not part of the current PORTAL system, reliability of these highways is important to personal and commercial travel because they provide the capacity required for the highway system to accommodate high-volume commercial traffic demand.

Measures of reliable highway travel that only focus on the Interstates or even the NHS overlook a vital element of overall reliability – the ability to move "door-to-door" on the highway system. Thus, local roadways, major intersections, and other key parts of the highway system can affect reliability through their performance. For personal travel, the obvious problem areas include urban centers and areas of high employment concentration. For commercial traffic, making these "last mile" connections can often significantly affect reliability because these roadways are where some of the greatest unpredictability occurs. Figure 4 shows a map of the Portland metropolitan area's regional truck network. It includes all of the PORTAL and NHS highways, as well as a number of connectors to major intermodal facilities and truck stops and those connections between NHS roadways that are most heavily used by commercial transportation. The location and density of these designated truck routes show those portions of the Portland metropolitan area likely to be the most sensitive to changes in highway system reliability.

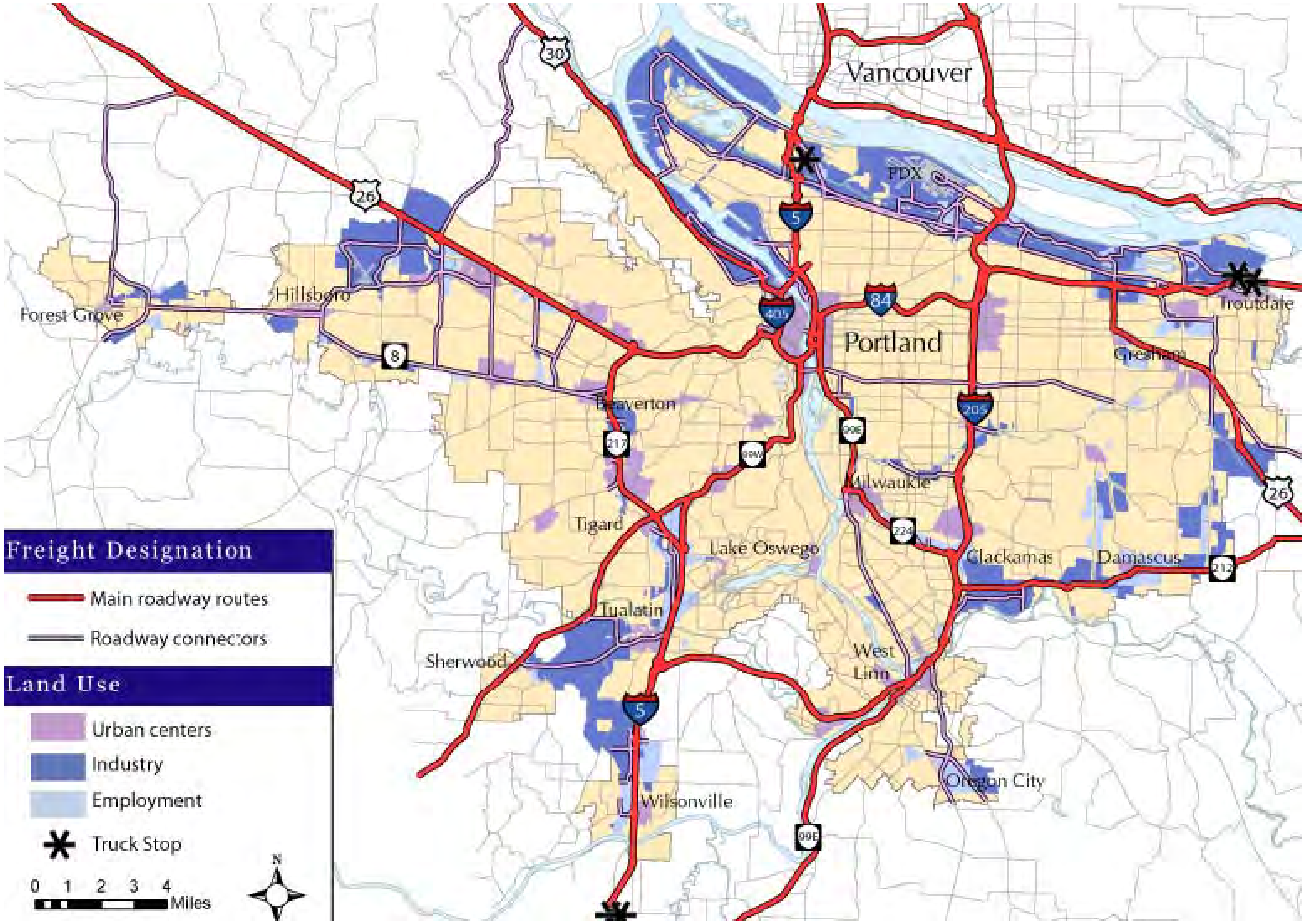
Statewide, the NHS covers most of the major US routes and state routes in the rest of Oregon. Local information about these highways is available through ODOT's TripCheck web site (at http://www.tripcheck.com/). This web site displays highway conditions in real-time, and includes information on weather, congestion, crash and incident warnings, construction, and commercial vehicle restrictions. Although this site provides important information about non-recurring factors that can affect reliability, this data is neither archived nor available for use in other than real-time requests. This limits its usefulness for measuring reliability and for contributing to any systematic economic impact assessment of reliability improvements for intercity travel.

[§§] The entire National Highway System (NHS) was designated by Congress in 1995. The NHS includes Interstates, other principal arterials, and intermodal connectors. It also includes highways of strategic military importance (i.e., the Strategic Highway Network (STRAHNET) and major strategic highway network connectors). Nationwide, these highways include approximately 160,000 miles of roadway considered important to the nation's economy, defense, and mobility.



Source: Profile of the Regional Freight Transportation System; Metro, 2007.

Figure 3 – National Highway System – Portland Region



Source: Profile of the Regional Freight Transportation System; Metro, 2007.

Figure 4 – Portland Regional Truck Network

However, reliability measures for intercity travel are important, and could be used to evaluate and compare the relative importance of investing in reliability improvements for rural and smaller metropolitan areas. Reliability measures for smaller metropolitan areas may be able to be modeled using systems similar to the PORTAL system. However, as seen in the Portland area, it would be important to develop a plan for coverage of those elements of the highway system in each metropolitan area or city for which reliability issues are most significant – from both personal and commercial travel perspectives.

Reliability measures for intercity traffic will require a careful examination of the applicability of metropolitan-style data. Data currently managed by the TripCheck program is important as it provides a basis for evaluating non-recurrent congestion and the resulting reliability effects. However, for more detailed assessments of intercity travel, reliability issues may require more emphasis on grades, availability of passing lanes, and access to Interstate highways, rather than the focus on peak hour congestion and the effects that concentrated volumes of traffic have in metropolitan areas. Also the methods used to gather operating data in non-metropolitan areas may require more in-vehicle data collection technology (e.g., GPS and vehicle tracking) than highway monitoring (loop detectors, cameras, etc.).

Emerging Technologies

Traffic flow and real-time traffic condition reporting has advanced significantly in the past decade as ITS initiatives have matured. Universities, governments and private corporations are actively pursuing new ways of collecting traffic flow and traffic reliability data. These new methods rely on everything from existing technologies such as those employed by the PORTAL system (loop detectors, embedded road sensors, and cameras) to in-vehicle tracking devices and even GPS-equipped mobile phone networks. These developments are important because data on reliability requires a combination of data integration (i.e., collecting data from a variety of sources or locations) and aggregation (combining this information in ways that it can be used and interpreted).

One example of a recent commercial application is the system being offered by INRIX (see http://www.inrix.com/). A consortium of private organizations, INRIX operates in the US and several European countries. Its services focus primarily on intercity and urban freeways. However, working with the public sector on various research projects, they have developed point-to-point travel time distribution data sets comparable to those generated by the PORTAL program.

One of the most recent mobile phone-based traffic monitoring systems was initiated by the California Center for Innovative Transportation (CCIT) at the University of California at Berkeley. In cooperation with Nokia, Caltrans, and several other public and private sector partners, CCIT has fielded a system for collecting and reporting real-time traffic data that is intended to include up to 10,000 participating vehicles in the San Francisco Bay area (see the Mobile Millennium Project at http://traffic.berkeley.edu/theproject.html). This program is specifically designed to address the need for travel data on metropolitan arterial and secondary roadways as well as on long-distance Interstate highways. The primary purpose is to collect and transmit – in real time – traffic speed and travel time information. Although there is no published plan to aggregate this data for use in determining operational reliability, that possibility exists if the data is properly archived.

Integration and visualization of data from multiple sources (loop-detectors, cameras, GPS-enabled devices and customized probes) is still in the early stages of development. Among the research institutions currently involved in assessing the usefulness of these technologies, the University of Maryland's Center for Advanced Transportation Technology Laboratory (CATT Lab) has been active in developing visualization and data integration technologies. However, even with the expansion of technologies and platforms for gathering traffic data, data density on arterials and secondary roadways is still too spare to provide adequate reliability data.

Anticipating the Response of Highway Users

Personal and commercial travelers are subject to many different motivating factors and constraints. Because of this, measuring the response of each user group should be considered independently. For personal travel, substantial data, modeling and surveys have been conducted in the Portland metropolitan area and in other parts of the U.S. The results of these surveys have been used to determine how individuals respond to congestion and delay, and are used extensively in current travel demand modeling applications.

However, a number of key questions about how improved reliability may affect personal travel decisions still need to be addressed. These questions center on the ways that households will likely use improved reliability in organizing or altering their trip-making patterns. If improved reliability leads to more efficient travel, will personal travelers make the same number of trips, and use the time saved for non-travel purposes? Or, will household members choose to travel more and by doing so contribute to congestion and ultimately declining reliability? Will alternatives to the automobile, increased vehicle operating costs, and the expected effects of changes in land use reduce the tendency to rely on automobiles for personal travel and thereby provide commercial operations with more opportunities to make use of reliability improvements?

Survey research into the response of travelers to improved reliability will need to be designed to answer these kinds of questions. It is important to understand how much improved reliability will be used for personal travel, and the degree to which non-auto alternatives, land use and public policy may influence personal decision-making and ultimately serve as realistic substitutes for auto travel. This is because reliability improvements are shared by both commercial and personal travelers, and commercial users – for the most part – have relatively few non-highway travel alternatives from which to choose. Developing the information needed to evaluate these prospective choices and the factors that influence personal travel decisions will require even more careful and probing surveys than have been fielded to date.

The survey research needed to assess responses of commercial travelers is much more basic and less subtle that for personal travelers. Because commercial travel is more explicitly tied to a variety of cost factors, and because these costs are allocated and absorbed differently in different commercial sectors, research into the decision-making and responses of commercial travel to changes in reliability requires more effort and more attention to the differences in operational requirements between various kinds of businesses. Anticipating the response of commercial travelers to improvements in reliability requires understanding the operational requirements of each sector in the context of highway reliability. For instance, food distribution and warehousing require different dispatch, routing, and delivery patterns than retail distribution. Manufacturing of electronics and components for high-technology involve much different logistics support than for automotive or transportation machinery. The organization of logistics services for public utilities and municipal services are quite different from those for health service, hospitals and clinics.

It is just as important to identify those characteristics of the current highway transportation system – including reliability – that prevent various sectors from instituting logistics and operational changes that could increase their efficiency or result in greater cost savings. Examples from previous studies suggest that reductions in early morning reliability have produced higher costs in the food distribution industry. Unreliable mid-morning trucking operations have severely reduced the options in health care for achieving efficiencies from cross-docking medical supply services. And declines in early afternoon reliability can reduce or eliminate the possibility of establishing reliable backhaul schedules for medical services and other logistics and warehousing operations (PBA et al. 2005). Information about how logistics systems operate, the factors that impede efficient operations, and the location and timing of reliability issues could inform decisions about investing in capital improvements or in better system management options.

It is also important to have information about how the private sector makes decisions about private capital investments and operations in logistics support systems, so that the full impact of reliability issues on the economy of a region and the choices, trade-offs and unrealized competitive opportunities that are foregone when reliability improvements are not made can be considered. This kind of information has not been explicitly included in highway studies and decision-making about reliability and capacity improvements in the past, and is only just beginning to be recognized as a vital component of infrastructure investment in metropolitan planning (Metro 2007). Some of the most innovative analyses are being conducted for international border crossings where the importance and costs of reliable movement of freight can be isolated and evaluated (Taylor et al. 2003; SANDAG and CalTrans 2006; Roelofs and Springer 2007).

Monetizing the Value of Reliability

Decisions and responses of highway users to improved reliability are, at least in theory, based on the idea that there are explicit and implicit costs associated with travel and reliability that can be measured and that are perceived by travelers. By assigning a monetary value to both time and reliability, transportation planners have attempted to quantify one of the most important (and controversial) elements in BCA used in project evaluation. These estimates are controversial because even small errors in estimating an individual or class of traveler's costs can swing the total benefits to favor projects that only marginally improve travel time reliability.

For personal travel, both the literature about and the practice of survey research has developed significantly over the past two decades (Kriger et al. 2007). Indeed, enough studies have been done on the monetization of travel time (and increasingly, the value of travel time reliability) that expected values of travel time and reliability of personal travel are often compared to prior studies to assess the validity of independent estimates. The studies and the methods used to develop estimates of the value of travel time and reliability for personal travel recognize the differences by purpose, type of respondent, and other socioeconomic factors that may influence the variation in estimating these values.

As information on the variation of travel times becomes better defined (e.g., PORTAL ADUS data), it should be possible to refine and improve the estimates of the value of reliability relative to other travel costs. Also, as more research and surveys on pricing studies (especially dynamic or time-of-day pricing) are completed, travel time values and estimates of the value of reliability will improve.

However, as noted in earlier discussions, monetization of the value of reliability for commercial operations requires valuing more than just the time of the driver, the operating costs of the vehicle and the opportunity costs associated with captive cargo. Reliability improvements can mean that route productivity increases. It can eliminate the need for extra shifts at receiving docks, and it can reduce costs associated with "rescue" drivers and services in situations where drivers have exceeded the hours-of-service rules. Reliability improvements can also make it possible for innovative and cost-saving logistics operations to be instituted. However, because each commercial sector is different, the cost savings and monetization of reliability improvements can vary substantially, even if the same amount of over-the-road time savings is realized. Current methods of valuing commercial time based on local wage rates and the value of commodities being transported omit many of the most important and relevant operations costs savings from consideration.

Therefore, improved and innovative methods for determining the value of improved reliability for commercial travel are required. As noted above, the value of time and reliability generally comprise the largest benefits attributable to highway improvement projects in BCA. It is highly likely that omitting many of the potential user benefits associated with commercial operations results in systematic under-reporting of the benefits of reliability improvement projects. Although methods and techniques for eliciting the value of reliability for commercial travel are far less developed than for personal travel, the methods described in the research cited in this paper and increased attention to monetizing the value of reliability for commercial travel can contribute to a better understanding and monetization of the value of reliability for commercial highway use. These approaches require more in-depth interviews and surveys, often at the establishment level. They also require that the professionals doing the interviewing understand commercial operations and logistics practices. Most important, development of monetized reliability values needs to consider the structure of businesses and industries in a region, and the supply chain, logistics processes, and highway system operating characteristics unique to that region.

Assessing the Economic Impacts of Reliability Improvements

Measuring reliability improvements, determining the behavioral and operational responses to improved reliability (or the possibility of improved reliability), and estimating the value of these improvements are potentially complex, but not insurmountably difficult. The greatest challenge to effective evaluation of reliability improvements is redefining the method by which reliability improvements will be evaluated and compared to other transportation investment options.

Reviews of the various methods of economic analysis and the issues that each addresses (Chapter 5) and the economic evaluation of alternatives provided in White Paper 6 both drew distinctions between BCA and EIA. These two analytic methods are designed to accomplish different goals. BCA is best used for project evaluation and, if done consistently and properly, can be used to select and prioritize projects based on benefits and costs to users and, with some caveats, on the broader benefits and costs to society from each project (e.g., safety and environmental benefits).

However, even with a fully developed commercial monetization of benefits, BCA will not provide insight into the ways that investing in a particular project or program will improve the competitiveness of businesses or the ways that they will benefit from reliability investments (e.g., whether their market access will increase, if they will add employees or increase output, if additional tax revenues will be generated due to these activities, etc.). Also, BCA will not address the multiplier effects of increased business activity resulting from reliability improvements in one industry or sector on the output required from others. These broader impacts are not particularly relevant when considering personal travel. Applying the principles of personal travel reliability evaluation to commercial travel without considering the full range of productivity and competitive advantages those commercial operations might receive, omits both important benefits accruing to commercial operations (which could be captured in BCA if the analysis were properly structured) and the multiplier effects captured in EIA.

Therefore, adequately assessing the economic impacts of reliability improvements to the highway system will require adding new elements to the multi-criteria decision process used to evaluate highway investments. If the full effects of reliability improvements are to be considered, then the economic impacts as developed in an EIA, the weighing of benefits and costs as developed in a BCA, and other equity and land use impacts and policy considerations will have to be brought into the decision-making process. How these different evaluations and issues are treated is best considered in a discussion of overall public policy and decision-making. However, it is clear that analysis currently being done using BCA suffers from serious omissions of important potential economic benefits because the full effects of reliability improvements on both personal and commercial travel are not assessed. Although improving competitiveness and fostering economic growth are important objectives of state and regional plans, no consideration of the contribution that investments in improved reliability make to competitiveness and economic growth are currently being considered in the economic evaluation of these investments.

Implementation Options

Implementation of key elements of reliability measurement and monitoring, survey research needed to develop better appreciation and understanding of commercial operations, and monetization of reliability improvements will require the effort and attention of agency staff and institutions currently involved in transportation planning in Oregon and in each of the state's metropolitan regions. Implementation of analytic methods and changes to decision processes that integrate EIA may require high-level policy and procedural changes.

Measurement. The physical measurement of reliability is currently being done under the auspices of ODOT's PORTAL ADUS program. It is being operated by Portland State University, and is supported by several governmental organizations including Portland Metro, the City of Portland, and TriMet. The geographic coverage of the system is quite extensive, and has received sponsorship from the National Science Foundation, FHWA and Oregon State University. As noted above, extension of coverage to more highway facilities within the metropolitan region should be considered, as should expansion to state-wide coverage using the technologies, performance measures, and display techniques developed and documented in this program. Both state-level and national guidance on ITS and ADUS programs has formed the basis for the current program. Adapting these technologies to smaller metropolitan areas, and considering how rural and Interstate reliability should be measured and monitored, are clearly areas where collaboration between ODOT, its regional administrators, and local governments and planning agencies will be required in the future. Also, emerging technologies, advanced methods of data aggregation, and multi-platform data collection systems are being developed throughout the country, and deserve a careful review. Although, the current system(s) provide a very good state-of-the-practice foundation upon which to begin expanding these capabilities state-wide, it is clear that installing in-highway hardware rather than integrating in-vehicle technologies into reliability data collection will be costly and time consuming. It is also unlikely to provide the extent of coverage needed to measure reliability on secondary and arterial roadways.

Operations Research and Monetization. In the areas of operational evaluation and monetization, both basic research into the ways that Oregon industries meet their logistical challenges and analysis of the structure of logistics for major commercial sectors will be required. This is an area where collaboration between university researchers, ODOT, and the private sector is important. Coordination though the Oregon Freight Advisory Committee (OFAC) should be considered, as the emphases on freight mobility and freight economics are clearly key elements of their mission and enabling legislation.

Entities such as the Port of Portland and business organizations like the Portland Business Alliance and the Oregon Business Alliance could form the basis for a collaborative effort to bring private businesses into the process. A number of freight working groups and committees have been developed and supported by Portland Metro and other MPOs in the state. Recent reports describing freight issues in the Portland region illustrate the interest in these issues, but also highlight the shortcomings of traditional planning studies in addressing fundamental logistics and reliability issues (Metro 2007).

Basic research into the monetization of improved reliability is essential to measuring and monitoring the economic impacts of reliability. As noted above, research into the values associated with personal travel time and variability are well-developed in the U.S. and in the Portland region. There are no known estimates of the value of reliability for commercial operations in the Portland region or in Oregon. Methods for developing this information exist, and have been applied in other areas of the U.S. and at various international border crossings. While determining the value of improved reliability for commercial operations is a significant undertaking, initiatives to develop this information could benefit from the active participation and cooperation of businesses and their representative organizations throughout the state. Many of these organizations currently participate in Metro's Freight Working Group. Members of the Portland Business Alliance and the Oregon Business Alliance have demonstrated the willingness and commitment to work with and encourage their members to participate in similar studies, and to sponsor investigations into commercial transportation issues.

Evaluation. Introducing changes in evaluation methods needed to address reliability will require making changes in the highway project planning and investment process by incorporating a more explicit recognition of the ways that economic evaluation and project prioritization are accomplished in Oregon and in the Portland region. First, as more explicit, quantitative assessments of reliability are introduced, other decision criteria will need to be reassessed. The Oregon Transportation Plan (OTP) prioritizes projects based on eight criteria, one of which is "economic vitality." The other criteria are mobility and accessibility, effectiveness and efficiency, equity, public support and financial feasibility, reliable and responsive service, safety, and sustainability. Reliability effects will need to be considered in a broader context of decision-making, along with the effects of investments on these criteria. Decisions will have to be made concerning where reliability "fits" in discussions of these criteria.

Second, increased emphasis on commercial operations may lead to concern that the traditional emphasis on personal travel may be reduced. In this regard, it is important to note that the sustainability of the region's economy rests on the viability of commercial establishments in the region. Also, commercial movements – including those supporting technology-oriented and service-based economies – require time-sensitive and highly reliable logistics support. Without reliable commercial freight operations, the competitive advantages and high levels of productivity needed to sustain a modern, high-tech, service-oriented economy risk being eroded. Other regions in the Pacific Northwest – including Seattle and Vancouver, BC as well as the San Francisco/San Jose region in California – are positioned very competitively with the Portland metropolitan area. The robustness of the local economy depends on attracting and retaining industries by preserving commercial competitiveness as well as a high quality of life.

Finally, Oregon, and especially the Portland metropolitan area, provide vital transportation links to global trade between the rest of the Pacific Northwest and the Northern Great Plains, and are on a major NAFTA trading corridor stretching from the southern Baja/Tijuana/San Diego area to the northern Pacific Great Circle Asian routes of Vancouver/Prince George. Trade flows and the logistics support they require depend on organizations and people in the transportation and logistics support industries in Oregon. The ability to move people and commodities through the state and the Portland region reliably and cost-effectively is vital to preserving the U.S. role as a major player in NAFTA and global trade.

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