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White Paper on Valuing Transportation Infrastructure

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White Paper on Valuing Transportation Infrastructure

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Prepared for the

Workshop on Data and Statistics for Valuing Transportation Infrastructure and Transportation's Contribution to the Economy

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I. PURPOSE

In 2014, the Workshop on Data and Statistics for Valuing Transportation Infrastructure and Transportation's contribution to the Economy initiated a three-year effort to review methods used to estimate the value of transportation infrastructure and its role in the economy and to explore and recommend how these methods might be extended and improved to provide more meaningful statistics for decision makers. The workshop was established in response to the mandate of the recently enacted highway transportation bill, Moving Ahead for Progress in the 21st Century Act (MAP-21), which requires a "national accounting of expenditures and capital stocks on each mode of transportation and intermodal combination." In addition, MAP-21 introduced performance-based management for federal surface transportation programs, which may require the creation of new data sets. Section 1203 of the Act (MAP-21) declared that performance management will transform the Federal-aid highway program and refocus it on national transportation goals, increase accountability and transparency of the Federal-aid highway program, and improve project decision making through performance-based planning and programming. It is expected that performance measures will be in effect by the second quarter of 2015.

The purpose of the Workshop is to provide decision makers with ideas of what statistics should be generated at the national level in the near term and to provide state DOT officials with ideas for proceeding within their own domains using state or regionally available statistics. The White paper was commissioned by the Taskforce as a resource for participants as they discussed current issues with existing data and methods, such as:

- Alternative strategies for using data and statistics in estimating infrastructure value;
- Relative strengths and weaknesses of these methods;
- Potential benefits of improved methods and data.

More specifically, the Task Force structured their discussion around six questions:

1. What are the public and private decisions that would be informed by statistics on the value of transportation?
2. What is the state of practice for generating value statistics in response to each of the types of decisions?
3. What are the criteria for identifying best practice, and how does the state of practice measure up?
4. What decisions are not being answered or are being answered poorly by current practice?
5. What are current data sources for statistics on value, and are those sources being tapped fully?
6. What methods for estimating value used outside the US might be applied to the US with existing data?

While the White Paper addresses the issues posed by each of these questions, the paper is not organized explicitly by these questions. However, an appendix summarizes the findings succinctly by these questions, as a helpful reference for the Task Force.

The paper focuses on methodologies and data requirements in valuing transportation infrastructure. While transportation encompasses several modes, highways will receive the most attention. It is fair to say that a majority of the studies on the effects of transportation on economic activity focus on highways. Highways embody most of the attributes that make transportation systems a rather difficult entity to value—most importantly their congestion and network characteristics. The paper examines the mature nature of the highway system and what this means for valuing it. It considers the complex relationships between the facility-related characteristics of highways, (such as lane miles, pavement conditions, and so forth), its outputs of transportation services, and outcomes of economic growth and externalities. The paper describes in detail the estimation of highway capital stock. It then looks at four ways to value highway system, which can be extended to other modes of transportation. These are: 1) valuing the capital itself, 2) relating capital stock to national output, 3) conducting benefit-cost analyses and the valuations of individual elements needed for this methodology, and 4) estimating production functions, or similar aggregate constructs, relating highway capital stock (or measures of the stock of other modes of transportation), as one of the production inputs, to a measure of economic output.

Since a motivation for this workshop is the performance measures required under MAP-21, the paper starts with the practical issues of defining the audience for the valuation estimates, how valuation may be related to the performance measures, and what it means for sound asset management practices. The paper concludes with a summary of the findings and a reminder about the need to coordinate data collection efforts, reflecting both the spirit of a highway (or more broadly a transportation) network and the requirements of MAP-21.

II. AUDIENCE

MAP-21 requires a coordinated effort among local (MPOs), state, and federal DOTs with respect to strategic planning and asset management. In general, each level of government has a specific role. The federal role involves the distribution of formula grants to states and metropolitan planning organizations. The USDOT also gives out grants for projects that meet specific criteria. As a result, most surface transportation planning, prioritization and funding takes place at the state and metropolitan levels. Generally, states tend to play a dominant role in highway planning and MPOs play a dominant role in multimodal planning for urban areas.[1]

Asset management, according to MAP-21, is a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based upon quality information. The process identifies a structured sequence of maintenance, preservation,

[1] NCHRP Project 2-24, Economic Productivity and Transportation Investment, "Task 1 Literature Review, Stakeholder Perspectives and Framework Outline," Washington, DC: Transportation Research Board, February 19, 2013.

repair, rehabilitation, and replacement actions that will achieve and sustain a desired state of good repair over the lifecycle of the assets at a minimum practical cost (23 U.S.C. 101(a)(2), MAP-21, para. 1103). Therefore, the public sector decision makers should include officials from all three levels of government.

However, the focus on asset management by MAP-21 and the challenges facing the management and improvement of the transport infrastructure also require collaboration with private sector decision makers. The most basic decision is for users of transport infrastructure to decide when, where, and how much of the transport capital to use. Users of transportation services need to know the optimal mode by which to ship their services, and households must decide on the appropriate modal option to use to commute or to shop. These decisions will be based on price, past investment in trucks or cars, or other moving stock, and the conditions of the transport facilities.

Since the construction and maintenance of highways and other transportation modes are paid for primarily through government financing, the cost to users and thus the price they pay may not necessarily reflect the entire cost of providing transportation services. Consequently, without true prices, transportation resources from a societal perspective may not be allocated efficiently. For example, if the use of highways by trucks is subsidized relative to rail transport, then highways may become congested with truck traffic and rail may be underutilized. Fuel taxes and tolls may approximate the price of using highways but fall short of acting as a true price. Accurate cost information must be available not only to policy makers and practitioners but also to users in order to manage transport assets efficiently.

In addition, ensuring that the existing highway infrastructure is able to accommodate increased use without reducing transport time and reliability requires new technology from the private sector. Cars of today, for example, are already considerably "smarter" than they were only five years ago, with guidance and warning systems that allow more efficient and safer use of highways, even with significant increases in highway volume. However, to take full advantage of these technological advances and the many more to come, public highway officials need to collaborate with auto and truck manufacturers and freight providers as well as software developers to ensure that highways are providing the infrastructure necessary to accommodate the technology. It may be the case that relevant stakeholders may come from business sectors that today seem totally irrelevant to the discussion of transportation but tomorrow may be major players. For instance, who would have thought five years ago that Google or Tesla Motors would become major players in the transportation arena.[2]

Moreover, the need for more information of all different types to monitor and improve the performance of the nation's transportation system requires the linking of information generated from many different sources. For instance, the discussion under MAP-21 performance monitoring of the possibility of linking serious accident data to hospital records as a way of monitoring the safety of highways is but one example of bringing together seemingly disparate stakeholders. This possibility of

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[2] NCHRP Report 418 entitled "Research on the Relationship between economic development and transportation investment" 1998 provides an exhaustive list of stakeholders including their role in transportation decision-making process and interest in economic development.

linking administrative data pales in comparison to the likely future of linking smart phones and other devices as sources of information to provide real-time data on road conditions and usage. Furthermore, local, regional, and national economic data will need to be linked more closely with highway and other transportation data in order to show the relationships between transportation infrastructure and the economy, which also requires partnerships with statistical agencies and private businesses and households.

The private sector also becomes an important stakeholder and audience member through the formation of private-public partnerships (P3) for financing infrastructure projects. According to a Federal Highway Administration primer on the topic, "expanded financial capacity is one of the primary reasons public agencies consider P3 concessions for transportation facilities…when the public is unable or unwilling to borrow for a project" (FHWA, 2010, p. 4).[3] For example, the state of Indiana leased its cross-state turnpike to a private entity for 75 years when the state faced a $2.8 billion highway funding gap. State officials saw the upfront money from the lease arrangement as a way to fund priority projects that were important to the state.[4] Other reasons for P3 concessions are for the government sector to share the risk of building and operating highways with the private sector and to provide incentives for better asset management (FHWA, 2010, p. 6). Consequently, investors need accurate information about the finances and traffic flows of highway segments under lease, for example, and each partner must have reliable information to know whether the other partners are upholding their agreements (e.g., with respect to maintenance, highway improvements). However, with private partners, particularly private financial arrangements that have limited disclosure requirements, maintaining some information about infrastructure conditions in the public domain can be a challenge.

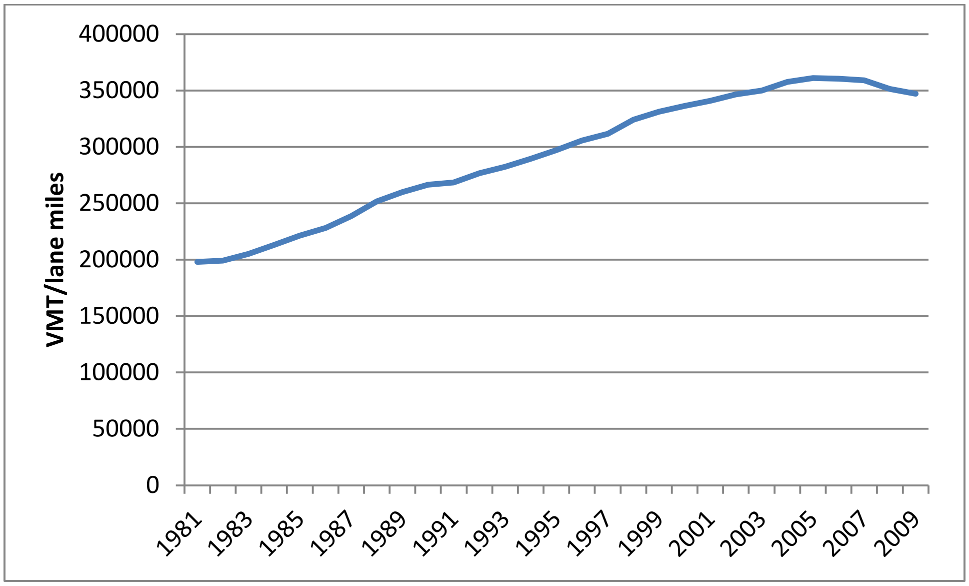
III. DECISIONS REGARDING TRANSPORT INFRASTRUCTURE

A. Decisions within the Context of a Mature Highway System

Evidence suggests that the U.S. transportation system has reached a mature stage in its development. Using the highway system as an example, total lane miles have increased very little over the past three decades, while the use of the highway system has increased dramatically. Total lane miles have increased 9 percent from 1981 through 2009 while vehicle miles traveled have increased 91 percent over that same period. The result is a much more intensive use of the highway system, as shown in figure 1 in which the vehicle miles traveled per lane mile of roads has increased 75 percent. Furthermore, empirical results from econometric studies, as discussed later, find the marginal benefit of an additional unit of highway infrastructure is approaching, if not equal to, the marginal cost of investing in an additional unit, suggesting that the quantity of highway capital stock may be in a steady state and the benefits of additional highway investment equals the cost of constructing it.

[3] Federal Highway Administration, "Public-Private Partnership Concessions for Highway Projects: A Primer," U.S. Department of Transportation, FHWA-OIPD-10-005, October 2010.
[4] Charles E. Schalliol, Director, Indiana Office of Management and Budget, "Infrastructure Privatization: The Indiana Toll Road, October, 19, 2006.

Figure 1. Vehicle Miles Traveled and Lane Miles



Source: FHWA, Highway Statistics

The mature nature of the transportation system frames the decisions transportation officials, policy makers, and private stakeholders will face in the coming years. A mature system focuses more on improving quality than quantity by which quantity is thought of as additional lane miles or extending the network of the highway system whereas quality means restoring and improving infrastructure so traffic can move more efficiently over the existing network, thus reducing travel time and increasing reliability.

A mature system also depends upon improvements from the private sector. For example, the navigational systems on today's cars and trucks provide drivers with information about construction delays and road closings and offer alternative routes. These systems reduce travel time and costs and improve the reliability of using the highway system, but their operation depends very little on features of the highway system, thus imposing little additional cost to constructing highways. Other features on vehicles do depend more on the state of the highway infrastructure. Safety features installed on vehicles that warn of inadvertent lane changes is one example. These devices depend upon well-defined lane markings. If the lane markings are non-existent or faded because of wear and neglect, then the systems won't work and drivers who depend upon them are put in undue jeopardy. As a result of these privately provided devices, state DOTs may find their priorities changing from straightening curves to focusing on painted lane dividers in pursuit of their goals of safer roads.

These issues facing the transportation sector have received considerable attention recently, particularly leading up to and following the enactment of MAP-21. For example, a NCHRP Task Panel (20-24 Task 80) was convened in 2012 to focus on assessing the economic benefit of transportation infrastructure investment in a mature surface transportation system.[5] The stated overall goals of the

[5] *Assessing the Economic Benefit of Transportation Infrastructure Investment in a Mature Surface Transportation System* Final Report Cambridge Systematics, Inc. 2012.

panel were to "inform decision makers at national, regional, state, and metropolitan levels as to the synergies and tradeoffs with regard to economic growth embodied in funding and financing surface transportation systems." It reviewed a host of studies that estimate the effect of transport infrastructure on broader economic and social effects, with the intent of exploring what further research is needed to assist policy makers and the general public alike in understanding the economic value of transportation improvements (p. 1-2).

Recognizing the mature nature of the transportation system, the broad question of how to value transportation hinges on whether one is interested in the value of the total capital stock in place or the value of investing in an additional unit of transportation capital stock. A mature system might lead one to focus on the capital stock in place and channel efforts to improve the efficient use of that existing capital stock through proper asset management and augmentation of the system with appropriate technological enhancements.

One also must recognize the tradeoff between new infrastructure investment and maintaining what one already has been put in place. If infrastructure is not well maintained, additional infrastructure investment will divert resources away from maintenance and operational expenditures and impinge negatively on growth.[6] Considerable interest in recent years has been placed on operating and maintaining infrastructure efficiently and effectively. A recently released white paper from the World Economic Forum states that "against the backdrop of increasing user demand, constrained financing and an aging asset base, it is imperative for governments to make the most of their existing infrastructure assets—specifically, to increase the assets' productivity and longevity" (p. 7).[7] The report asserts that a proper strategic plan is a step change in infrastructure asset management. It is more than a maintenance plan but a plan to optimize the service life of the infrastructure asset.

A recent report from the International Transport Forum states that "deferring maintenance can make roadway costs much greater than indicated by current expenditures" (Crist, Kauppila, Vassallo, and Wlaschin, 2013, p. 7).[8] The report continues with a reminder of the importance of information in asset management by saying "the challenge is to provide additional information on the value of roadway facilities and the costs associated with deferred spending, in order to bring these to the attention of decision makers" (Crist, Kauppila, Vassallo, and Wlaschin, 2013, p. 7).

The question then is whether this focus on asset management requires the same understanding of the broader effects of transportation infrastructure on the economy that is considered when the focus is on expanding the highway network. Network externalities include market expansion, economies of scale, more efficient labor markets, more efficient spatial allocation of production, and improved management techniques. One could argue that using a relatively narrow set of outcomes, which could

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[6] Hulten, C.R. (1996), "Infrastructure Capital and Economic Growth: How Well You Use it May Be More Important than how Much You Have", *National Bureau of Economic Research Working Paper*, No. 5847.

[7] World Economic Forum, *Strategic Infrastructure: Steps to Operate and Maintain Infrastructure Efficiently and Effectively*, prepared in collaboration with the Boston Consulting Group, April 2014.

[8] Phillippe Crist, Jari Kauppila, Jose Vassallo, Butch Wlaschin, "Asset Management for Sustainable Road Funding," OECD, International Transport Forum Discussion Paper No. 2013-13, May 2013.

include travel time, reliability, and safety, as goals and targets to maintain the efficient use of the system may offer sufficient information even as the use of the system continues to increase.

It could also be argued that considering the broader economic and social effects of transportation infrastructure investment, such as externalities, is necessary in order to properly assess the benefits and costs of maintaining and improving the existing system so that proper investment decisions can be made. The magnitude and scope of these benefits change with the changing dynamics and structure of the U.S. economy and its global competitors. Consequently, the broader effects must be closely monitored and quantified in order to gauge whether sufficient and appropriate investments continue to be made. One cannot necessarily assume that the value of a segment of highway, for example, is the same today as it was when it was first constructed. Not only has the infrastructure deteriorated (depending upon the level of maintenance over the course of its life to date), but also the economic activities it once supported may have changed. An example is access to the coals fields of West Virginia. As coal deposits are depleted and coal is replaced by lower-carbon emitting fuels, the economic value of the roads in supporting the coal industry is reduced.

The benefits of a mature transportation system may be even harder to quantify than that of a less developed one. The 2012 NCHRP Panel concluded that a mature highway system makes understanding the link between transportation services and economic outcomes that much more difficult. One reason is that transportation services are woven into the economic fabric of the nation, which makes them difficult to study and even harder to isolate from other forces that they enable. The study also raised the conceptual issue that limitations on available data make it much more difficult to analyze causes and effects for actions that optimize existing service within a mature system than for one that is expanding with completely new facilities (p. 1-2). Stated more succinctly, a mature transportation system provides few empirical data points to relate an expanded transportation system with expanded economic benefits, and consequently it is difficult to estimate the contribution of the quantitative expansion of the system to economic outcomes.

Infrastructure projects are typically undertaken with specific purposes in mind, such as relieving congestion, linking areas of economic activities, or improving the quality of the road surface. The TPICS searchable database, developed for use by state DOTs and local MPOs, documents the actual, post-construction economic impact of 100 highway and multimodal investment projects. Among these 100 projects, the three dominant motivations were to 1) reduce congestion bottlenecks that add to delay and travel time unreliability, 2) enhance market access for jobs and businesses, and 3) enhance connectivity to intermodal terminals.[9]

States and MPOs are given wide latitude in deciding their priorities and the methods they use to make these decisions. Guidance on what methodologies to use and how to use them is provided by the US DOT and other organizations. For instance, USDOT provides guidance along modal lines and functions. There is existing guidance on how to use benefit-cost analysis pertaining to decisions regarding highway asset management (FHWA, 2003), freight project investment (FHWA, 2008), rail

[9] The database is described in SHRP 2 project (C-03) final report and is found at http://tpics.us.

transit new starts (FTA, 2008), aviation improvement (FAA, 1999) and ground transportation discretionary grants (US DOT, 2011).

Therefore, policy makers face two basic decisions: The decision to add to the transportation system, and the decision to manage the existing asset. With a mature transportation system, the issue of properly managing the existing system is larger than the decision to add to the system, where adding to the system means in this case constructing new linkages between nodes of activities, such as between metropolitan areas. Adding a lane or repaving an existing surface would fall under management, for the most part. This distinction between expanding and managing a transportation asset may be too fine, since some consider expansion of a transportation asset as falling under management. But this distinction is still helpful in sorting out the utility of different ways of valuing transportation infrastructure.

B. Optimal Investment Decisions

The economic value of transportation capital, and any asset for that matter, reflects the benefits consumers and producers derive from its use. Two questions face decision makers regarding transportation investment and asset management. The first question addresses the issue of the optimal amount of transport capital and asks whether government should invest in more transport infrastructure, either from a project perspective or a system perspective. The second question addresses the value of the existing transportation capital stock as it relates to its overall contribution to the economy. This question relates to asset management and understanding the value of the existing infrastructure, and will be discussed in more detail in the next section. The first question deals with an additional unit of infrastructure and considers the marginal rate of return as the value of the additional unit invested. The second concept of value considers the value of the transport infrastructure already in place.

The question regarding the optimal amount of transport capital is typically posed with respect to a specific mode of transportation, such as highways, and for the entire transportation system within a country. The decision rule is whether the benefits of an additional unit of transportation capital is greater or less than the cost of providing that unit of capital stock. The many other questions listed in previous sections are offshoots of this basic one. If this were a private-sector decision, prices and profitability would be the key metrics. Decisions about publicly provided investments must derive the value of benefits and costs in a similar way that private sector allocation decisions rely on prices in perfectly competitive markets to capture the value of benefits and costs.

The optimality conditions for transport infrastructure can be expressed in two equivalent ways, under standard assumptions. The user-cost version states that the amount that consumers and producers are willing to pay for an additional unit of highway capital is equal to the user cost of highway capital. If the marginal value is greater than the user cost, then the government (society) has underinvested in highway capital stock; if it is less than the user cost, then the government has over-invested.

The other, equivalent, decision rule is that the net rate of return of highway capital should be equal to the rate of return of private capital. Again, if the net rate of return of highway capital is greater than the rate of return of private capital, then the government has underinvested in highways relative to private capital. If the net rate of return of highway capital is less than the rate of return of private capital, then the government has overinvested in highways (Barro, 1990).[10] Rates of return of private capital and transport infrastructure can be estimated by specifying a production function with labor, private capital, and transportation capital as the three inputs into the production function and GDP as output.

From a social perspective, which includes all parties affected by transportation investment and not just those who directly use the transportation capital, one needs to compare marginal social benefits with marginal social costs to determine the optimal level of infrastructure. The conditions state that the marginal social value of an additional unit of highway investment should equal the marginal social cost of producing a unit of highway investment. The marginal social value is the value each consumer places on an additional unit of highway investment, summed over all consumers. If the marginal social value is greater than the social marginal cost, then the quantity of highway infrastructure is less than desired (under built) and additional investment is warranted, according to the decision rules generated from this methodology. If the social marginal value is less than social marginal cost, then highway infrastructure is overbuilt, and no additional investment is warranted.

C. Asset Management

As defined by the AASHTO Standing Committee on Highways, Planning Subcommittee on Asset Management, transportation asset management is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based upon quality information and well defined objectives. The distinguishing feature of asset management is its focus on assets, their condition, and their performance. Asset management is governed by several core principles: policy-driven goals, performance-based decisions, analysis of options and tradeoffs, decisions based on quality information, and monitoring that provides clear understanding and feedback.[11]

The first question to consider in managing an asset is to understand the economic value of the existing asset. To address this question, an average net rate of return is applied to the total capital stock. An average net return represents a transportation system as a steady and dependable input in

[10] Robert J. Barro, "Government Spending in a Simple Model of Endogenous Growth," Journal of Political Economy, 98(5), part 2, 1990, S103-S125.

[11] Adapted from NCHRP Report 551, *Performance Measures and Targets for Transportation Asset Management, Vol. I, Research Report,* 2006, p. ii. The FHWA defines asset management similarly, but it does not include the expansion of the asset. FHWA's definition is "a strategic and systematic process of operating, maintaining, and improving physical assets, with a focus on engineering and economic analysis based on quality information, to identify a structured sequence of maintenance, preservation, repair, rehabilitation and replacement actions…" (23 U.S.C. 101(a)(2), MAP-21, para. 1103).

the production process or a household's well-being. The typical approach, which will be discussed in more detail later, is to look at the growth in transportation capital input and GDP over time.

An alternative approach is to consider the cost of maintaining the transportation system at its initial level of performance. Many of the performance measures discussed earlier are figured into estimates of maintaining the functionality of infrastructure. For instance, the Federal Highway Administration defines the system's performance in terms of average user costs, including the costs of travel time, operations, and accidents. FHWA estimated that based on 2006 data maintaining the highway system at its current performance would require $126 billion per year in capital spending by all levels of government.[12] If one assumes that the highway system is mature and most of the system is already in place and decisions to construct the system over the years were optimal in the sense that benefits exceeded costs, then the cost of maintaining the performance of the capital stock figures into the decisions related to the optimal management of the asset.

However, the cost of maintaining the existing infrastructure is not necessarily a measure of the value of transportation capital to the economy. Even if each previous investment decision that built the current capital stock was optimal when the project was constructed, the economy and population continue to change, which also changes the value of the infrastructure.

A simpler approach to assessing the value of an asset, but even less useful, is based on depreciated replacement cost. The first step is to calculate what it would cost to replace the existing asset today; the second step is to depreciate the current dollar amount by some depreciation schedule, usually straight-line, over the life of the asset. This approach represents the cost to construct an asset that is equivalent to what currently exists. It is different from simply valuing the asset based on its original cost. However, like the depreciated replacement cost basis, this approach does not reflect the current economic value of the infrastructure asset.

With respect to data requirements, several of the principles should be highlighted. The focus on performance-based decisions requires that policy objectives are translated into system performance measures that are used for both day-to-day operations and strategic management. The analysis of options and tradeoffs considers decisions on how to allocate funds, within and across different types of investments (e.g., preventive maintenance versus rehabilitation, pavements versus bridges). Decisions based on quality information explore the merits of different options with respect to an agency's policy goals are evaluated using credible and current data.

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[12] Department of Transportation, Federal Highway Administration and Federal Transit Administration, *2008 Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance,*pp. ix, xii.

Box 1. Guidelines for Asset Management

The Michigan Transportation Asset Management Council prepared guidelines for local agencies in developing an asset management plan (Local Agency Guidelines for Developing an Asset Management Process and Plan, May 2011). The purpose of the guide is to be a reference for public agencies looking to implement asset management. The guide provides common terminology, definitions, and procedures to be used in managing their highway assets. It provides a template that can be used to 1) introduce the concepts of asset management, 2) assist with the implementation of asset management, and 3) assist with the preparation of an asset management plan. It also endorses and describes software called *Roadsoft*, which was developed by the Center for Technology and Training at Michigan Technological University. The tool has modules for strategy evaluation, pavement deterioration, culvert inventory, road inventory, and other assets.

In promoting standardizing definitions, the guideline also provides a logic model for understanding the different types of work activity related to the management of highway assets. It offers a decision tree that asks various questions about the activity. For example, it poses the question "Will the work fundamentally change an existing asset or add a new asset (eg., add a turn lane, install a median barrier, lengthen a guardrail, etc)? If the answer is yes, the work type is defined as "improvement." Another question inquires "Does the work return the asset to a previous or original condition (e.g., mill or fill or overlay, replace monument box, upgrade guard rail end section, etc.)? A positive answer identifies this activity as "renewal."

D. Performance Measurement under MAP-21

Under MAP-21, the FHWA is required to establish measures through a rulemaking process that assesses performance in 12 areas generalized as follows: (1) serious injuries per Vehicle Miles Traveled (VMT); (2) fatalities per VMT; (3) number of serious injuries; (4) number of fatalities; (5) pavement condition on the Interstate system; (6) pavement condition on the non-Interstate NHS; (7) bridge condition on the NHS; (8) traffic congestion; (9) on-road mobile source emissions; (10) freight movement on the Interstate system; (11) performance of the Interstate system; and (12) performance of the non-Interstate NHS. For measures of system performance, AASHTO recommends two metrics: annual hours of delay and a reliability index.[13] AASHTO also recommends a metric to monitor air quality: criteria pollutant emissions.

It should be noted that these performance measures help to link a transportation asset, in this case highways, to the economy and offer some notion of valuation based on economic activity. However, each measure has its own metrics and thus cannot be aggregated to provide a single estimate of the "value" of the transportation asset. If one could place a monetary value on the measures from each of the 12 areas, then one would come closer to using performance measures to value the asset.

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[13] SCOPM Task Force Findings on National-Level Performance Measures, AASHTO Standing Committee on Performance Management, Task Force on Performance Measure Development, Coordination and Reporting, November 9, 2012.

Federal and state government agencies are already preparing for the broad implementation of these performance measures. TRB, FHA, and FTA sponsored a conference in 2011 on performance measurement of transportation systems in anticipation of the performance targeting requirements in MAP-21. According to a Pew Charitable Trust survey, most states have performance measures of some kind, and 18 states have what are defined as mature performance systems (p. 8).[14]

Yet, harmonizing performance measures and targets across states is essential so that all work together to improve the highway system that they all contribute to and benefit from. For example, under its Office of Infrastructure, FHWA has established an Office of Transportation Performance Management, which is working to define the role and agenda of the office to ensure alignment with the AASHTO Standing Committee on Performance Management. The Office of Transportation Performance Management coordinates the crosscutting aspects of performance management, as well as the efforts of individual offices. For example, the Office of Safety will still lead safety performance measures, but the Office of Transportation Performance Management will ensure internal coordination. FHWA is also developing analysis tools and training to assist states and local governments in advancing performance management and is working with the Federal Transit Administration to facilitate collaboration between the highway and the transit communities (p. 45). Undoubtedly, additional efforts have commenced since these initiatives were reported out at the 2011 conference.

IV. UNDERSTANDING THE RELATIONSHIP BETWEEN TRANSPORT FACILITIES AND BENEFITS

To see how best to assess the economic value of transportation systems, one must first understand the relationships between transportation infrastructure and economic and social outcomes. These relationships are often complex and are not as well articulated or quantified in some valuation studies as required to properly assess the value of transportation. For example, many of the econometric studies that estimate this relationship devote little space to laying out the linkages. To understand these linkages, the nexus between transportation infrastructure and economic and social benefits is conceptualized as several components. Transportation infrastructure, or facility for short, is characterized by a list of physical features. For highways, a partial list would include lane-miles and pavement conditions, for example. For airports, it would include the number and length of runways. For railroads, the list would include track miles and speed limitations, to mention only a few features. All transportation systems connect nodes of activities, and these network characteristics must also be taken into consideration.

The private sector—households and businesses--receives three types of benefits from the use of transportation infrastructure:

- The first of the three components includes the benefits to direct users of the transportation system. Direct users are the transportation industry, which run trucks on highways, airplanes

[14]Transportation Research Board, *International Conference on Performance Measurement of Transportation Systems*, 2011.

through airports, and ships through ports in order to generate transportation services. Direct users are also household members that drive to work or to shop.

- The second type includes the benefits to those who use transportation services but do not directly drive the cars or trucks that use the highway infrastructure, for example, or ride on trains or plains. A manufacturing firm that uses an independent trucking company to ship its products benefits from highway infrastructure through the transport services provided by the trucking company. The benefits included in this component are those transmitted through the price mechanisms of a perfectly competitive market economy. For example, investment in additional lanes along a stretch of congested highway would be expected to increase travel speeds and lower travel costs. The lower travel costs reduce the cost of transportation services which in turn lowers the cost of production of those firms located close enough to the investment to benefit from the investment.
- The third component includes benefits that are not transmitted through the markets tied to transportation services but instead are related to the existence of market failures or imperfect competition. These benefits are typically referred to as wider effects. According to Hulten (1994), cases of this sort result from spillover externalities, increasing returns to scale, and the network characteristics of transportation which can generate agglomeration economies, enlarge labor pools and expand customer markets. Transportation infrastructure investment can affect these growth factors by improving accessibility.

Figure 2, reproduced from Berechman (2001), summarizes the three types of benefits outlined above and links them to economic growth.[15] Transportation services, such as those outputs described in the previous section, are derived from fixed assets funded primarily by government and built by private sector contractors. The actual construction, operations, and maintenance of the infrastructure generate jobs and personal income directly and indirectly through a multiplier effect, under certain conditions. The fixed assets, in most cases, generate transport services when combined with private sector assets, such as cars, trucks, aircraft and so forth.[16] With respect to highway investment, for example, the direct benefits to users come through access to the highway network and savings from a reduction in travel time and increased safety, which generate welfare gains to users and to those who purchase transportation services. A highway system also generates externalities through its public good and network characteristics, which ultimately affect economic growth though network economies, labor market efficiencies, and agglomeration effects. Some of the externalities are captured through their effects on market prices but others take place through allocative externalities in specific markets.

Berechman draws two conclusions from these relationships. First, economic growth is a function of the primary transportation benefits generated by the investment, so that the size and scope of the benefits derived from economic growth are predicated on the size and scope of the primary benefits to the direct users of the infrastructure investment. The second message is that the benefits from growth

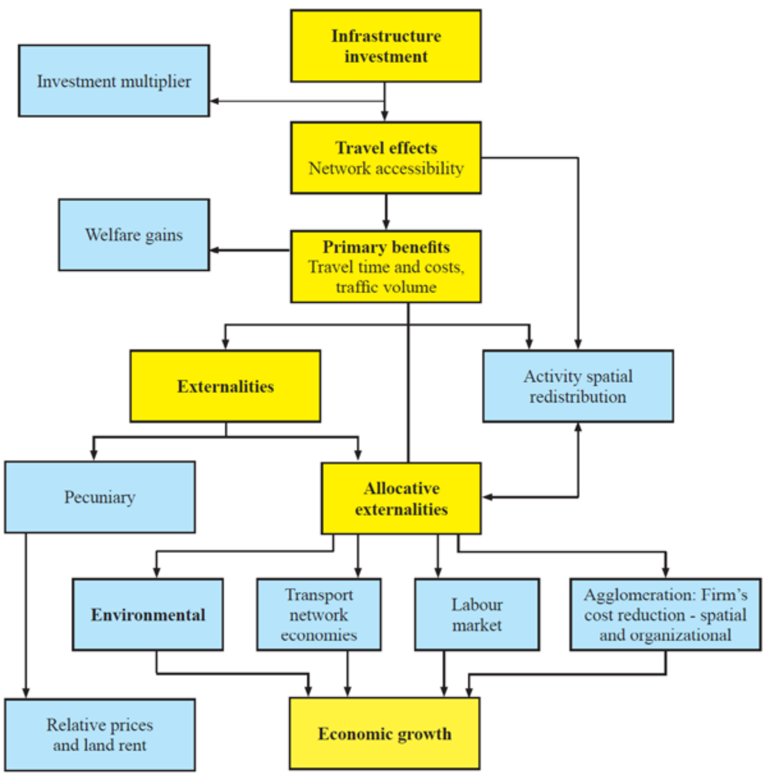
[15] Joseph Berechman, "Transport Investment and Economic Development: Is There a Link? In OECD Report of the 119 Roundtable on Transport Economics, Economic Research Centre, March 2001.

[16] In some instances, the rolling stock is owned by the same entity that owns the tracks or right of ways, but for most modes, this is not the case.

due to allocative externalities may not occur unless certain conditions are present. For instance, transportation investment may not lead to greater clustering of firms unless a sufficient number of firms sharing a common labor pool or purchasing from each other already exists. Furthermore, these pre-conditions do not exist in every place and circumstance and must be identified and scrutinized before including them in the list of benefits (Berechman 2001, p. 118).

To illustrate the types of benefits outlined above and to further delve into the various channels from infrastructure to economic growth, highways will be the primary focus.

Figure 2. Link between Transportation Investment and Economic Growth



Source: Berechman (2001)

A. Highway Facilities

Highway infrastructure is characterized by a number of features: lane-miles, grade, tightness of curves, pavement condition, number of bridges, bridge load capacity, bridge conditions, and volume capacity, to mention a few. When combined with the vehicles that use the roads, the highway infrastructure generates benefits to the users in the form of transportation services. The use of highways can also yield negative effects, such as noise and air pollution for those driving along the road and those living beside it. Each of these characteristics can affect the level and quality of services generated from the highway facility. The number of lane miles affects the speed of travel, the tightness of the curve affects speed and safety, grade impacts fuel efficiency of trucks, and bridge load capacity determines the type of truck traffic that can use the roads.[17]

In a mature highway system, highway facilities with these characteristics have been built, maintained and restored over a number of years, and the quality of the highway system varies by highway segments. Consequently, one cannot assume that a dollar spent on highway investment on one part of the system is the same as a dollar spent on another part of the system. The cost of building a mile of highway may vary across regions due to differences in labor costs, differences in the terrain, and because of the purpose of the project, such as to add lanes, straighten curves, or reduce travel distance by bridging a river. Benefits derived from an additional dollar of investment also differ at different points along the highway system, as a result of variation in congestion, demand for transportation services in and around the highway system and other circumstances and conditions.

Furthermore, the network nature of highways, and other transport systems, adds another dimension to the facility and thus to measuring infrastructure. For instance, constructing an additional lane between mile marker 10 and 20 on a stretch of interstate, for example, affects more than that 10-mile stretch of highway. The additional lane can increase the traffic flow over the entire network that is larger than the additional traffic over that specific segment. If the additional lane reduced congestion on that segment of highway, then a manufacturing facility on that stretch now has greater access to other parts of the network. A manufacturer 100 miles away that was affected by delayed shipments due to the congestion along that segment benefits even though the investment might be in another state.

Consequently, measurements of infrastructure must take into account the various features that characterize a segment of infrastructure as well as the network relationships of that particular segment. Simply adding up past highway outlays and applying a generic depreciation rate is not sufficient, and such an approach obviously does not capture the network characteristics of that stretch of highway.

Scope and scale of transportation facilities are also important. The previous example considered the construction of an additional lane on a 10-mile segment of highway. Obviously the scale is much larger because of the network features, but also the scope may be greater if there are other transportation options within the vicinity. The obvious situation of other options would be intermodal connections—car to air, car to rail, truck to freighter. However, other possibilities occur when light rail may be another option for commuting by car or railcar transport may substitute for truck transport. Consequently, the transport "facility" may need to cross modal lines even though the actual investment decision involves only one mode—highways—for the same reason that network features require an examination of other parts of the network. How much consideration should be given to other modes or other parts of the highway networks depends on the location of the investment (within a metropolitan area or in the Mohave Desert) and the importance of that investment to the rest of the network.

[17] If past investment was considered to be optimal, then restoring the highway infrastructure to its former quality and capacity would be optimal if the existing highway stock, before any additional investment, is still considered to be optimal under the current private use of the highway facilities. With a dynamic economy, it is difficult to imagine how that could be the case.

Accurate measurement of the characteristics of the investment and other features listed above are important for understanding the types of benefits that may flow from the investment. It is also important in estimating the effects of transport infrastructure because such estimation techniques typically look for comparable investments and locations in order to more accurately estimate the effects, such as the TPICS database provides (as mentioned in section III-A). Accurate measurement of expenditures and knowledge of what the expenditures have paid for is important for methods such as benefit-cost analysis.

The European Commission provides a convenient typology of investments that helps to clarify the types of investment that relate to the characteristics of highways discussed in this section and how these characteristics relate to the benefits of infrastructure improvements of direct users discussed in the next section. As shown in table 1, the types of investment range from increasing accessibility to peripheral regions through constructing a new link in the highway network to improving the use of existing networks. The typology also highlights the type of service, which includes the characteristics of the region within which the project is intended to be built.[18]

Table 1. Typology of Transport Investments

Typology of Investments	Financial Characteristics	Types of Services
New infrastructure to satisfy transport demand	Increasing capacity of existing networks	Infrastructures for densely populated areas
Completion of existing networks	Reducing congestion	Infrastructures for long distance
Extension of existing infrastructure	Reducing externalities	Infrastructures for freight transport
Investment in safety measures on existing links or networks	Improving accessibility to peripheral regions	Infrastructures for passengers transport
Improved use of existing networks	Reducing transport-operating costs	
Improvement in intermodality		
Improvement in networks interoperability		
Improvement in management of infrastructure		

Source: European Commission, 2008.

B. Benefits to Direct Users

The benefits to the direct users of the highway facilities include, among others, access, mobility, movement of goods, reliability of service, and safety. These users of highways—those driving the automobiles and the trucks—receive direct benefits typically measured as:

- Travel time savings
- Improved transportation system reliability

[18] European Commission, "Guide to Cost-Benefit Analysis of Investment Projects, Directorate General Regional Policy, 2008.

- Vehicle operating cost savings
- Reductions in crash-related costs
- Improved mobility, and
- Availability of travel options (NCHRP 20-24 Task 80 Panel, White Paper, 2012, p. 3).

For manufacturers who provide their own transportation, for example, reduced travel time from highway investment affects their production costs directly. For households who drive to work, the reduced travel time gives more time for other activities, resulting in welfare gains.

C. Benefits to Purchasers of Transportation Services

The direct benefits to users can also affect those who use or purchase the transportation services produced by these direct users. For those who purchase services from a transport service company (e.g., Yellow Freight), their "production" of transport services includes an unpaid factor of production—the highway. The savings from reduced travel time are included in the cost of the transport services, and this upstream externality is internalized in the market price of the transport services.[19] The SHRP 2 Capacity Project C-11 Report refers to these as broader indirect effects and offers as examples the effect of reduced travel time on businesses and households. For businesses, the savings in delivery costs may allow businesses to generate greater income, or products to be offered at lower prices—which in term can lead to greater profits and economic growth. For households, savings in transportation costs may also allow households to buy more local goods and services, which can also lead to greater economic growth. The greater economic growth can be viewed in terms of added jobs, wages or value added.

D. Wider Effects

The third type of benefits includes wider effects, as reflected in social and economic outcomes, which operate largely outside the market place and are not mediated by prices (Hulten, p. 14).[20] Economic theory states that under conditions of perfect competition, all benefits of highways and transport services would be captured in estimates of consumer surplus. However, markets are not perfect, and highways affect markets other than transport, such as labor and land markets. Studies have shown that these effects can be significant and can be an important part of the appraisal of highway benefits. These effects are related to the market access that transportation infrastructure investment can provide. Firms can benefit by being closer to their suppliers, workers, and customers. A portion of the benefits from increased accessibility may come through cost reductions resulting from reduced travel time on existing routes. These benefits, however, are already picked up in the market

[19] Highways are considered a quasi-public good, which in many instances is not paid for on a per unit basis (except perhaps on some toll roads). Highway infrastructure is quasi-public because producers cannot choose the amount that they use the same way they choose the amount of private capital or labor they purchase. Therefore, the entire highway capital stock is entered in the production function. Optimality conditions, therefore, reflect the public nature of the infrastructure, as discussed in a later section.

[20] Charles R. Hulten, "Transportation Infrastructure, Productivity, and Externalities," in *Transport Infrastructure Investment and Economic Productivity*, Report of the One Hundred and Thirty Second Round Table on Transport Economics, OECD and European Conference of Ministers of Transport, 2007.

transactions and more specifically in the user cost reduction, as reflected in the first two types of benefits outlined above.

Benefits classified as wider effects are derived from a non-compensatory effect of transportation investment, which was referred to in figure 2 as allocative externalities. Allocative externalities result when the economic behavior of one entity impacts another entity without the ability for one to compensate the other for the gain or loss. The microeconomic representation of the externality is the presence of one producer's inputs or output in other producers' production functions. A classic example of allocative externalities is the relationship between a honey producer and an apple grower. The honey bees pollinate the apple trees, and the honey bees carry away pollen from the apple blossoms. The honey producer cannot determine the number of apple blossoms in her production function to produce honey, and the apple grower cannot determine the number of bees in his production function to grow apples. And neither one can monitor the activity of the other with sufficient accuracy to charge a fee.

Berechman (2001) offers the construction of an intermodal freight terminal as an example of positive externalities in transportation. By enabling intermodality between truck and rail, a new freight terminal improves "just-in-time" production, reducing inventory costs to producers. An example of a negative externality is the increased congestion and the reduction in travel time imposed on existing users of a highway by new users entering a crowded roadway, where the new users do not compensate the existing users for their reduced utilities (p. 15).

These indirect effects are related to the public good nature of public transportation infrastructure, both in terms of its connectivity or network characteristics and in terms of its public goods characteristics. Hulten frames it in terms of "spillover externalities and the economic theory of partial public goods, or clubs" (Hulten, p. 12). "Roads and highways, for example, are joint-use facilities with many different simultaneous users and uses" (Hulten p. 12). Highways are considered partial public goods, in economic terms, because there is a point of usage when congestion sets in and adding an additional user reduces the benefits for everyone else already using it.

The network characteristics of highways introduce another dimension of externalities. Infrastructure facilities are typically interlocking networks of investment. Highways and bridges, mass transit, rail transport, and air transport are all made up of networks of interdependent components, which connect pairs of nodes. Even the nodes—an urban center, subway station, train depot, and airport—can be seen as a partial public good, in that each can accommodate a number of users up to a point before congestion sets in. Furthermore, the flow of services from any one component depends on the capacity and congestion of other links in the network. The capacity of the entire highway system, for example, is determined from the perspective of each component, which means that the decision to invest in a particular project within the highway network must take into account the utilization of other parts of the system. Each component of the system sees the rest of the system differently, from its own vantage point. Consequently, the benefit of the highway network will be different for producers located at each node of the highway network. And the production function of each producer will have as inputs the segments of the highway network that are most important to the transport needs of producers at each node.

Following Krugman's (1998) work on location theory and economic geography, expanded transport systems may have several effects:

- Expansion of product and input markets, which in turn leads to efficiency gains through economies of scale and access to specialized inputs (Eberts and McMillan);
- Concentration of production at various points in the network that lead to further economies of scale and scope;
- Improvement in transport services, which may also cause a reallocation of production within the network to exploit specialized local resources, lower regional input costs and a more favorable regulatory or tax climate; and
- An increase in total productivity directly through improved technologies (e.g. just-in-time inventory management).

Duranton and Puga (2004), in reviewing the microfoundations of the existence of cities or in a broader sense the advantage of place, categorized three mechanisms through which these externalities take place: sharing, matching, and learning.

- Sharing of indivisible facilities leads to increasing returns to activities located in a particular place, and accessibility through improved transportation enables new economic activity that could otherwise not exist at that location and makes existing activities there more productive.
- Matching relates to specialization and has possible effects in all three markets—labor, intermediate inputs, and final products. Larger markets accompanied by a greater number of agents in the market improve the expected quality of each match. Pooling of labor increases the likelihood that employers will find the qualified workers they need; pooling of firms makes it more likely that firms will find the specialized products they need; and more customers within a market will increase the availability of specialized products.
- Learning is tied to the interaction of people and the exchange of knowledge and ideas. Closer proximity of people leads to greater interaction and the greater diffusion of ideas, which in turn leads to greater productivity.

The increase in accessibility brought about by improvements in transportation can generate economic growth if the conditions of positive externalities are present. Duranton and Puga (2004), however, warn that identifying these different mechanisms is not easy. It becomes even more difficult because the benefits of agglomeration may not percolate through wages or output per worker but accrue directly to workers through the utility of a higher quality match.

How important are these wider benefits within a mature highway system? The simple fact is that the system is so large that any investment in the system, even a major one, may not be large enough to make a difference in overall travel time. However, some markets may have positive externalities that are amenable to greater accessibility brought about by transportation improvements. For those markets that do, transportation investment can reduce production costs, improve productivity, enable more efficient use of resources and expand output. These allocative externalities are typically represented by economies of scale and scope, agglomeration, and network. The resulting economic growth can be measured by the traditional metrics of output, employment and personal income. Berechman (2001) asserts that "these benefits must be *in addition* to the primary transportation benefits that have prompted them."

On the other hand, for those markets that do not have the preconditions for positive externalities, improved accessibility through transportation investment will not necessarily generate economic growth. More generally, less economic growth benefits can be expected from a specific infrastructure investment the weaker the allocative impact of these externalities.

Box 2. The UK "Value of Money" Nomenclature

A white paper produced by Cambridge Systematics on assessing the economic benefits of a mature infrastructure system suggested that "at the current time the United Kingdom may be furthest along both in formulating an overall framework and in filling in the details of procedures and methods to make economic evaluation a driving factor in transportation investment decisions" (p.1)[1] This approach, as developed by Sir Rod Eddington and referred to as the Eddington Report, attempts to identify and quantify wider benefits of transport investment than are typically captured in traditional benefit-cost analyses. The Eddington Report identifies seven microeconomic mechanisms that transport investment can affect:

- Increasing business efficiency through time savings and improved reliability for business travelers, freight, and logistic operations;
- Increasing business investment and innovation by supporting economies of scale or new ways of working;
- Supporting clusters and agglomerations of economic activity;
- Improving the efficient functioning of labor markets, increasing labor market flexibility and the accessibility of jobs;
- Increasing competition by opening up access to new markets;
- Increasing domestic and international trade by reducing the costs of trading;
- Attracting globally mobile activity by providing an attractive business environment and good quality of life.[1]

Eddington asserts that a detailed assessment of the impacts of transport projects form the bedrock of project appraisal, covering economic, environmental and social impacts. A significant portion of economic benefits are already captured by benefit-cost analysis, but current methodologies do not reflect other influences of transportation infrastructure on the economy. If new evidence of agglomerations and reliability were taken into consideration, assessments on a project-by-project basis would increase by as much as 50 percent, according to Eddington.

V. VALUE OF TRANSPORTATION AND PERFORMANCE MEASURES

It is useful from a practical standpoint to return to the performance measures and asset management concept to consider the extent to which these measures encompass the full value of the highway system. The link between performance measures and outcomes is critical in establishing a meaningful performance measurement and target-setting system. At the Fourth International

Conference on Performance Measurement of Transportation Systems, the setting of performance targets was discussed, with the observation that "it is crucial to have good data and to understand the relationship between strategies and outcomes and between input (i.e., resources) and outcomes" (p. 9). Recommendations from the conference included expanding "performance measures to assess the economic impact of the transportation system" (p. 82). [21] This statement is perhaps more profound that it may appear at first glance since performance measures are typically not used to measure the net impact of a system unless combined with other factors or even the construction of a comparison group.

Using the relationships defined in the previous sections, one can map the proposed performance measures to the measures of highway characteristics and the three different types of benefits, as displayed in table 2. One can see that the performance measures relate to highway characteristics and direct users of highways but not to direct users of transport services or wider effects, with the exception of air quality and perhaps other environment issues. However, the absence of performance measures for direct users of transport services may be picked up by the performance measures of direct users of the facility if one can be confident that the two are proportionally related. However, the same relationship is not necessarily true for wider benefits since these benefits will vary by the region according to their preconditions for positive externalities.

Table 2. Relationship between Performance Measures and Highway Effects

Performance Measures	Highway Characteristics	Benefits		
		Direct users of infrastructure	Direct users of transport services	Wider effects
Serious injuries		Safety		
Fatalities		Safety		
Pavement Conditions	Facility quality			
Bridge conditions	Facility quality			
Freight movement		Mobility; expected speed (travel time); reliability		
System performance		Mobility; expected speed (travel time); reliability		
Air Quality				Environmental quality

Source: SCOPM Task Force Findings on National-Level Performance Measures, 2012; author.

The network nature of transportation infrastructure also informs the spatial perspective of various decision makers. From an MPO perspective, the vantage point is the region they represent and the investment decisions for which they are responsible. For the state DOT, it is the state and the

[21] *Performance Measurement of Transportation Systems: Summary of the Fourth International Conference*, Conference Proceedings 49, Transportation Research Board, May 18-20, 2011.

relationship between its own highway system and that of neighboring states and the rest of the national system. The network characteristics of transport infrastructure and what it means for making appropriate investment decisions underscores the need for coordination of effort across the system and the sharing of information. This calls for common definitions of performance measures across the system and coordination of the setting of performance targets.

VI. METHODS OF MEASURING TRANSPORT CAPITAL STOCK

Several methods are used to measure transport capital stock, and the specific measure is determined by the type of analysis used to estimate the benefits of transportation investment and the questions being asked. However, there are some overlaps in their use. The methods of measurement are classified into four types, with highways used as an example.

1. Deriving accurate cost estimates of different types of facility expansion or upgrades, such as adding connectors, adding lane miles, reconfiguring grades or curves, or resurfacing. These estimates are used primarily to decide on undertaking specific projects, typically through the microeconomic approach of benefit-cost analysis.
2. Characterizing highway infrastructure by a compilation of physical attributes of highway capital stock, such as total lane miles within a specific region (e.g., county or state), perhaps adjusted for highway conditions. These estimates are typically used in the macroeconomic approach of estimating production functions of the relationship between economic activity and highway capital stock.
3. Using the perpetual inventory method (PIM) to sum the value of past capital outlays adjusted for depreciation and discard. PIM is used in the macroeconomic approach of estimating production functions and in addressing the question of the value of existing capital stock using national income accounts.

For the purpose of valuing transport infrastructure, each method is more appropriate for one approach of estimation than another. For instance, since benefit-cost-analysis typically focuses on a specific project (such as adding an additional lane) constructed for a specific purpose (such as a reduction in congestion), the first method described above is the most appropriate since the cost of the project is most important. Since the purpose of the project under the BCA approach is well-specified as are the improvements undertaken to achieve that purpose, the need for a capital stock estimate such as derived from PIM is not necessary. Yet, in modeling the various channels of effects generated by the infrastructure improvement, it is important, particularly when considering the wider effects, to understand the positioning of that project within the broader highway system. In this case, the broader system-wide context within which the project is constructed will be reflected in the estimation of the costs and benefits and not in the measure of capital stock. The data necessary to estimate the costs of the improvement are approximately the same data required for cost estimates of the project. The same is true for the engineering data that characterizes the nature of the improvement—location, highway type, lanes, curve dimensions, free-flow speed, average annual daily traffic counts, and so forth.

Consequently, the data burden is not much more than compiling the information needed to construct the project.

On the other hand, using the macroeconomic approach to relate highway capital stock to economic activity requires an accurate reflection of the quantity and quality of the highway capital stock. This can be done using either the PIM approach or a metric based on physical attributes. While each approach has advantages and disadvantages, the majority of researchers studying the macroeconomic effects have adopted some variant of the PIM.[22] The PIM's primary advantage is that by encompassing all expenditures on highways, it is a comprehensive measure of the amount of highway stock available for use. For valuation techniques addressing the valuation of existing highway capital stock (the second question posed in the previous section), it is best for the highway capital stock measure to be consistent with national income accounts. The PIM approach, with the appropriate adjustments, meets that criterion.

The PIM technique approaches the measurement of highway capital stock from a more aggregate perspective but also from a broader system-wide perspective. At the same time, the assumption regarding the use of highway capital stock (or any asset stock) in a production function is that the size of the capital stock is proportional to the services it yields. But the flow of services also depends on the characteristics of the highway and its utilization. Also, highways connect nodes of activity, as previously mentioned. Adding these dimensions to the PIM (or to the specification of the production functions) presents challenges in constructing the highway capital stock, which will be discussed in a later section.

Because of the prominence of using the PIM approach to estimate the relationship between transportation capital and economic activity, a description of the most recent refinements to this approach will be discussed before the discussion of the macroeconomic approach to estimating the benefits of highways.

A. Perpetual Inventory Method

The perpetual inventory method of estimating capital stock is based on summing past outlays (in constant dollars) that were used to construct the capital stock currently in place, subtracting the proportion of capital stock that has been retired and adjusting for the wear and tear and obsolescence of the current stock. The primary advantage of this approach is that it is a comprehensive measure of the amount of highway stock available for use. It also is consistent with national income accounts. The major challenge of using this technique is the data needed to make the proper adjustments.

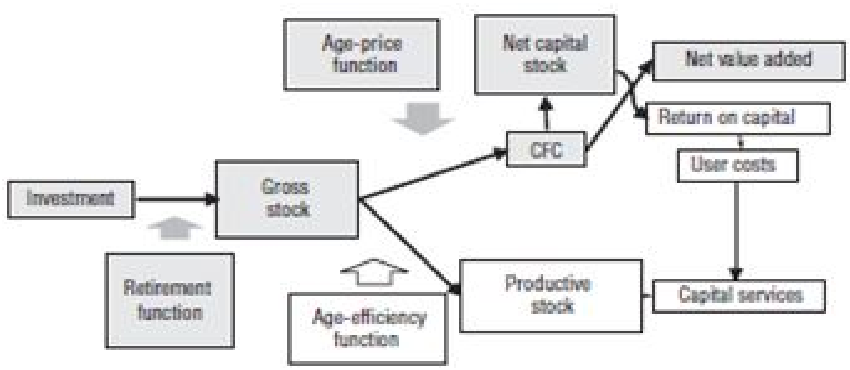
Figure 3, reproduced from the OECD manual for measuring capital stock, depicts the various types of capital measures and the steps necessary to construct them. There are two types of net capital stock. One is considered a wealth measure and is the type estimated by BEA. The other is productive capital stock, which is the type appropriate for estimating the effects of transportation infrastructure. Net or wealth capital stock is the stock of assets surviving from past periods and corrected for depreciation.

[22] According to Melo et. al (2013), 75 percent of the estimates included in their meta analysis were based on capital stock estimates that were constructed using financial data as opposed to physical units such as lane-miles.

The net stock is valued as if the capital good (used or new) were acquired on the date to which a balance sheet relates. The net stock is designed to reflect the wealth of the owner of the asset at a particular point in time, hence the name. However, it is important not to confuse this "net" capital stock with the "net" capital stock that accounts for efficiency losses of capital stock due to ageing or obsolescence, referred to as productive capital.

Productive capital stock is a "net" capital stock, but unlike the definition of a "wealth" capital stock described above, this definition corrects the particular type of asset surviving from past periods for its loss in productive efficiency. Thus, productive stocks are directly related to the quantity and production aspect of capital. Productive stocks constitute an intermediate step towards the measurement of capital services. If the assumption is made that the flow of capital services – the actual capital input into production – is proportional to the productive stock of an asset class, and the proportionality is constant, the rate of change of capital services will equal the rate of change of the productive stock (OECD, p. 60).

Figure 3. Integrated Set of Capital Measures



Source: OECD, Measuring Capital, OECD Manual 2009, p. 25.

Along with physical deterioration, depreciation should include normal or foreseen obsolescence. A representative definition of obsolescence from the literature is "…the loss in value of existing capital because it is no longer technologically suited to economic conditions or because technically superior alternatives become available" (Hulten and Wykoff 1981 p. 255).

B. Fraumeni's National Productive Capital Stock Estimates

The Bureau of Economic Analysis estimates national government capital stock using the perpetual inventory approach. Their estimates include depreciation (retirements) but not deterioration, and thus are considered "wealth" estimates of capital not "productive" estimates. The perpetual inventory technique adds over time the investment (or outlays) in highways and subtracts out the portion that is retired. If the length of the outlay series sufficiently exceeds the life of an asset then the perpetual inventory technique takes into account all the investments that are embodied in the asset at a particular point in time.

Fraumeni (1999) uses the same perpetual inventory technique as BEA to estimate national productive highway capital. In order to provide more detail regarding the highway system, she uses outlays and other highway characteristics compiled by FHWA in *Highway Statistics*. Fraumeni also uses AASHTO pavement curves to construct the age-efficiency function and adopts BEA all government highway deflators. Her estimates are considered the most accurate series of national productive highway capital stock available from 1921 through 2005.[23] Therefore, it is worthwhile highlighting the methodology Fraumeni employed in estimating highway capital stocks.

Fraumeni's construction of highway capital stock uses four components: 1) capital outlays 2) outlay percentage splits, 3) deflators, and 4) pavement curves. Highway capital outlays are disaggregated into:

- Interstate System,
- Non-interstate State System,
- Local System,
- Right-of Way (ROW),
- New construction or reconstruction,
- Other than new construction or reconstruction,
- Pavement,
- Grading,
- Structures.

The allocation of outlays into these various components differs from year to year reflecting changes in how capital outlays are invested. Pavement conditions are reflected in net efficiency pavement curves. The estimation of net efficiency curves begins with the construction of a pavement serviceability index – time relationship based on the intensity and type of traffic, and the road system: Interstate, Non-Interstate State, or Local System. Pavement serviceability determines the pavement condition, which in turn indicates how productive pavement could be. Net efficiency, which is the basis for productive capacity, is reduced if pavement conditions reduce speed or increase motor vehicle operating cost. Fraumeni reports that pavement net efficiency on average never gets below 93% for the Interstate System curves; 84% for the Non-interstate System curves; and 72% for the Local System curves (Fraumeni, 2009, p.3).

Fraumeni also experimented with adjusting existing bridge capital stock estimates by the quality and condition of the structures. She found that adjusting the bridge stock estimates for quality increased the annual rate of growth of the highway structure series by about four-tenths of a percentage point from 1983-1996 and by about two-tenths of a percentage point from a 1996-2006.

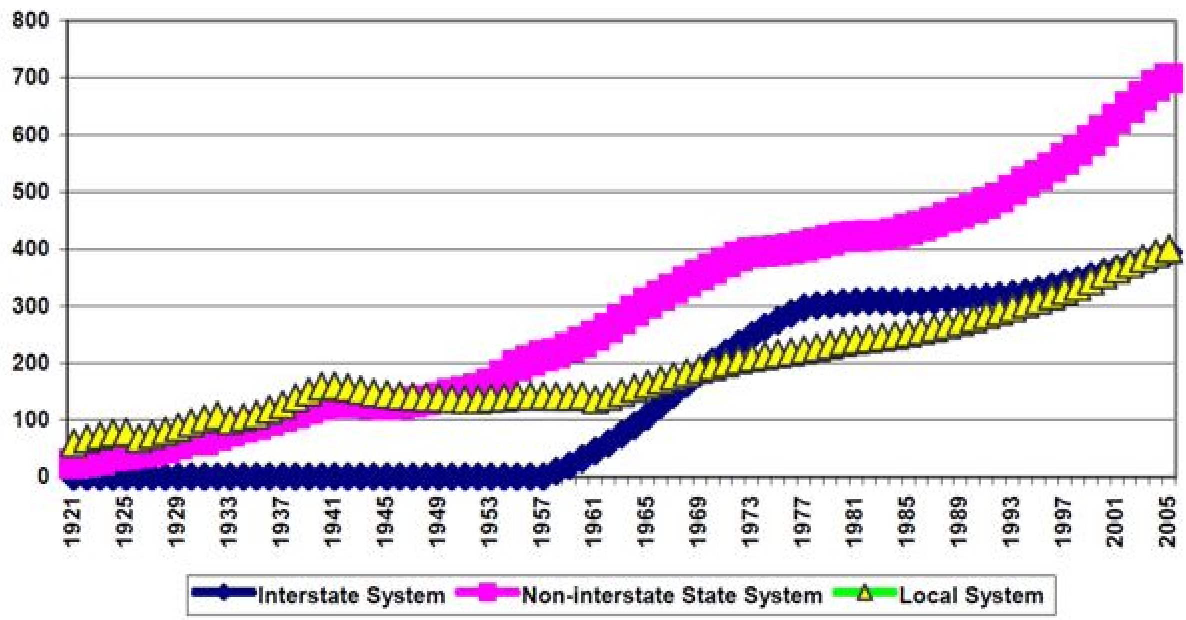
Fraumeni (2007) noted much larger differences between her highway capital stock estimates and BEA's. The differences relate to annual rates of growth as well as the level of the stock. BEA's estimates produce a larger capital stock than Fraumeni's, particularly from 1930 through 2000. The growth rates of Fraumeni's estimates are significantly lower than those of BEA's estimates from the 1970s and 1980s

[23] Fraumeni (2007) states that the only difference in the two series of highway capital stock estimates is a slight difference due to different BEA deflators (p. 31).

and then are higher thereafter. She attributes this difference to deflators and differences in the component series underlying her estimates (Fraumeni, 2007, p. 33).

Figure 4 displays the estimates derived by Fraumeni (2007) for the interstate system, non-interstate system and local road system. One can see that construction of the interstate system did not begin until the late 1950s and most of the construction of what is in place today occurred during the next twenty years. The interstate highway capital stock expanded again in the late 1990s, with much of that construction around metropolitan areas. The non-interstate highway capital stock has grown since the series began in 1921 and as of 2005 was valued in 2000 dollars at 75 percent higher than the interstate system.

Figure 4. Productive Capital Stocks: Interstate, Non-Interstate & Local Systems Billions of 2000$s 1921-2005



C. Direct Observation of Capital (DOC)

Another method of estimating highway capital stock is the direct observation of capital (DOC).[24] DOC is conceptually simpler than PIM because it simply counts the number of physical segments of the highway capital stock using surveys of physical assets. The simplest aggregate DOC measure of highways is the total number of miles of highways. A slightly more complex approach is to add up the number of highway units by type of highway and even more extensive is to add the number of lane-miles. However, this approach of simply adding the length of segments (by number of lanes) ignores the condition of these segments. One could come up with a measure of effective miles of highway capital

[24] See Bingsong Fang and Xiaoli Hang, "Highway Capital Stock: Concepts and Measurement," OECD, Statistics Directorate, Second Meeting of the Canberra Group on Capital Stock Estimates, October 1998, for a detailed discussion of the differences between DOC and PIM.

by weighting the miles (or lane-miles) by each segment's condition. HPMS provides an inventory of the pavement condition of samples of highway units. Rating the pavement condition of highway segments by a value between 0 and 1, with 0 being impassable and 1 being newly constructed state of the art, and multiplying the applicable segment by this weight would provide some measure of conditional miles (or lane miles).

However, pavement condition may not be the only characteristic of a segment of highway that matters with respect to the level of service received from it. Tightness of the curves, steepness of the grades, and weight limits on bridges could be other characteristics that determine the flow of services from highways. Adding these features to miles of highways is less straightforward and requires more complicated weighting schemes.

It may not be necessary, however, to use a weighting scheme to derive a single measure of the physical asset of highway capital if the purpose of constructing such a stock is to enter it into a production function. Production functions are specified with private and public inputs on the right side of the equation, which means that multiple entries of capital characteristics could be entered separately instead of as one number. Furthermore, the U.S. has highway inventories over multiple years so a time series of physical capital assets and characteristics are available. However, multiple components of capital stock entered separately into a production function would make it difficult to interpret the coefficients as a measure of the total value of infrastructure.

A drawback of DOC is the incomparability across modal types. A mile of highway is not the same as a mile of track or a mile of transit rail. Airports and intermodal freight facilities, even though they may cost the same, are different entities. PIM provides a common metric of monetary value, which may be misleading if used in a way that a dollar worth of airports is naively compared with a dollar worth of intermodal freight facilities. Another issue with the DOC method has to do with a mature economy. Since the number of miles of highways is the basic building block of the DOC method and a mature system is not constructing many additional miles of highways, the major differences across regions or over time would be in minor variations in the number of lanes or pavement conditions, which may not reflect the true investment activity for highways.

For measuring productive highway capital stock, PIM and DOC are conceptually equivalent (Bingsong and Han 1997, p. 13). However, there are differences in available data to construct the necessary components of these two estimation methods. One of the major data problems for DOC is the difficulty in distinguishing different vintages of highway capital stock, which is necessary for calculating efficiency patterns. PIM has similar problems with accurate efficiency patterns but for different data reasons. An advantage of DOC is the detailed information on pavement conditions, characteristics of highway segments and cost per lane-mile from the HPMS and some state reporting systems. These differences in available data are summarized in table 3. Bingsong and Han (1997) conclude that there is no conclusive reason to choose one method over the other, even though the majority of macroeconomic studies relating highway capital stock to economic activity use the PIM method to estimate highway capital stock. One reason is that it matches the method typically used to estimate private capital stock, which is also included in the production function. Dalenberg and Eberts

(1997) propose a hybrid approach in which the physical characteristics are integrated into the PIM estimates to adjust for some of these issues.

Table 3. Data Requirements of PIM and DOC for Measuring Productive Highway Capital

Feature	PIM		DOC		Preferred method
	Needed	Comment	Needed	Comment	
Highway Retirement Pattern	Yes	Not readily available	No	Automatically excluded from physical asset inventory	DOC
Physical Characteristics	Yes	Difficult aggregating	Yes	More detailed than for investment measures	DOC
Original Acquisition or Replacement Cost	Yes		Yes	Level of detail of acquisition cost does not match level of detail of physical characteristics	PIM
Efficiency Pattern	Yes	• Unit based • Uses it to adjust original investments • Not readily available	Yes	• Aggregate • Uses it to value existing physical assets by vintage • Not readily available	DOC (if highway maintenance & repair keeps highways intact

Source: Author's analysis of Bingsong and Hang (1998).

D. Estimating Highway Network Characteristics using State-Level Capital Stock

National estimates do not reflect the network aspect of transport systems, such as the highway system. To begin to capture these characteristics, one must consider how the highway system connects the various nodes of activity within its network. This means considering the flows of freight and passenger traffic between each pair of metropolitan areas, for example, and then considering from the vantage point of each metropolitan what possible routes are possible.

Another approach of estimating highway network characteristics is to use the commodity flows to measure the shipments from point of origin to point of destination. The Commodity Flow Survey reports this information aggregated at the state level. It is also possible to obtain the micro data of shipments from each establishment included in the survey. The use of the micro data is discussed in the next section.

By combining the state-level flows with highway capital stock estimated at the state level, one can provide an estimate of the weighted average of the capital stock from other states used by producers in a specific state. The weights are the percentage of goods shipped from a specific state to all the other states connected by the highway system. For example, if shippers in Ohio use highways in Pennsylvania and Michigan more intensively than in Kentucky and Indiana, then the commodity flows will weight the capital stock in those two states more than the capital stock in Indiana. This approach, however, requires the estimation of state-level highway capital stock.

State-level highway capital stock measures have been estimated in basically two ways. The first approach estimates highway capital stock for each state the same way the national capital stock estimates are constructed. That requires obtaining a sufficiently long time series of highway capital outlays for each state as well as appropriate retirement and depreciation estimates. Price deflators must also be available for each state to reflect the differences in material costs and wages by state and differences in constructing highways in states with different terrain. Issues with estimating state-level capital stock are discussed in NCHRP Report 389.[25]

Another approach of estimating state capital stock is to apportion national estimates using a weighting factor. Munnell (1990) used this approach for her estimates. This approach can be used if the time-series for highway outlays is not long enough so that the first outlays in place would have been retired by the date the capital stock is needed. She uses the average of several years of outlays at the beginning of the outlay series to weight the national capital for each state. That provides a starting point for the highway capital estimation for each state using the outlay series available for all states. This approach several drawbacks. If state employment shares are used to apportion the national capital stock to each state, then the state capital stock, if used in a production function, will be correlated with labor inputs simply because of the construction of the capital stock. The resulting multicollinearity among the labor and highway capital stock will bias the estimates of the effect of highway capital on output, and thus its valuation.

Another approach of capturing the network characteristics of highway capital is to measure the redundancy of the highway system by constructing a measure of circuity or impedance. Eberts (1997) merged the Commodity Flow Survey with the Longitudinal Research Database (LRD), which together provides information on where each establishment ships its goods. Merging the two data sets creates a representative sample of the shipments made by each of nearly 80,000 manufacturing establishments in which we know not only the production characteristics of an establishment but also the output shipped, by what mode, the shipment's final destination, the distance between origin and destination of shipments, and an estimate of the miles actually shipped. This data set provides the means to link an establishment's location with the highway infrastructure close by and thus the highway system it most likely uses. Furthermore, it provides a way to trace the destination of the goods produced by each plant.

Merging the two datasets offers several advantages in studying the effects of highways on productivity. First, as previously mentioned, the linked data set gives researchers information on where individual manufacturing facilities ship their output. We thus know the extent to which plants use highways, as measured by the percentage of goods shipped by trucks and by the distance plants ship their output. Previous studies have not been able to measure highway use and thus treat all businesses as if they use highways to the same extent.[26] This assumption can bias estimates of the effect of highways on productivity.

[25] See Dalenberg and Eberts (1997) and Bell and McGuire (1997).

[26] One exception is Fernald (1994) who uses the number of vehicles owned by businesses within two-digit industries. He uses this information to adjust for the use of highways at the two-digit industry level in obtaining

Second, the data set allows researchers to link the location of an establishment to the location of highway infrastructure within the plant's proximity. Studies based on aggregate data, particularly at the state and national levels, do not differentiate between highways that are close to an establishment and those that are far away. For example, studies using national level data for individual industries assume that highways on one coast affect firms located on the other coast. This wide dispersion in the location of businesses and highways may exacerbate the problem of estimating productivity effects when industries are spatially concentrated, such as the primary metals industries and the furniture industry. Unless the spillover effects of highways outside the immediate area of the plant are substantial, there is little reason to expect the highway stock in Southern California or in Florida, for example, to contribute significantly to the primary metals industry, which is heavily concentrated in places like Indiana and Ohio.

Third, the LRD provides the means to examine the effect of highways on the performance of individual plants, not aggregations of plants to the state or national industry levels, which has been the case in previous studies. With the LRD, researchers can now explore more detailed behavior of plants and can account for the heterogeneity among individual plants even within narrow industry groups. Furthermore, basing the analysis on individual plants mitigates some of the econometric problems that plague analyzes based on aggregate data. One of the most serious problems is simultaneity bias: does highway infrastructure "cause" business behavior or does business behavior "cause" highway investment? Using aggregate data confounds this problem because aggregate highway expenditures are in essence placed on par with aggregate business output at some government jurisdictional level, typically at the state or national level. It is equally likely that an increase in business activity within a state, say, could affect the level of highway spending (through the greater need for highways and the enhanced ability to finance the investments) as an increase in net highway investment could affect business performance (as an unpaid factor of production). With plant-level data, on the other hand, it is less likely that the behavior of an individual plant could influence highway investments in a government jurisdiction as large as a state or even a county, which is the smallest unit of observation used for the highway variables in this study. Therefore, estimates of the effects of highways on productivity are less likely to be subject to simultaneity bias when plant-level data are used.

A measure of circuity or impedance was constructed by using the actual distance traveled by a shipment, as estimated by Oak Ridge Laboratories, compared with the shortest distance to the destination of the shipment. A ratio of actual miles to shortest distance miles is a measure of circuity or impedance. The more directly the highway system connects the points of origin and destination, the closer the ratio is to one.[27] One can imagine a time in the not-too-distant future when the location of shipments will be tracked by GPS sensors or other devices and the information collected and analyzed to

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national-level estimates of the effect of highways on productivity. An immediate problem with this approach is that private trucks, that is, those owned by businesses to carry their own goods, transport less than half of the value of commodities shipped by trucks and thus underrepresents the use of the highway system.

[27] Estimates show that the impedance ratio is negatively related to productivity of the shipping establishment (Eberts 2002).

show the use of the transportation system. Businesses are already doing this; the information now must be shared and processed to provide a real-time perspective of transportation usage.

VII. METHODS OF ESTIMATING THE BENEFITS OF TRANSPORTATION INFRASTRUCTURE

Two approaches are typically taken to estimate the benefits of transportation capital as they relate to the value of an additional unit of investment. One is referred to as the microeconomic approach, in which a benefit-cost analysis framework is used, and the other is the macroeconomic approach in which production functions (or cost functions) are estimated. Figure 2, which lays out the channels by which transportation infrastructure investment can affect economic growth, is useful in understanding the differences between the two approaches. The microeconomic approach starts at the top of figure 2 and monetizes each of the major channels and sums them to obtain a total value. The macroeconomic approach starts at the bottom of figure 2 with an aggregate measure of economic growth such as GDP and statistically relates it to an aggregate measure of highway capital stock. Typically, production functions are estimated using time series data or cross-section data (across states or metropolitan areas), or both (in the form of a panel dataset), to estimate the elasticity of output with respect to highway capital stock (or other transportation capital stock). Most studies using this approach do not identify the causal linkages between transportation infrastructure and economic growth in the same detail as is typically done using benefit-cost analysis. Thus, the challenge when interpreting the results is to find causal linkages between infrastructure investments and economic output. On the other hand, the challenge with using benefit-cost analysis is to include all the relevant channels and to find credible estimates of their effects.

Even though the two approaches converge, so to speak, after starting at opposite ends of the figure 2, the two approaches do not completely overlap. Hulten (1994) shows that the benefit-cost analysis might miss the spillover effect, whereas an analysis of the macroeconomic production function would capture it. One can always add elements to the benefit-cost analysis that take into account wider benefits, as will be discussed later in the paper, but the theoretical basis of the benefit-cost framework is welfare theory and includes elements that will maximize total welfare for society. Effects of different actions are valued in monetary terms and expressed as opportunity costs for users and others who benefit or suffer from the impact of the transportation system under study.[28] The econometric approach casts a wider net but it is difficult to identify the channels by which infrastructure affects output and to be sure that the estimated effects are reflecting the appropriate causal relationships.[29] Without identifying the individual channels, it is difficult to first see how much the estimated value from the benefit cost analysis matches the value from the production function approach (that is, whether enough channels are included in the benefit-cost analysis) and whether the direction of causation is appropriate in the production function estimates.

[28] OECD “Assessing the Benefits of Transport, European Conference of Ministers of Transport, 2001, p. 21.

[29] One of the major concerns with the production function/econometric approach, particularly when estimated only using time series data, is whether the causation is running in the right direction. Is infrastructure “causing” output or is output “causing” infrastructure investment. Both channels are possible.

Methods to address the question of the *average* net return of transportation capital are typically tied to the national income accounts in which production from business, nonprofit, and government sectors are considered in this estimation. Since this approach focuses on the use of highways by producers, the household sector is not included, except in the form of owner-occupied housing. Also, externalities such as expansion of economies of scale or increased agglomeration economies are not included in these estimates, since they are not included in national income accounts. Fraumeni's (2007) approach to estimating the average net rate of return, which will be described in another section of this paper, is to look at the growth in highway capital input and GDP over time, based on assumptions about the rate of return of government assets.

A. Microeconomic Approach: Benefit Cost Analysis

Benefit cost analysis (BCA) is used mostly for single project assessments. Although benefit-cost analysis methodologies differ across users, they share common aspects:

- A large set of benefits and costs generated by infrastructure projects are scrutinized,
- A long planning horizon (20 or more years) is often needed,
- Future benefits and costs are discounted to calculate the net present value of a project,
- All costs and benefits are converted into monetary values,
- Geographical region within which benefits are costs are estimated, and
- Sensitivity analyses are conducted to verify the robustness of the results (Pisu, et.al. 2012, p.7).

The net socio-economic benefit includes the following components, with some omitted such as externalities if reliable estimates are not available:

- Change in consumer surplus,
- Revenues for the infrastructure operator minus operating costs of infrastructure services,
- Change in welfare because of externalities, and
- Effect on government budgets.

For this decision tool to provide accurate information, all appropriate benefits and costs need to be monetized over the life of the project. In perfectly competitive markets, prices can be used to monetize the benefits and costs, but in imperfect markets or for externalities where no market prices exist, shadow prices are used instead. After discounting, the social rate of return of infrastructure projects derived from monetized benefits can be compared across projects (but only if the same elements are used) and with the costs of the project (Pisu, Hoeller, and Joumard, 2012).[30]

Externalities, such as those listed as allocative externalities in figure 3, must be properly measured and explicitly entered into the benefit calculation. Valuations may be derived from demonstration projects, they may be based on observed behavior (e.g. intermediate good method, hedonic pricing,

[30] Mauro Pisu, Peter Hoeller, and Isabelle Joumard, "Options for Benchmarking Infrastructure Performance," OECD Economics Department Working Paper No. 956, 2012.

travel cost method, defensive expenditures, etc.) or they may be imputed from surveys.[31] As described in the previous section, the valuation of externalities should be included only if the location has the pre-conditions for the externalities to lead to economic benefits. The benefits of agglomeration economies resulting from increased accessibility brought about by improvement in highway infrastructure, for example, can be included in the benefit cost calculations only if there is sufficient clustering of economic activity within the vicinity of the proposed project to "incite" benefits.

Another confounding issue in estimating the benefits of the highway system is the network characteristics of highways. Investment at each node of the network has implications for the other nodes and taking into account these effects are important in obtaining a true reading from the benefit-cost analysis. There are obviously different decisions at each node, and different benefits as revealed by different relationships between the highway system, as viewed from that node, and output. With these externalities and network characteristics, it is important not to double-count the benefits when adding up the benefits from the vantage point of any specific node as being part of the network (Hulten 1994, p. 14)

Since benefit cost analysis is basically an adding up process: adding up the discounted net socio-economic benefits and matching them to the costs of construction or operations and maintenance, it is important to include the major channels through which infrastructure affects users of transportation capital so that the full effect of infrastructure on the economy is recorded. The concern that elements may be missing is what spawned interest in the macroeconomic approach, which had the advantage that most of the channels would be included by relating the final aggregate outcome—GDP—with the transportation infrastructure variable.[32]

To promote greater consistency in the criteria used to select projects, more prescriptive guidelines have been established by federal agencies or national organizations on what elements should be included in benefit cost analysis and what values could be used. A recent study compares the elements typically included in benefit-cost analyses across selected countries and finds many elements in common, but also differences in what elements are included. The table in Box 5 shows these differences.[33] There are even detailed guidelines on which of the so-called "wider effects," such as the allocative externalities in figure 3, should be included and how to estimate their effects.

TRB recently released a guide to assessing wider economic benefits of transportation, accompanied by a set of tools for state DOTs and others to incorporate into their benefit cost analyses. The guide (SHRP 2014) targets three classes of wider effects: reliability, intermodal connectivity, and market access. These benefits go beyond the traditional measures of traveler impact, which are based on average travel time and travel cost, and include factors that enable businesses to gain efficiency by

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[31] Anthony Boardman, David Greenberg, Aidan Vining, and David Weimer, "Plug-in Shadow Prices Estimates for Policy Analysis, Annals of Regional Science, 1997 (31): 299-324.

[32] Of course, the macroeconomic economic approach will not capture environmental effects if they are not included on the left-hand side of he equation along with GDP unless transmitted through the prices in a perfectly competitive market.

[33] Pisu, M., P. Hoeller and I. Joumard (2012), "Options for Benchmarking Infrastructure Performance," OECD Economics Department Working Papers, No. 956, OECD Publishing.

reorganizing their operations or by changing the mix of inputs used to generate products or services.[34] The tools available to incorporate these benefits within benefit cost analyses are based on a searchable database of ex post evaluations of 100 projects across the country. It also includes an expert system that draws from the database to estimate the range of economic impacts likely to result from any specified project in any defined setting (p. 3). In addition, estimates of the more traditional elements included in benefit cost analyses, such as congestion costs, are available from various sources, so that the combination of the TRB tools for estimating wider effects and the standard sources for travel-related estimates provide more consistency in the estimates while still being able to customize the estimates to specific settings.

The UK has taken a similar approach to TRB/SHRP's study by developing guidelines and detailed instructions on what to include, how to estimate the benefits, and when to use them. The instructions extend to estimating the value of externalities and how to include them in the benefit-cost analysis. This detailed set of instructions, which includes the definitions of specific externalities, metrics, calculation procedures, and data required, provide a common approach that can be used to compare across highway construction projects. This approach also allows close scrutiny of what benefits are included in the analysis and how the valuations are estimated. Box 5 describes the guidelines and estimation procedures for one of the externalities that the UK Department for Transport has included in the benefit cost analysis.

The European Commission provides a handbook of estimates of external costs of transport which includes costs associated with congestion, pollution, noise, accidents and climate change, which the SHRP approach does not. The estimates are based on accepted methodologies and are intended to provide a consistent measure that can be used to provide comparability in benefit cost analyses. Table 4 displays the estimated congestion costs for different regions, road type and road use. The costs are measured as Euro cents per vehicle kilometer. One can see from the table that congestion caused by cars on motorways is more than three times as high in urban areas than rural areas (48.7 vs. 13.4) for roads that are being used at near capacity. The highest cost in urban areas is due in part to higher wages there than in rural areas.

[34] SHRP 2 Project Brief Capacity Project C11, "Tools for Assessing Wider Economic Benefits of Transportation," June 2014.

Table 4. Estimates of Congestion Costs by Vehicle, Region, Road Type, and Road Use

Vehicle	Region	Road type	Free flow (€ct/vkm)	Near capacity (€ct/vkm)	Over capacity (€ct/vkm)
Car	Metropolitan	Motorway	0.0	26.8	61.5
		Main roads	0.9	141.3	181.3
		Other roads	2.5	159.5	242.6
	Urban	Main roads	0.6	48.7	75.8
		Other roads	2.5	139.4	230.5
	Rural	Motorway	0.0	13.4	30.8
		Main roads	0.4	18.3	60.7
		Other roads	0.2	42.0	139.2
Rigid truck	Metropolitan	Motorway	0.0	50.9	116.9
		Main roads	1.8	268.5	344.4
		Other roads	4.7	303.0	460.9
	Urban	Main roads	1.2	92.5	144.1
		Other roads	4.7	264.9	438.0
	Rural	Motorway	0.0	25.4	58.4
		Main roads	0.8	34.8	115.3
		Other roads	0.4	79.8	264.5
Articulated truck	Metropolitan	Motorway	0.0	77.6	178.4
		Main roads	2.7	409.8	525.6
		Other roads	7.2	462.5	703.5
	Urban	Main roads	1.8	141.1	219.9
		Other roads	7.2	404.4	668.6
	Rural	Motorway	0.0	38.8	89.2
		Main roads	1.2	53.1	176.0
		Other roads	0.6	121.9	403.8
Bus	Metropolitan	Motorway	0.0	66.9	153.8
		Main roads	2.3	353.3	453.1
		Other roads	6.2	398.7	606.4
	Urban	Main roads	1.6	121.7	189.6
		Other roads	6.2	348.6	576.3
	Rural	Motorway	0.0	33.5	76.9
		Main roads	1.0	45.8	151.7
		Other roads	0.5	105.0	348.1

Source: Own calculations based on the FORGE estimates in Table 6. Values for the EU are derived from the UK values by means of value transfer, using the ratio of respective nominal GDPs per capita and the average exchange rate of year 2010 (0.86 GBP/EUR). Congestion bands (free flow, near capacity, over capacity) are defined in Table 7. Metropolitan: cities with the population > 250,000 people; urban: population > 10,000 people. All other areas are considered rural.

** Country-specific values are provided in Excel tables as Annexes to this report.*

Source: Update on the Handbook of External Costs of Transport, Report for the European Commission, 2014.

Similar estimates of external costs have been derived for the United States and include other modes in addition to highways (Delucchi and McCubbin, 2010). These estimates, for rail, air, water, and highways, provide external costs for air pollution, climate change, noise and energy security. As shown in table 5 the range of estimates is pretty wide. For example, external costs of climate change range from less than a cent to 4.8 cents per passenger mile. Obviously, including one end of the range or the other could have a substantial effect on the estimates of the value of benefit (or cost of highways) and affect the benefit-cost ratio.

Table 5. U.S. Estimates of External Transport Costs by Type and Mode (2006 cents)

	Passenger (per passenger-mile)				**Freight (per ton-mile)**			
	Road	*Rail*	*Air*	*Water*	*Road*	*Rail*	*Air*	*Water*
Congestion delay	0.88 - 7.5	n.e.	0.35	n.e.	0.54	0.03	n.e.	n.e.
Accident	1.4 - 14.4	n.e.	n.e.	n.e.	0.11 – 2.0	0.22	n.e.	n.e.
Air pollution, health	0.09 - 6.7	0.49	0.01 - 0.39	1.1	0.10 - 18.7	0.01 - 0.35	0.0 - 1.9	0.08 – 1.7
Air pollution, other	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.	n.e.
Climate change	0.06 - 4.8	0.02 - 1.7	0.08	0.16	0.02 - 5.9	0.01 - 0.47	0.45	0.00 - 0.23
Noise	0.0 - 3.5	0.52 - 0.89	0.88	n.e.	0.0 - 5.3	0.05	n.e.	n.e.
Water pollution	0.01 - 0.05	n.e.	n.e.	n.e.	0.003 to 0.05	n.e.	n.e.	n.e.
Energy security	0.20 - 0.84	0.15 - 0.58	0.18 - 0.69	n.e.	0.22 - 0.84	0.02 - 0.07	n.e.	0.03 - 0.11

Source: Delucchi and McCubbin, 2010.

A handbook developed by the OECD to provide guidance in estimating benefits for benefit cost analyses states that there is a "significant risk of double counting if additional effects beyond the primary pecuniary benefits are added to BCAs" (OECD, 2001, p. 43). This means that time savings and other cost advantages for infrastructure users are assumed to cover all the external pecuniary effects and no additional effects should be added to BCAs. Current practice in some other countries, e.g. the UK and France, suggests that external benefits should be covered in a non-quantitative way in order to avoid the high uncertainties of quantitative assessments. For example the new approach to appraisal of road investments in England involves regeneration issues by responding yes or no to questions such as "does the road project serve the regeneration priority?" and "does development depend on the scheme?"[35]

Box 3. Elements of Benefit Cost Analyses across Selected Countries

Although benefit cost analyses include similar sources of benefits and costs, there can be notable differences in the elements that they include. According to a recent study comparing benefit cost practices across selected OECD countries, notable differences were found.[36][37] The UK appeared to standout among the six countries selected in not including environment elements or tax financing costs in its benefit cost analyses. The UK was unique in including an element that adjusted for the bias in optimism regarding infrastructure projects. Three of the six countries, including the UK, incorporated monetized estimates of socioeconomic indirect effects.

Element	Norway	Netherlands	Korea	Sweden	United Kingdom	France
Passenger transport time saving	√	√	√	√	√	√
Benefits for goods transport	√	√	√	√	√	√
Safety	√	√	√	√	√	√
Noise	√	√	√	√		√
Local air pollution	√	√	√	√		√
Climate change	√	√	√	√		
Indirect socioeconomic effects		√		√	√	√
Construction cost	√	√	√	√	√	√
Costs for maintenance, operation and administration	√	√	√	√	√	√
Cost of tax financing	√			√		√
User charges and revenues	√	√	√	√	√	√
Vehicle operating costs	√	√	√	√	√	√
Adjustment for optimism bias					√	

Source: Persson and Song (2010) and Odgaard *et al.* (2005).

a. Estimating Wider Benefits in the SHRP Study

The recently released SHRP report for TRB on estimating wider effects using benefit-cost analysis provides a framework for including the various channels (or elements) by which transportation infrastructure, highways specifically, can affect output. The study provides an accounting framework that lays out the categories of direct economic benefits that a given roadway improvement may have on travelers using it and on the operation of businesses that depend on it (e.g., basically the first two effects described in the previous section). It does not include environmental, social and other broader impacts, nor does it include indirect and secondary effects on the economy (SHRP, p. 24). The tools are designed to be used for highways but the framework can be used for other modes. The results can be

[35] OECD "Assessing the Benefits of Transport, European Conference of Ministers of Transport, 2001.
[36] Persson, J. and D. Song (2010), "The Land Transport Sector: Policy and Performance", *OECD Economics Department Working Papers*, No. 817, OECD Publishing.
[37] Odgaard, T., C. Kelly and J. Laird (2005), *Current Practice in Project Appraisal in Europe*, Project Report, HEATCO.

used in benefit cost analyses and to drive economic impact forecasting models to estimate the long-term regional economic growth implications of proposed projects (SHRP 2014, p. 2).

Table 6 shows the study's classification of benefits which are divided into three groups: 1) traditionally measured benefits, 2) wider economic benefits, and 3) other external (environment and social) benefits.

Table 6. Classification of Benefits of Transportation Improvements

Benefit or Impact Element	Units for Measuring Change
Traditionally Measured Benefits	
Travel Time Savings	$ Value of driver + passenger travel time savings
Vehicle Operating Cost Savings	$ Cost savings from reduced vehicle-miles or vehicle-hours of travel
Safety Improvements	$ value of reduction in crash incidents
$ Value of Environmental Benefit	$ value of reduction in tons of emissions
Wider Economic Benefits	
Reliability Benefit	$ Cost savings of income gain from less non-recurring delay
Market Access Benefit	$ Income or GDP gain from effective size or density gain
Connectivity Benefit	$ Income or GDP gain from connectivity benefit
Other External (Environmental and Social Benefits	
Other Environmental Impacts	$ Value of reduction in water, noise, visual, other pollution
Social Impacts	$ Value of enhancement in social factors

Source: Final Report SHRP 2 Project C11, p. 20

The SHRP report describes the way in which the values for each of the elements are computed. Focusing on the three elements classified as wider economic benefits, one sees immediately from the right hand column of table 6 that several layers of information are required since in some cases the beneficiaries are not the direct users of the highways or, as in the case of the reliability estimate, time must be considered in two moments: average or median and variation. Therefore, the data requirements and the number of underlying assumptions increase when including the wider benefits compared with including only the traditionally measured benefits.

Estimating the value of the reliability benefit starts with the standard estimate of the savings from reduced travel time. The next step is to estimate the variation in travel time around that average, as expressed as a percentage of the average, referred to as the reliability ratio. Two types of delays are considered, recurring and non-recurring. Recurring delays happen because of congestion and reduced traffic flow, whereas non-recurring delays result from accidents and resultant delays. Assuming an appropriate hourly wage for the region within which the project is being considered and the number of people potentially affected, the reliability ratio can be monetized and entered into the benefit cost analysis structure as one of the elements.

The value of intermodal connectivity is also included as a wider effect. It is related to the type of service that the intermodal terminal connects to, the location of the terminal, the overall level of activity at the terminal and the number of other locations that can be reached through the terminal.

Market access is measured through a statistical indicator of effective market size or effective market density. The intent of this metric is to reflect the magnitude of the opportunities for businesses to access workers within a labor market or customers within a delivery area. It incorporates many of the same factors discussed in the previous section on wider effects including scale and scope economies, shared inputs, and urbanization and localization. As mentioned in that discussion, these factors are relevant in generating economic benefits under specific pre-conditions of the region. Furthermore, they affect parties that are not directly using the highway system, so various steps from the infrastructure improvement to its affect on accessibility and market expansion to output needs to be taken into account.

The market access tool is described in more detail in order to show how the framework is developed and what data and assumptions are required to estimate the value. As described in the final report (Chapter 5), the market access tool is based on the following components:

- Identification of relevant markets and the associated triggers for market access to have economic value and for what groups,
- Sensitivity to transportation costs and transportation scenarios,
- Spatial scale for consideration, aggregation, and comparability,
- Spatial unit within the context of spreadsheet drive tools,
- Types of measures and economic implications of access changes, and
- Simplicity in communicating (SHRP Report, p. 70).

The tool defines the value of accessibility as the percentage increase in economic activity (measured by income or GDP) that is generated by a one percent increase in effective market scale or effective density. The study lays out specific channels through which transportation improvements can affect market access and from what perspective—consumption, production, or distribution. It uses features (or economic triggers) identified in the literature on agglomeration effects to provide a framework for capturing the economic value associated with market access. For example, the feature (or economic trigger) of scale economies or scope can lead to higher outputs and benefits through providing greater market activity for indivisible assets, such as warehousing and production facilities when viewed from the production and distribution perspective. The calculation of the value of market access then becomes an exercise of identifying each channel and coming up with metrics and data to estimate a specific linkage. Table 7 provides examples of several, but not all the, channels for market access identified in the study.

Table 7. Transportation/Highways, Specific Markets, and Two Types of Measures to Capture Economic Value of Market Access

Linkage Perspective	Origin Market	Destination Market	User Group	Measurable Direct Economic Value	Measure Type
Production	Intermediate goods—Input markets-Labor Home Locations	Places of Work/Employment Locations	Commuters	Economic costs associated with commuting	Access to key employment centers
Production	Intermediate goods—input markets-raw materials	Production locations	Trucks, freight	Economic costs associated with shipments	Access to key supplier sites within reasonable travel times
Production-consumption	Final Goods—production sites	Locations of final demand-product markets	Trucks, freight	Economic costs associated with shipments delivery and potential price effects	Access to key customer markets within reasonable travel times
Distribution - consumption	Final goods—distribution sites/warehouse sites	Locations of final demand-product markets	Trucks, freight	Economic costs associated with shipment delivery	Access to key customer markets within reasonable travel times

Source: SHRP 2 Capacity Project C11 Prepublicaton Draft, 2014.

Once these channels have been identified, specific formulations are developed for the various access points, and these formulations are used to build a model based on a number of steps that relates highway use to value of access. For example, the economic implications of a change in market access for productivity is described by an equation that includes effective densities, elasticities of productivity (response of productivity to changes in market access) and estimates of distance or cost decay with distance. These estimates require considerable data and measures of local economic conditions and characteristics to know whether the economic trigger is likely to occur. The study recognizes that MPOs and state DOTs will have difficulty attaining the necessary data and may not have the resources to estimate the required relationships, so the study offers rules of thumb for various key parameters. Table 8 lists the data required to estimate the gravity model and the measures of market access. Additional data, such as market wages among other data, are still needed to estimate productivity measures and value of time.

Table 8. Public Data Sources for Gravity and Daily Measures of Market Access

Market Access Measure	Data	Public Data Activity Sources Base Year	Base/Future-Future Forecast Years
Potential Access	Employment/Population	1. Census Files 2. County business patterns and Bureau of Economic Analysis 3. American FactFinder—population, employment	Base year of analysis and forecasts
Effective Density	Employment typically (but population may also be used)	Employment by place of work-Longitudinal Household Employment Dynamics (LEHD) On-the-Map Data (LEHD) (allows online GIS visualization of data)	Base year of analysis and forecasts Forecasts from MPO or private sources for years for which scenarios are developed
Daily Access-Labor Market	Employment	LEHD – by place of residence and place of workby sector and worker quality	Base year data and forecast year data
Daily Access-Labor Market	Commute thresholds	Census Transportation Planning Package/American Community Survey	

Source: SHRP 2 Capacity Project C11 Prepublicaton Draft, 2014.

The study offers an example of the benefits of a project that expands capacity with a new or upgraded route to enhance access. The results for passenger trips and for commercial trips are shown in table 9. One can see that for this example, including wider benefits increases the value of benefits for the target year. For passenger trips, the wider benefits are 9 percent of total value and for commercial trips it is 16 percent.

Table 9. Value for Highway Capacity Expansion by Benefit Element

	Value of Benefit for Target Year	
Benefit Element	Passenger Trips	Commercial Trips
Value of Vehicle-Hours Saved	$148,068	$37,968
Value of VMT Savings	$0	$0
Value of Safety: Crash reduction	$2957	-$1311
Value of Benefit for Induced Trips	$0	$0
Value of Traditional Benefits	$151,021	$36657
Value of Reliability Improvement	$14,281	$5862
Value of Enhanced Labor Market Access	$352	$0
Value of Enhanced Delivery Market Access	$0	$456
Value of Enhanced Intermodal Connectivity	$388	$457
Adjustment for Overlap in Above	$0	$0
Value of Wider Benefits	$15021	$6775
Total	$166046	$42976
Value of Wider Benefits as percent of total	9%	16%

Source: SHRP 2 Capacity Project C11 Prepublicaton Draft, 2014.

The credibility of this approach of building a model that links transportation improvements to the value to households and businesses of market access, or to the other wider effects, is based on the structure of the model that captures the various channels and on the ability to see the explicit features. The study cites a broad literature of research that focuses on specific aspects of the linkages. The downside of this approach is that some channels may not be included and more importantly that the equations used are crude approximations of the real effects and that the data are course proxies for the actual values needed. In many cases, such information is not available to MPOs and state DOTs so rules of thumb are applied, and the appropriateness and accuracy of these metrics are difficult to assess. The study itself addresses four remaining needs (SHRP 2014, pp. 121-122):

- Assessing the differences and similarities between the multiple alternative measures of transportation impact and assessing which are better than others;
- Economic valuation of these wider transportation impacts vary extensively depending on the type of transportation and industries that are involved or affected, and the tools developed in the study are simple approximations, which require further refinement;
- The channels of impact developed in the study are still incomplete and additional channels need to be added for a more complete valuation of these effects; and
- The tools do not include the broader, longer term effects on business location patterns and expansion, supply and demand for labor, prices and import/export patterns—all of which can affect productivity, competitiveness and economic growth.

Box 4. UK TAGunits

The UK Department for Transport has developed detailed guidelines for estimating indirect benefits, such as agglomeration effects, labor supply, and movements to more or less productive jobs. The guidelines, referred to as Transportation Analysis Guidance Units (TAG Units), define the specific effects, describe how to estimate the effects, show how to conduct sensitivity test, list the data required, and show how to incorporate the effects into the decision tool. The TAG Units also provide software tools to help with the analysis.

To illustrate the approach taken by the TAG Units, agglomeration effects will be considered. TAG Unit 2.1 on Wider Effects (January 2014) defines agglomeration as the “concentration of economic activity over an area.” It continues by saying that transport can affect agglomeration by altering the accessibility of firms in an area to other firms and workers” (p. 2). It goes on to say that “agglomeration impacts arise because firms derive productivity benefits from being close to one another and from being close to large labor markets.” If transport brings firms closer together and closer to their workforce, this may generate an increase in labor productivity above and beyond that which would be expected from direct user benefits alone.

The TAG Unit describes which schemes an appraisal of agglomeration should consider. The guidance states that appraisals should be conducted for transport schemes that are likely to increase accessibility in an area in close proximity to an urban center or large employment center. The guidance goes on to identify “functional urban regions” where this might happen.

The guidance describes how to calculate the effects of agglomeration by defining an agglomeration metric, known as effective density, which provides a measure of the mass of economic activity across the modeled area. It is akin to a gravity model and measures the accessibility of firms and workers to each other. This metric is then used to estimate the elasticity of productivity with respect to effective density.

The guidelines specify the data and the agglomeration elasticities by sector as described in the following table.

Agglomeration Data

Agglomeration Data	
Data	Value
Local GDP per Worker	By Local Authority District
Sectoral Employment Forecasts	By Local Authority District
Total Employment Forecasts	By Local Authority District
Agglomeration Elasticities by Industrial Sector	Manufacturing= 0.021 Construction = 0.034 Consumer services = 0.024 Producer services = 0.083

Based on the data and definitions, the guidelines offer detailed procedures to calculate the welfare impacts of agglomeration. It entails estimating average generalized cost and the effective density, which leads to the calculation of agglomeration effects in monetary terms. This estimate can then be entered into a benefit cost analysis.

Procedures are prescribed in similar detail for labor supply effects and relocation effects.

Source: TAG Unit A2.1, Wider Impacts, UK Department for Transport, Transport Analysis Guide (TAG), January 2014.

To conclude, the different approaches are complementary. Microeconomic benefit cost analyses are the best approach for project assessments and should be used both to achieve an optimal capacity standard of a new investment and to compare the cost efficiency of different investment projects. Macroeconomic assessments should be used for complementary information on possible long term network effects which are not covered in benefit cost analyses.

B. Macroeconomic Approach – Production Function Estimation

Indirect effects of network externalities are estimated using econometric techniques, typically modeled as production or cost functions and sometimes social welfare functions. Econometric techniques used to estimate transport externalities (including its effect on economic activity) are less prescribed than measuring the value of direct benefits, accept to follow widely accepted econometric estimation techniques when dealing with aggregation, direction of causation, spillovers, spatial autocorrelation, and other factors that may confound estimation that attempts to identify and isolate the effects of highways from other confounding factors. An exception is the United Kingdom. Following the Eddington Report (Box 2), the Ministry of Transport provided modularized guidance on estimating all aspects of the broader impacts of transportation and on incorporating these estimates into evaluations.

The general empirical approach is to estimate a production function in which output is a function of private inputs—capital and labor—and publicly provided transport capital stock. Most studies use a simple functional form in relating output to inputs. In log form, the estimating equation takes for the form:

$$\ln Y_{it} = b_L \ln L_{it} + b_K \ln K_{it} + b_T \ln T_{it,}$$

where Y is output, L is labor, K is private capital, and T is transportation capital. The subscript i denotes the level of aggregation (establishment, or county, or state) and t denotes the year. The b_T coefficient estimates the elasticity of output with respect to transportation capital, which is interpreted as a percentage change in output brought about by a 1 percent change in transportation capital stock. For example, if the estimate of b_T is 0.05, then a one percent increase in transportation capital stock is related to a 0.05 percent increase in output. To calculate the rate of return of transportation capital stock, one would multiply the elasticity by (Y/K). Some studies expand the specification so that the output elasticity is a function of the level of transportation infrastructure and the other two inputs—capital and labor. Other specifications have been used that places public capital in the production function as a factor affecting technology. This specification is equivalent to the simple Cobb-Douglas specification listed above. Studies have also used a more flexible form, such as a translog production function, in order to estimate the interactions of highway capital with the private inputs of labor and capital. Cost functions are used as an attempt to pin down the exogeneity of inputs by using prices instead of quantities, but since highways do not have a per unit price, it is entered in the cost function as a quantity. At times, the production function has been estimated within a system of equations that also include demand equations for the private inputs and public capital.[38]

Hulten (1993) notes that the highway capital stock elasticity (b_T) may vary by the use of the stock, as perhaps measured by congestion. The elasticity would be close to zero if the stock (or facility) has close to no use and a smaller facility (fewer lane miles) could produce the same output equally well. The elasticity could be very large if the facility is highly congested, in which case adding new capacity (adding lane miles) would greatly increase output. Thus, a simple regression model, which does not take into account congestion, may not yield a reliable estimate of the elasticity (that is, the value of transportation) (p. 30).[39]

a. Estimation with Network Externalities

Hulten (1993) also points out that because of the network characteristics of highways, highway capital stock is no longer a single variable in the production function, but a matrix of all possible connections of the network nodes. Consequently, there is no single elasticity of output but a separate elasticity of output for each possible connection. The interdependence of network links implies that the marginal product of any link shifts as segments are added or expanded. A regression of output on private capital and a single estimate of highway capital, such as the national estimate of highway capital stock, will not provide a true estimate of the total effect of the highway network, because of the changing response by the private sector throughout the network to changes in the network. Thus, there is no single estimate of the elasticity of highway capital stock, and conversely, there is no single measure of public capital that is suitable for insertion in an aggregate production function.

The extent to which this is true is an empirical issue and depends upon the flows of traffic throughout the network. For instance, if little traffic flows out of a state along the interstate highway system, then the network effects of multiple elasticities may not be that important. Studies that focus on state-level highway capital stock, such as Munnell, assume that only the highway capital stock within the state affects the state's output. From a network perspective, this in essence assumes that manufacturers located within a state ship only within the state. State-level estimates typically find much smaller output elasticities than studies at the national level, perhaps since their estimates do not capture broader network effects from other states. The few studies that have estimated spillover

[38] See Randall W. Eberts, "How Levels of Investment in Transportation Affect Economic Health, Conference Proceedings 21, Information Requirements for Transportation Economic Analysis, Transportation Research Board, 2000 and Ward Romp and Jakob de Haan, "Public Capital and Economic Growth," in EIB Papers Innovative Financing of Infrastructure – the Role of Public-private Partnerships, Vol. 10(1), 2005 for two of several literature reviews on this topic.

[39] Some studies posit the dual approach of a cost function, in which the cost of production is related to the price of labor and private capital inputs and the stock of transportation infrastructure. Theoretically, the results should be the same, but since the data requirements are different—cost and price data instead of output and quantity data--the results differ. One benefit of this approach is that the issue of reserve causation—output "causing" investment in highway infrastructure instead of highway infrastructure "causing" output—is mitigated somewhat. Other approaches that model consumer and producer surplus are also used and will be discussed separately.

effects in other states have not found large effects, if any. Some have even found negative spillover effects. This may indicate that shipments outside a state are low compared to shipments within a state.

Table 10 shows the commodity flows between two neighboring states—Ohio and Michigan—linked by major interstates and a common industrial structure. Here we see that for each state at most 24 percent of the goods are produced in the state and shipped within a state. At the same time, at most only 10 percent is shipped between states, from Michigan to Ohio, and only 3 percent is shipped from Ohio to Michigan. The low interstate percentages means that for these two states the use of the highway network extends far beyond neighboring states. In addition, using establishment data matched to Commodity Flow Survey, estimates show that 56% of output is shipped within 250 miles of plant, which leaves 44 percent shipped beyond 250 miles.

The network aspect of highways makes it important to establish the spatial linkage between a business and the highway system it uses. Unfortunately, few studies have been able to make this correspondence. Eberts (1997) adjusts highway capital stock by the percentage of shipments by truck within a state, and adjusts highway capital stock by the percentage of shipments by truck from state of origin to state of destination. He finds that including the capital stock from other states that firms within a given state ship to changes the estimates of the effect of highway capital stock on output. As shown in table 10, the estimated output elasticities with respect to in-state capital is higher than estimated output elasticities of highway capital that does not take into account the network characteristics (unadjusted). However, the output elasticity of out-of-state highway capital is quite small.

Table 10. Percentage of State's Manufactured Goods Shipped by Truck by Origin and Destination

From/To (ton-miles)	**Michigan**	**Ohio**
Michigan	23.97%	9.29%
Ohio	3.36%	16.46%
Factors	**Output elasticities of:**	
Unadjusted Highways		0.035
Highways in-state	0.065	
Highways out-of-state	0.006	
Private capital	0.453	0.45
Labor hours	0.543	0.56

Source: Commodity Flow Survey, 2002 and author's estimates of output elasticities.

The other empirical issue that may mitigate the problems with estimating the output elasticity of highways within a network is the mature nature of the current system. From a national perspective, few additional connections are being built between metropolitan areas, or nodes of economic activity. Most of the construction is within metropolitan areas, in order to alleviate congestion and to connect the expanding boundaries of metro areas. Taking into account the network characteristics of highway systems may be a concern for estimating the output elasticity within metro areas, but less so at the national level. Nonetheless, even though additional connections may not occur within a mature highway network, adding additional lanes to existing connections could relieve congestion to the point of changing traffic flows within the network, which could affect output elasticities at the various nodes.

b. Estimation Results

Dozens of studies have estimated production functions with various levels of aggregation of data (national, state, local), for different time periods, for various industries, using different measures of transport infrastructure and for different countries. Some have used different econometric techniques to correct for estimation issues, such as spurious correlation due to nonstationarity in the data, omitted variable bias, spatial externalities, and issues with measuring transport capital stock. Most posit a single estimate of output elasticity.

Magnitudes of the estimates vary by the dimensions mentioned above. Melo et. al. (2013) examined the variation in the estimated output elasticity of transport infrastructure from a sample of 563 estimates obtained from 33 studies conducted between 1988 and 2012.[40] To sort through the various aspects of these studies that could lead to different estimates, the authors conduct a meta-analysis of the empirical evidence. A meta-analysis is a regression-based approach of identifying sources of systematic variation in existing empirical findings through statistical testing of the role of the various study features on the size of the empirical estimates (p. 696). The following table of results from their analysis is reproduced in order to convey the effects of different dimensions on the elasticity estimates.

The mean and median estimates of the output elasticity for each of the various categories are displayed in table 11. Focusing first on the median estimate, the results show that the overall estimate of the effect of transport infrastructure on output is 0.016, which means that a 1 percent increase in transport capital investment relates to a 0.016 percent increase in output. The mean of the elasticity estimates is 0.060 with a rather larger variation around this estimate. For those studies that focus on highways (roads) the median elasticity estimate is 0.045 and the mean is 0.088, which is well above railways (0.011) and airports (0.006). Once again the variability is relatively high. By sector, manufacturing has a higher median value than the overall economy, 0.057 compared with 0.016. The U.S. and Europe, two regions with mature economies, exhibit much lower median elasticities (0.014 and 0.013) than other countries (0.083), some of which are developing countries.

Not shown in this table, the authors also found that studies that accounted for urbanization had lower estimates of elasticities but those that controlled for spatial spillovers found no statistically significant effect, although the coefficient was positive. The authors also reported that studies that used state or local data found lower estimated elasticities than those that used national level data.

[40] Patricia C. Melo, Daniel J. Graham, Ruben Brage-Ardao, "The Productivity of Transport Infrastructure Investment: A Meta-Analysis of Empirical Evidence," *Regional Science and Urban Economics* 43 (2013) 695-706.

Table 11. Summary Statistics of the Sample of Studies Used in the Meta-Analysis

Dimension of study design		N	Share(%)	Mean	Median	SD	CV
Country	Europe	177	31.44	0.039	0.013	0.219	5.618
	Other countries	34	6.04	0.083	0.082	0.079	0.950
	US	352	62.52	0.069	0.014	0.328	4.775
Measure of transport infrastructure	Monetary	431	76.55	0.046	0.010	0.319	7.006
	Physical	132	23.45	0.108	0.038	0.134	1.241
Publication status	Published	544	96.63	0.060	0.015	0.292	4.896
	Unpublished	19	3.37	0.074	0.051	0.079	1.072
Industry	Whole economy	411	73	0.065	0.016	0.179	2.754
	Primary	38	6.75	0.071	0.051	0.761	10.718
	Manufacturing	65	11.55	0.082	0.057	0.423	5.183
	Construction	23	4.09	− 0.012	0.001	0.061	− 5.154
	Energy	3	0.53	− 0.002	− 0.002	0.001	− 0.500
	Services	23	4.09	− 0.016	0.002	0.049	− 3.110
Mode of transport	All	196	34.81	0.028	0.005	0.108	3.893
	Airport	26	4.62	0.027	0.006	0.094	3.481
	Port/ferry	27	4.80	0.068	0.016	0.170	2.495
	Railway	32	5.68	0.037	0.011	0.097	2.607
	Roads	282	50.09	0.088	0.045	0.389	4.435
Time frame	Short-run	187	33.21	0.038	0.012	0.080	2.083
	Intermediate-run	74	13.14	0.079	0.030	0.678	8.583
	Long-run	302	53.64	0.069	0.015	0.197	2.845
Total		563	100	0.060	0.016	0.288	4.780

N – number of observations; SD – standard deviation; CV – coefficient of variation.
Source: Melo et. al. (2013)

C. Identifying Specific Channels Of External Effects

While the meta-analysis was able to quantify various aspects of network externalities, such as urbanization and spillovers, the individual production studies cast a wide net to capture the broad externalities that may arise from infrastructure investment and are seldom able to identify the specific channels through which infrastructure affects those outcomes. Consequently, the results from these production function studies are a black box. However, the problem with estimating specific effects, such as agglomeration, is that the estimation may miss other externalities. On the other hand, if estimates of several externalities are combined, the additive effects may overstate the total effects, because of positive correlation among the various effects.

a. Generalized Cost Approach

Prudhomme (1999) suggests that transport improvement has a qualitative as well as quantitative dimension. It does not mean merely more (greater quantity) transport infrastructure; it means more speed, more comfort, more safety, more reliability, and less cost. It means more value for money. Prudhomme proposes a "generalized cost" approach. It includes the economic cost of moving say a ton of goods one mile (ton/mile), plus the time cost, plus an unreliability cost, plus a discomfort cost. "A transport improvement can therefore be seen as a change that decreases this generalized cost" (p. 86). The problem according to Prudhomme can be restated as: "by what mechanisms does a decrease in the generalized cost of transportation contribute to economic development?" He also makes the point that production function analysis can at best assess the benefits associated with only one type of transport improvement: better infrastructure. It cannot separate out the benefits coming from improved vehicles, from organizational changes in the transport sector and from modal shifts. The United Kingdom uses average generalized cost when estimating elements of benefit cost analyses.

b. Direct Benefits to Producers—Inventory Costs

Shirley and Winston (2004) use the effect of highway spending on inventories to show that highway spending raises productivity by improving the cost, speed, reliability.[41] They depart from the public/macro research programs by focusing on this mechanism to understand why returns have declined over time. Using their approach, they estimate an annual return that reaches 17.6 percent during the 1970s but then falls to 4.9 percent during the 1980s and to 1 percent by the 1990s. The authors point to several trends that may account for the decline. First, the network has matured but spending on the capital stock has accelerated in the 1980s and 1990s. Second, inefficient highway pricing and investment policies may have undermined the benefits of government spending. Policies include wasteful pork-barrel spending, poor responses to demographic changes, and suboptimal maintenance of the road system. Shirley and Winston conclude that "it appears that large investments in a mature highway system during the 1980s and 1990s may have had only a small positive impact on firms' logistic costs and generated low returns because they were in part undermined by suboptimal policies."

c. State-level Aggregation

Another approach in opening up the black box of externalities is to devise measures of the various externalities and include them in the estimation. This approach may be particularly useful when trying to estimate externalities at the subnational level, such as for states and metropolitan areas. Some researchers have argued that confining the estimation of production or cost functions to observations based on small geographical areas, such as counties or metropolitan areas, may reduce the ability of these estimation methods to capture the indirect benefits of transportation investment. Munnell (1990), for one, has argued that the fact that state-level estimates of the effect of highways on productivity are smaller than national-level estimates is evidence that the state-level estimates are not capturing the externalities of networks and spillover effects of highways. Munnell's position is debatable. Furthermore, it may be possible to capture indirect effects by using measures of highways and other transportation systems that more directly measure the network effects.

d. Network Metrics

One possibility is to find alternative measures of highway capital stocks that measure more directly network effects. A measure explored by Eberts (1999) is to compare the number of miles between origin and destination that goods are actually transported with the shortest possible distance between the two points (i.e., as the crow flies). According to this metric, a highway network would be considered more efficient as the gap between the actual distance and the shortest possible distance

[41] Shirley, Chad, and Clifford Winston. "Firm Inventory Behavior and the Returns from Highway Infrastructure Investments." *Journal of Urban Economics 55, no. 2 (March 2004): 398-415.*,

narrows. For several two-digit industries, the impedance ratio was negatively related to plant-level productivity, suggesting that plants with access to highway systems that offer the most direct routes to

e. Spatial Correspondence

Another level of criticism against current research practices is the lack of spatial correspondence between the location of transportation infrastructure and the establishments using the infrastructure. The benefits from transportation infrastructure–roads, highways, rail–are location-specific. Businesses benefit from their proximity to highways, which provide access to local suppliers and customers and to the wider national network of highways. National-level, and even state-level, estimates do not provide precise geographical linkages between infrastructure facilities and business activities. For national-level estimates, it is typically assumed that the entire highway system affects national productivity. This assumption may be defensible at this broad level of aggregation in which all economic activity in the country is related to all the stock of public capital. One can also argue that the national-level measure of highways captures the system or network effect of the highway system. However, even if estimates based on national-level studies were credible, they are not very informative from a policy perspective.[42] Highway investment takes place on a project-by-project basis. State decision makers want to know how their investment will affect the economic health of their states.

The lack of spatial correspondence between highways and businesses within national-level studies becomes more problematic when individual industries are considered. The problem is that some industries are concentrated in specific parts of the country, such as of primary metal production or transportation equipment in the Great Lakes states. Therefore, national-level studies implicitly assume that highways in large states such as California and New York are as important to establishments located in Indiana or Rhode Island as they are to establishments located in those two states. Fernald (1999) suggests that estimation bias due to differences in the location manufacturing firms vis-a-vis highways could be substantial.

f. Measures of Highway Utilization

Another issue that has not been satisfactorily treated in the literature is the utilization of highways. Since capital stock is fixed, at least in the short run, businesses do not have the capability of adjusting the quantity of capital in response to short-run changes in demand for highway services. Therefore, while the quantity of highway capital may remain unchanged, businesses may use their fixed stock with different levels of intensity. To account for the variation in private capital utilization over time and across plants, researchers typically include a variable in the production function that proxies the utilization rate. Yet, researchers have not typically included a variable that accounts for the difference in utilization of highways. Fernald (1999) measures congestion as the ratio of miles driven by trucks, automobiles, and other motor vehicles to road stock (constructed using the perpetual inventory method). He shows that congestion measured in this way reduces productivity after 1973. Potentially

[42]Furthermore, in order for national level estimates to yield precise estimates, they rely on historical data. Therefore, since the relation between investment and output change over time most national level studies do not provide estimates of current relations.

better measures of congestion and service flow of highways are available from the HPMS data. Dalenberg and Eberts (1997) proposed a hybrid method of constructing highway capital stock which integrates highway characteristics into the perpetual inventory method.

Hulten (1994) notes that the partial public good nature of highways makes it even more important to include a highway utilization measure in the production function estimation. Fundamentally, the public good aspect of highways drives a wedge between the size of the highway capital stock and the size of the transportation service flows generated by the stock. Using highway stock as a proxy for highway services, assumes that they are proportional—a 10 percent increase in highway capital brings about a 10 percent increase in services. However, it is likely that the same stock of capital could generate two different levels of services if congestion differs significantly between the two sites.

Highway utilization takes two forms. The first is similar to the utilization of private capital. As product demand fluctuates in the short run, the firm's use of highway capital may fluctuate along with its use of private capital. In this case, the same variable used to adjust private capital stock for differences in use could be used to adjust highway capital stock. The second form of highway utilization is different, and is not captured by the variable measuring fluctuations in product demand. Businesses in different industries and in different parts of the country use highways with different intensities. For example, in Illinois, businesses in the food and kindred products industry ship 64 percent of their output by trucks, whereas establishments in the chemical industry ship 83 percent of their products by truck. Similar differences in the use of trucks are found regionally. For example, 60 percent of the commodities originating within Illinois are shipped by trucks, while 77 percent of the commodities originating within Michigan are shipped by trucks. Therefore, since businesses within industries and states use highways with different levels of intensity, treating highway capital stock the same across industries and states would misrepresent its contribution to economic activity.

g. Comparison of Estimated Output Elasticities

A study by Eberts (1999) explored various measures of highway capital stock in order to take into the issues discussed in the previous sections. He also examined factors that affect the magnitude of the output elasticities. Using a production function specification and capital stock constructed at the state level over time, he was able to estimate elasticities of output with respect to the various measures. Much more detail is available about the construction of the different measures of highway capital and the estimation methodologies and only a description of the results are offered here, primarily to show that there is considerable more work that can be done to better understand the contribution of highways, and other transport capital, to economic activity.

To examine factors that influence the magnitude of the contribution of highway capital stock to output, a small set of possible factors were considered: 1) the ratio of highway capital to private manufacturing capital; 2) the ratio of highway capital to manufacturing employment; 3) population (and population squared); 4) the ratio of highway capital stock to miles traveled; and 5) truck mileage as a percent of total miles traveled. The output elasticities with respect to highway capital (measured using PIM) were regressed against these factors. Essentially all of the factors that were used to explain variations in output elasticity with respect to highways can be considered measures of highway capacity or utilization. Overall, the results suggest that an increase in highway capacity (measured by highway per mile traveled and highways per employment) increases the contribution of highways to output. The effects of highway per miles traveled and highway per employment were both positive and statistically significant for estimates based on cross-state variation. Only highways per mile were statistically significant when the variation over time was considered. An increase in highway utilization (measured by population and percent trucks to total miles traveled) also increases the contribution of highways to output when the variation is across states. These two variables are statistically significant. However, when the variation is over time, these effects turn negative and remain statistically significant. The contrast between these two results may suggest that agglomeration economies, particularly as captured by the population variable, are related to the effect of highways output.

The same study also examined differences in output elasticities when highway capital stock estimates were adjusted for different measures of highway utilization based on statistics of truck usage obtained from the Commodity Flow Survey. In order to reflect the use of highways within a state, highway capital stock was adjusted by the percentage of goods produced in the state that were shipped by truck. The number of ton-miles was also used to make this adjustment. In order to account for the use of highways in other states, highway capital stock was adjusted by adding a weighted share of highways from other states to the state's highway system in which the production facility was located. The weights were based on tons shipped and ton-miles.

In both cases, the adjusted capital stock measures yielded different estimates of the output elasticity of highways. The utilization measure reduced the effective amount of highway capital used by firms resulting in higher estimates of the output elasticity of highways than found using the unadjusted highway measure. The spillover or network adjustment increased the effective highway capital stock for most states compared with the unadjusted highway stock. However, estimates of output elasticity with respect to highways varied widely using this adjustment depending upon whether it was based on tons shipped or ton-miles. The highway measure using ton-miles yielded an elasticity estimate that was lower than the one found using the unadjusted highway measure, while the adjusted highway measure based on tons yielded an elasticity estimate that was higher than the estimate using the unadjusted highway measure. The elasticity estimate using tons as the adjustment factor was much higher than any of the other estimates.

The study also compared output elasticities estimated using highway capital stock constructed using PIM with highway capital stock measured as lane miles. The output elasticities were estimated with a production function specification using cross-section time series data at the state level. The two measures of state highway capital stock were highly correlated with a cross-section correlation of 0.716. With the high correlation between the two measures, one would expect the output elasticity estimates to also be similar. On the contrary, the estimates were quite different. For the model specifications in which the PIM-measured highway capital was positive and statistically significant the output elasticity estimates using lane miles were negative and not statistically significant, except for one specification. Including highway factors in the regression along with the highway capital stock measure yielded output elasticity estimates that were positive and statistically significant for both measures of highway capital stock. One possible reason for the difference in estimates between the two types of highway measures is the different relationships between the two highway measures and the private capital measure. The private capital measure is computed using the same perpetual inventory method that was used to estimate the PIM-measured highway capital stock. Estimates of the output elasticity with respect to private capital are different under the various highway measures. When the PIM-measured highway capital stock is used, the estimate of private capital stock is 0.275, and when lane miles is used, the estimate is considerably higher: 0.404. This difference holds across the other specifications. It appears that the private capital stock measure is more highly correlated with the PIM-measured highway capital stock (correlation coefficient of 0.87) than with lane miles (correlation coefficient of 0.49). These results are similar to those found by Jones et al.[43] Using cross-section, time-series data at the state level, they estimated a production function with gross state product as output and found that lane miles were negatively related to output and under some specifications the coefficient was large, negative, and statistically significant.

D. General Equilibrium Approach

The general equilibrium approach is described in some detail because it attempts to estimate the broad effects of highways on both producers and consumers. This approach is similar to the production function approach in that it estimates the relationship between highway capital stock and a aggregate economic activity. It differs in that instead of using a production function model in which inputs and related to output it consider the household's willingness to pay for highway infrastructure. As a general equilibrium model, it brings into consideration the production of the goods consumed by the household, the distortionary effects of financing highway construction through taxes, and brings in other markets such as housing, other consumption and the use of motor vehicles. Therefore, this approach attempts to estimate much of what is included in the various elements that could be included in the benefit cost analysis. It also expands the effects beyond the production function by including households. This type of general equilibrium specification of the household willingness to pay function should not be confused with a computable general equilibrium approach which depends on a calibrated dynamic model based on estimates for various behavioral points in the model. They are considered an extension of input-output models in which prices are introduced to allow the model to be more flexible and dynamic than adhering to the rigid assumptions of fixed input-output ratios the factor demand is sensitive to changes in prices.

The paper by Mamuneas (2008) written for FHWA is one of the recent studies of the effects of highway infrastructure using the general equilibrium approach and will be described in some detail to illustrate this approach. This paper is also useful because it uses the recent version of the Fraumeni highway capital stock estimates. And even though this approach looks at the effect of an additional unit

[43] Jones, Donald W., Shaw-Pin Miaou, Russell Lee, and Scott Rickard, "Performance-Based Measures of the Transportation-Productivity Linkage," Oak Ridge National Laboratory, prepared for the Industry and Economic Analysis Branch, Transportation Studies Division, The Office of Policy Development, Federal Highway Administration, November 1995.

of highway capital stock, it is still interesting to compare Mamuneas' estimate of the marginal rate of return with Fraumeni's estimates of average rate of return. This comparison may not be that disjointed, since one would expect the two to converge as the highway system matures.

a. Methodology

Mamuneas's approach posits that consumers are the final beneficiaries of highway investment. An increase in highway infrastructure may increase transportation services such as shorter commuting times, more reliable arrival times, safer trips, and less wear and tear on privately owned vehicles. Increases in these benefits may be reflected in the consumption decisions of consumers, such as more leisure time, housing decisions (location and size of houses), purchase of motor vehicles, and transportation-related services primarily servicing privately-owned vehicles. Producers of private goods may also be affected by highway investment. Highways are considered an unpaid input in the production function, reducing the cost of production. Highways can also affect the use of other inputs and can expand scale by accessing greater market area. Therefore, highways affect the price of private inputs, which in turn ultimately affect the consumption decisions and well-being of consumers.

The methodology entails minimizing society's loss function due to extracting funds from the private sector to build highway infrastructure. This is a typical approach for evaluating the distorting effects of taxes on the economy. However, it may be better to think of the problem as one of maximizing the social welfare function subject to production relationships and government financing. The optimality conditions are the same, so even though the econometrics are more tractable, thinking of the results in this context may help provide a better understanding of their implications.

Investment Decisions Rules

The primary result of this approach, and of the paper, is to derive conditions for the optimal investment in highway infrastructure. The conditions state that the marginal social value of an additional unit of highway investment should equal the marginal social cost of producing a unit of highway investment. The marginal social value is the value each consumer places on an additional unit of highway investment, summed over all consumers. If the marginal social value is greater than the social marginal cost, then the quantity of highway infrastructure is less than desired (under built) and additional investment is warranted, according to the decision rules generated from this methodology. If the social marginal value is less than social marginal cost, then highway infrastructure is overbuilt, and no additional investment is warranted.

Estimating the Value and Cost of Highway Infrastructure

Estimating the contribution of highways to these consumption and production decisions is difficult. Typical benefit-cost analysis evaluating tangible outcomes, such as whether it is economically viable to produce a marketed good or service, uses market-determined prices as the basis to value benefits and costs. However, the value of highways is less tangible and is not priced by the market. Therefore, the value has to be imputed by estimating how highway investment changes consumption and production decisions, either through changes in relative prices or through changes in consumer income. This approach estimates shadow prices for highway investment, which estimate a consumer's willingness to pay for an additional unit of highways.

In addition, the fact that highways are financed through a tax on motor fuel can distort economic decisions, leading to additional social costs. The distortionary effects must also be factored into the social marginal cost of providing an additional unit of highway, which Mamuneas includes in the analysis.[44]

In order to estimate social marginal value (consumers' willingness to pay) of highway capital stock, Mamuneas estimates an expenditure function with housing, motor vehicles, transportation services, residual consumption, and leisure as elements of a representative consumer's well-being. This results in estimates of the marginal benefit of highways to consumers.

Mamuneas also estimates a profit function in order to estimate the effect of highway infrastructure on the cost and thus the price of each of these consumption items. Highway-induced changes in price also affect consumer consumption decisions and their well-being.

The crux of Mamuneas's methodology is to derive the optimality condition for highway capital investment for the whole national economy. The optimality condition states that the social marginal benefit of capital (for both consumers and producers) equals the social marginal cost. The marginal benefit for consumers is the amount the consumer would be willing to pay (in the form of reduced consumption) to receive an additional unit (dollar) of highways capital stock. Conversely, it is the amount the consumer would need to be compensated for one less unit of highway capital stock. For the producer, the marginal benefit is the increase in profits (or reduction in costs, holding output constant) resulting from a unit increase in highway capital stock.

The marginal benefit equations are derived from an expenditure function for consumers and a profit function for producers. Taking the derivative of each function with respect to highway capital stock yields the marginal benefit equation. What drives the model is the variation over time in highway capital, prices of outputs and inputs, and a quadratic time trend. Both the expenditure function and profit function are nonlinear in the key variables, and so are the marginal benefit functions. Therefore, the relationships are quite complex. The estimates of the parameters are also constrained by conditions that must hold in order for the functional forms to make economic sense in reflecting expenditure functions and profit functions.

Econometric Issues

Estimating the social marginal value and social marginal costs is difficult. It is difficult to assemble the appropriate variables to provide a sufficiently complete coverage of consumer and producer decisions while providing the detail necessary to show the effects of highways on these decisions, which

[44] It appears that Mamuneas includes more taxes than fuel taxes in constructing the distortionary factor. He defines the distortionary factor as "the deadweight loss associated with the financing of public infrastructure capital" (p. 41). He includes taxes in this factor that are not used to finance highways, which may distort the computation of the rate of return of highway capital stock.

can be quite subtle. There are also econometric concerns when using time series data to estimate expenditure functions and profit functions. These problems have been well-documented in the literature, particularly the literature on estimating the effect of highways on production relationships. Since the critical result of the paper is to determine if two imputed numbers—social marginal value and social marginal cost—are close to being equal, the precision of these estimates is critical. Issues regarding the stationarity of time series data, particularly GDP-related variables, have been well-documented and have been shown to lead to spurious correlation and inflated estimates of precision. In addition, the endogeneity of input prices and the strong correlation among these prices can lead to inconsistent estimates that distort the estimates of social marginal value and marginal costs. Mamuneas addresses these issues in the estimation using several econometric approaches.[45]

b. Results

Mamuneas finds that from 1949 through 2005, the net rate of return of highways averages 28.7 percent. However, for both consumers and producers the gross rate of return is much smaller in recent years as the highway system matures. As shown in figure 5, except for the first 20 years of the estimates, the gross rate of return of highways to producers generally declines, and the gross rate of return of highways for consumers declines throughout the entire period, except for an uptick in the early 1990s followed by a decline in the 2000s. He compares this rate with the return on private capital (as reflected in interest rate on the 10-year U.S. Treasury security) averaged over the same time period. Finding that the net rate of return on highways (28.7 percent) is higher than the average long-term interest rate (6.2 percent), he concludes that highways make a contribution to the economy and the country has been underinvested in highway capital stock until recently when the net rate of return fell below the interest rate, as shown in figure 6.

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[45] Hsiao, G., 1997, "Statistical Properties of the Two-Stage Least Squares Estimator under Cointegration," *Review of Economic Studies*, 64, 385-398. "In a structural approach one needs to worry about the issues of identification and simultaneity bias, but one need not worry about the issues of nonstationarity and cointegration. All one needs to do in structural model building is to follow the conventional wisdom." (Hsiao 1997, p. 395

Figure 5. Gross Rate of Return of Highways to Consumers and Producers

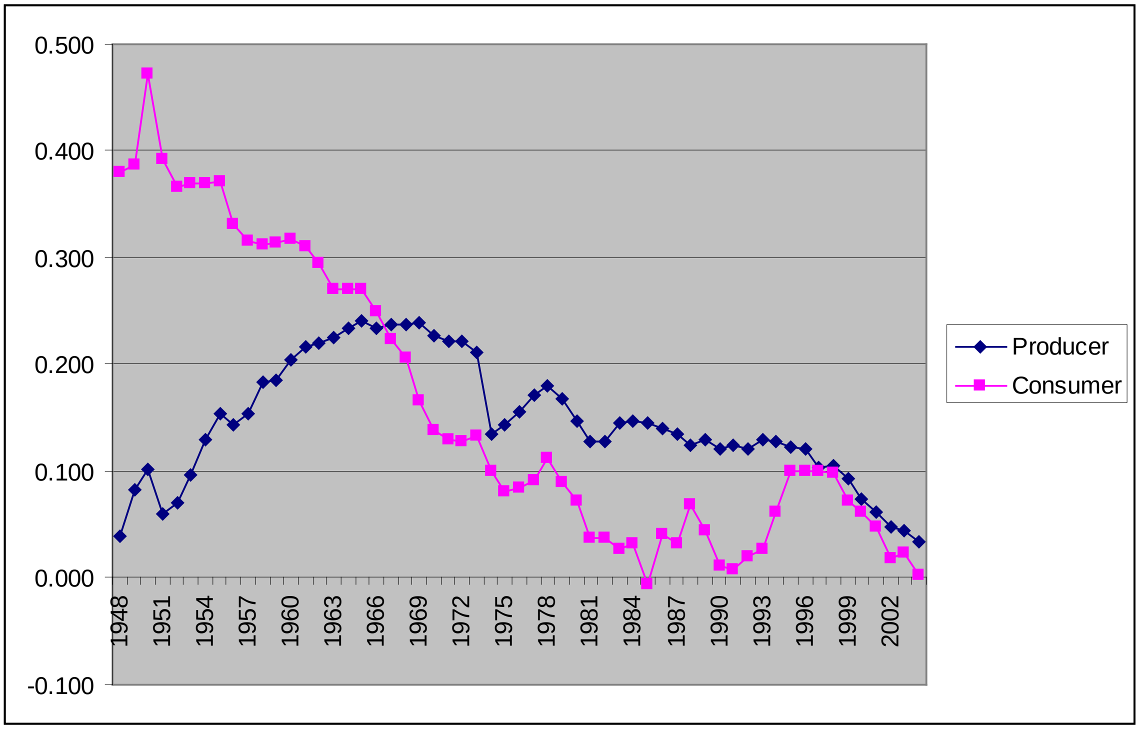
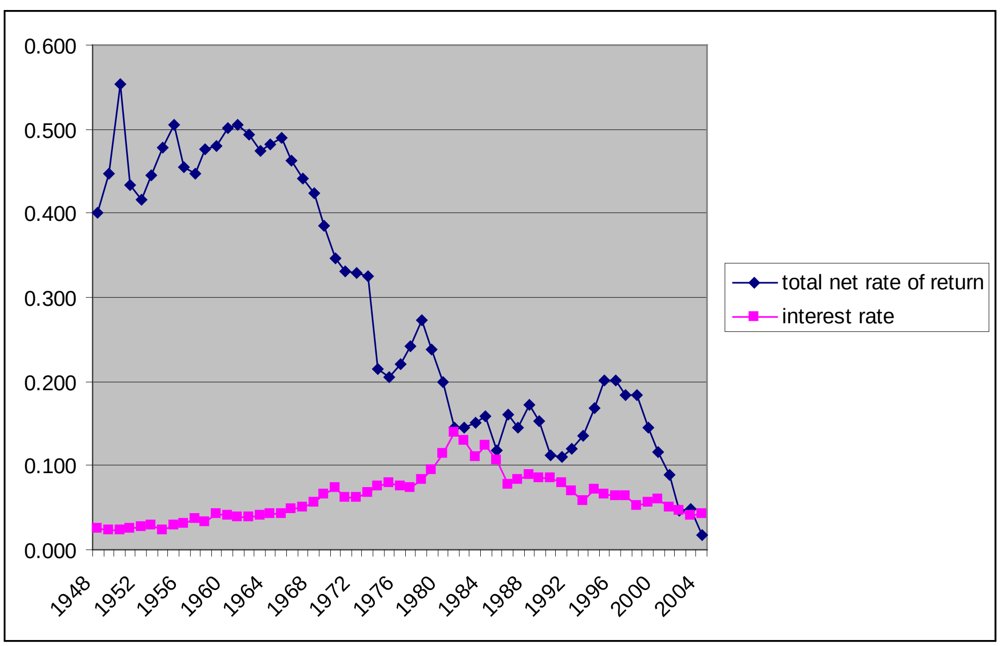


Figure 6. Net Rate of Return of Highways and Interest Rates



Source: Author's calculations of Mamuneas's data.

E. Contribution of Highways to GDP through National Accounts

Through the national income accounts and the creation of productive highway capital stock, the value of existing highway capital stock can be estimated. Fraumeni (2007) describes the methodology to do this as well as to address two related questions. The three contributions are described in sequence beginning with the economic activity generated in constructing highway capital stock and ending with the contribution of highway capital stock to national output. Fraumeni (2007) estimates these contributions using her updated highway capital stock estimates. The results are shown in table 12. It should be noted that while the national income accounts can be used to relate highway capital stock to output, the national accounts do not consider network externalities as described by Hulten nor do they incorporate economies of scale, agglomeration or spillovers. Therefore, these estimates include only those indirect effects that are internalized by the market.

1) The contribution of highway investment (capital outlays) to growth in GDP.

This contribution measures the economic activity of constructing the highway capital stock each year. It includes major durable additions or changes to the existing highway stock and new construction or reconstruction and other than new construction or reconstruction (Fraumeni, p. 35). As displayed in column 2 of the table, the production of highways takes little of the U.S. GDP to produce highways, or conversely, the contribution of highways to economic growth is very small, accounting for only one one-hundreth (0.01) of GDP growth from 1930 through 2005. The largest impact was during the Great Depression of the 1930s in which highway construction was used as an economic stimulus and welfare program and during the beginning of construction of the interstate highway system in the 1950s.

2) The contribution of highway gross output to adjusted U.S. gross output.

In this second case, government can be thought of as an industry that produces highway services for use by other sectors and for its own use. The analogy here is for highways to be considered as one of several inputs in the production of highway services the same way a machine is used along with labor and other inputs to produce another product. Estimates of the second relationship suggest that constructed highway capital accounts for half of gross output of the highway services, by far the largest share of inputs into the production of highway services. Fraumeni points out that the nominal share of capital input in value-added GDP is typically 40 percent and the nominal share of labor is 60 percent. Clearly, highway capital, compared with the other inputs of labor and capital other than highways, is by far the largest input in the production of highway transportation services (Fraumeni, 2007, p. 51).

3) The contribution of highway gross output to growth in adjusted U.S. gross output.

This relationship considers the contribution of the services derived from the highway capital stock to the economy. Production from business, nonprofit, and government sectors is considered in this estimation. Since this approach focuses on the use of highways by producers, the household sector is not included, except in the form of owner-occupied housing. Also, externalities such as expansion of economies of scale or increased agglomeration economies are not included in these estimates, since they are not included in national income accounts. The third relationship estimates the average net return to highway capital stock. Fraumeni's approach to estimating the average net rate of return is to look at the growth in highway capital input and GDP over time, based on assumptions about the rate of return of government assets.   As displayed in table 12, she estimates the contribution to GDP growth of the services from highway capital stock at 4.7 percent for the period 1930-2005, using mid-range assumption regarding the net return to government assets (Fraumeni. 2007, p. 48). Fraumeni chose a net return to private assets of 11 percent and a net return to government assets of 4.4 percent, which is consistent with BEA estimates. The government and private rate is the average of the two (p. 45).

Table 12. Contributions of Highways to National Output

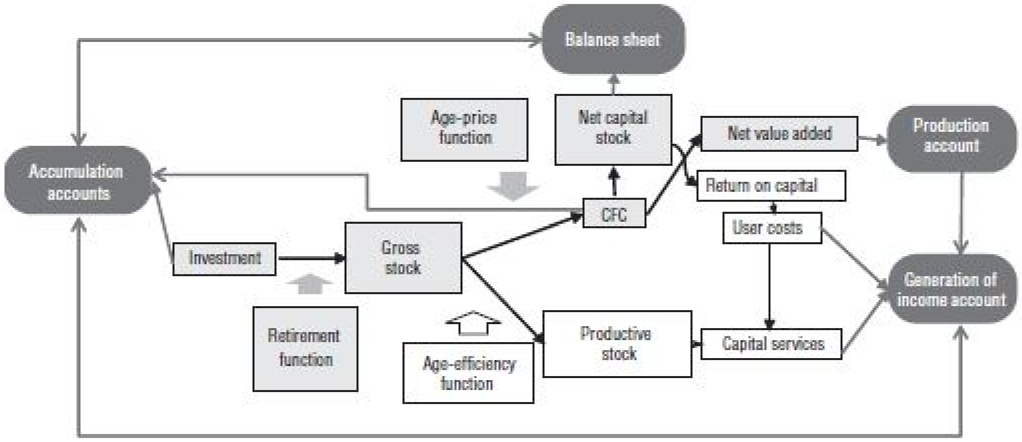
Year	Contribution 1	Contribution 2			Contribution 3		
		Assumed rate of return			Assumed rate of return		
		A	B	C	A	B	C
1930-39	.09				.09	.09	.17
1940-49	-.01				.01	.01	.02
1950-59	.11				.03	.03	.05
1960-69	.02	.04	.06	.06	.05	.10	.11
1970-79	-.02	.02	.03	.04	.03	.06	.07
1980-89	.01	.01	.01	.01	.01	.02	.02
1990-99	.02	.01	.02	.02	.02	.03	.03
2000-2005	-.01	.01	.02	.03	.02	.04	.04
1930-2005	.029				.034	.047	.066
1950-2005	.024				.028	.046	.055

Source: Fraumeni, 2007

Note: A: Government rate only; B: government and private rate; C: private rate only

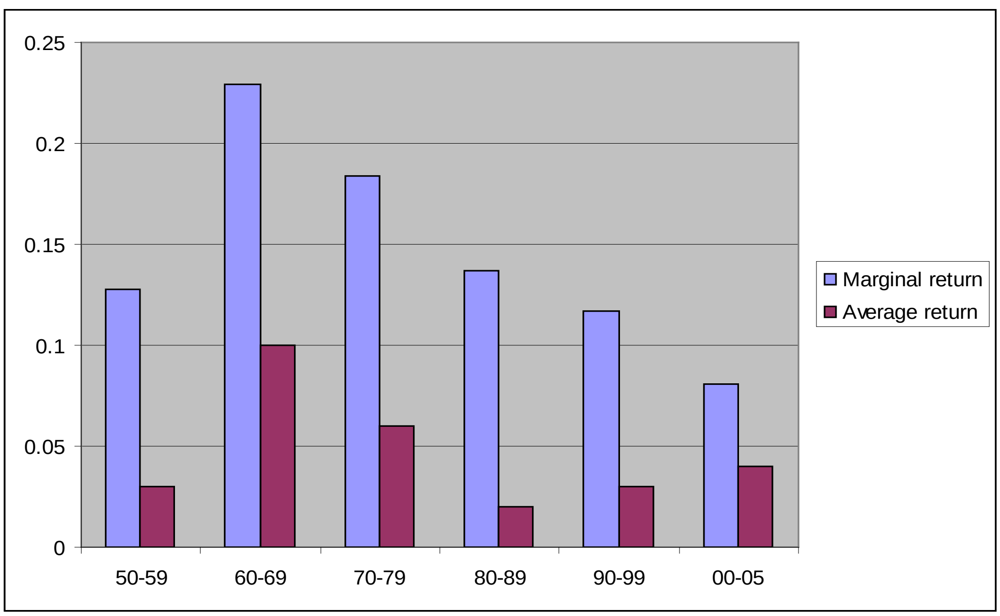
Figure 7 depicts capital measures in a system of accounts, such as the national income accounts. Three flows are important with respect to highways. One is the contribution to production of highway assets, another is the decline in the value of the highway asset, and the third is the income generated by the highway asset. Obviously the middle term corresponds to consumption of fixed capital as normally understood in the system of national accounts. The contribution of capital to production is what is called gross operating surplus and so the third flow, income, corresponds fittingly to net operating surplus. However, these flows can also be described by alternative terminology. The contribution of highways to production, is also known as the value of highway capital services. The income element is the return to capital. The rate of return on capital is the ratio of income to the value of capital (United Nations, System of National Accounts, 2008, p. 417).

Figure 7. Capital Measures in a System of Accounts



Comparing the net return of highways of both consumers and producers with the interest rates, it would appear that only in the past few years has the highway system matured and the optimal level has been reached. Using the user-cost version of the rule would suggest instead that the highway system matured in the 1980s and that it has remained at the optimal level until recently when it appears that the system may be overbuilt.

Figure 8. Average Net Return versus Net Rate of Return



Source: Fraumeni (2007) and Mamuneas (2008)

Fraumeni (2007) distinguishes between the two questions by stating: “An average net rate of return should be applied to the total capital stock; a marginal net rate of return should be applied to the last dollar of capital outlay, which is the marginal increment to the capital stock” (p. 46). Mamuneas (2008) and his previous work use a marginal approach. She adds that “recognizing the essential difference between the two net rates of return explains in part why the Nadiri and Mamuneus estimated net rates of return are so high when the Interstate System was being built" (p. 46). The average net return represents a highway system as a steady and dependable input in the production process. Her approach to estimating the average net rate of return is to look at the growth in highway capital input and GDP over time and including assumptions about the rate of return of government assets.

As shown in figure 8, the average rates estimated by Fraumeni and the net rate of returns estimated with Mamuneas's marginal approach follow similar patterns until the last two time periods when the average returns start to increase. In addition, the levels are quite different, as stated previously.

Estimating the net rate of the return of the last dollar invested in highway capital stock raises a host of other issues. Highway investment takes place in specific locations that have specific characteristics, such as congestion, growth, proximity to firms and consumers, connectivity to highway networks, all of which can affect the rate of return of that particular investment. That additional dollar may be invested in a location one year in which the conditions are more favorable for positive impacts than it is in another year. For instance, as the interstate was developed, the benefits of relieving bottlenecks in the Northeast corridor may have produced greater economic benefits than connecting Denver with Omaha. Furthermore, as the interstate system became more connected, the benefits also multiplied. The location of projects and the type of investments change each year. Finding a net rate of return to describe on average the economic benefit of the last dollar invested is therefore difficult.

F. Input-Output Models

A shortcoming of the national income accounts is that the contribution of highway capital cannot be estimated for individual industries. Input-output models offer the ability to estimate the effect of infrastructure expenditures and service output on the output of individual industries. Input-output models can also estimate the direct effects and multiplier effects of activity within the transportation sector on other industries. This methodology is typically used to estimate the employment effects of highway construction.

a. Transportation Satellite Accounts

To more accurately measure transportation services, the Bureau of Transportation Statistics (BTS) of the U.S. Department of Transportation and the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce, jointly developed the Transportation Satellite Accounts (TSAs). The TSAs, as a supplement to the U.S. Input-Output (I-O) Accounts, measure the contribution of both for-hire and in-house transportation. The TSAs include all seven of the for-hire transportation industries reported in the U.S. I-O accounts and five in-house transportation modes. Four of the five in-house transportation modes are related to business activities and one is related to household activity. Household transportation covers transportation provided by households for their own use through the use of an automobile and is a new component of the TSAs.

The Transportation Satellite Accounts (TSAs) provide a means for measuring the contribution of transportation services to the national economy. Specifically, the TSAs show a more complete picture of the:

- Contribution of transportation to the gross domestic product,
- Use of transportation by industry,
- Cost of transportation services in producing goods, and
- Direct and indirect effects of transportation on the economy.

More specifically, the TSAs provide a way to answer questions such as:

- How much do transportation services (both for-hire and in-house) contribute to U.S. gross domestic output and gross domestic product?
- What industries rely heavily on transportation services, and what modes do these industries depend more heavily on?
- What transportation costs do industries incur during production?
- What is transportation's share in the total cost of commodities purchased by consumers and other end-users?
- How much must transportation services increase to meet an increase in the final demand of particular goods and services?

The TSAs currently are available for 1992, 1997, and 2002, the years corresponding to the release of the five-year Census which is required to estimate the relationships between the various sectors.

For I-O models, such as the TSAs, capital stock is not directly entered into the calculations. I-O tables relate the output from one sector as inputs into another sector, or vice versa. Consequently, the output of the various transportation sectors included in the TSAs are related to the other sectors as inputs or purchased services. The effects of the assumed service flow from highway capital stock can be included in the I-O similar to Fraumeni's approach of estimating the effect of highway stock in the national income accounts. Rates of return are assumed and then used to estimate the flow of services from the existing capital stock for each year.

b. Regional I-O and Econometric Models

The TSA accounts provide additional information than what the national accounts can provide. The TSA considers the direct and indirect effect of expenditures on transportation services, whereas the national accounts consider only the direct effects. The TSA accounts provide an estimation of the direct and indirect effects of transportation expenditures on individual industries and other sectors of the economy. The national accounts cannot apportion the contribution of transportation services to individual sectors.

Regional I-O models provide a level of spatial disaggregation by offering tools to estimate the direct and indirect effects of transportation-related expenditures at the regional and local level, which typically is disaggregated to the county level. Three models are typically used: RIMS II (developed and maintained by the U.S. Department of Commerce), IMPLAN (a modestly priced privately provided package), and REMI (a much more complex and expensive modeling package). Availability of RIMS II through the U.S. Department of Commerce Bureau of Economic Analysis has been discontinued because of sequestration and reduction in FY2013 funding levels. Unless funding is restored at some future date, RIMS II will not be available.

Both IMPLAN and REMI are computer software packages that provide a host of options in specifying models and storing results. In addition, REMI offers a neoclassical econometric system that allows for the estimation of additional indirect effects such as agglomeration effects. Despite similarities in methodologies and data sources for IMPLAN and REMI's IO models, the results are different. A study sponsored by USDOT compared the results derived from IMPLAN and REMI for an identical project and found that results varied. For a project related to transit, output effects under REMI were twice the effects under RIMS II. For another project related to rail, the output effects of the RIMS II and REMI were nearly identical.[46]

While the estimated impacts may vary across the available models, adoption of any one package provides consistency in the methodology and basic data across applications. For instance, if states wanted to coordinate their approaches in analyzing the effects (direct and indirect) of highway construction or improvements across the highway system, then each state would adopt the same model and coordinate their use so that any parameter assumptions and scope of effects would be aligned across the network.

It should be noted, however, that none of these models accounts for the effects of transport capital directly. Rather, they account for expenditures during a specific time period. Only when rates of return on transport capital are assumed, such as Fraumeni used when estimating the contribution of highway capital to GDP, can the service flows from highway capital stock be incorporated into these models based on national income accounts or I-O tables.

[46] Tim Lynch, "Analyzing the Economic Impact of Transportation Projects using RIMS II, IMPLAN, and REMI," Florida State University, Institute for Science and Public Affairs, October 2000.

VIII. SUMMARY

This paper has reviewed the issues with valuing transportation infrastructure based on the public good and network characteristics of transportation systems and the far-ranging effects these systems have on the economy and society. Four methods used to value transport infrastructure have been described and compared.

1. Value the highway capital stock and maintain the quantity and quality of the infrastructure to the standards established when it was built.

   This requires estimates of highway capital stock, measures of the wear and tear and retirement of the stock, and the obsolescence due to outdated standards or technology. Investment decisions are based on the maintenance and construction costs necessary to restore the highways to their original state. Cost estimates are based on current construction costs necessary to maintain engineering standards. Accurate accounting depends upon comprehensive measures of the physical state of the infrastructure, well established engineering standards, and the costs associated with maintaining those standards.

   - The advantage of this approach is that much research has been devoted to the engineering aspects of highways, standards are well established, and costing out projects is a standard procedure.
   - The disadvantage is that this approach says nothing about the value to society of the infrastructure itself, except to assume that it had value when the decision was made to build that infrastructure and the value remains the same, if not more.

2. Value highway capital based on growth contributions.

   This approach estimates the value of existing capital stock by relating it to national output derived from national income accounts. The analysis yields an average rate of return of existing highway capital stock.

   - The advantage of this approach is that it ties directly with national income accounts, which follow prescribed and widely accepted methodologies and are based on rigorously collected and scrutinized data.
   - The disadvantage in this approach considers the value of highway capital stock in place and not the marginal value of an additional unit of highway capital, which is critical for investment decisions. This may be less of an issue for a mature system, but it still does not help with investment decisions related to segments of the highway system.
   - Another disadvantage is that the highway capital stock must be estimated accurately, which requires detailed information on highway performance, deterioration, and obsolescence. Such information is not consistently available across all highway segments. Furthermore, national highway capital estimates do not provide the detail to capture the network characteristics of the highway system nor its utilization. Accurate estimates of highway

capital stock at the state and metropolitan levels would be necessary to begin to reflect the network nature of highways.

- A third disadvantage is this approach does not take into account indirect effects of highways resulting from externalities, which could be significant.

3. Use benefit cost analysis to assess the impact on welfare of new infrastructure projects.

   This approach aims at monetizing all possible outcomes of infrastructure over the life of an infrastructure project. It involves both market and non-market evaluations, and non-market evaluations are based on shadow prices derived by using various techniques.

   - An advantage of this approach is that it clearly lays out the various direct and indirect benefits included in the analysis.
   - A disadvantage is that each benefit (or cost) requires a credible and acceptable value. Some benefits are more difficult to estimate than others and may be based on studies that are not related to the highway segment under consideration. Some of these concerns can be mitigated by providing very detailed guidelines stating a common definition of each element, prescribing metrics for the element, indicating when to use it, describing how to calculate it, and listing the data necessary to carry out the estimation. The UK has established such a system and it offers common procedures to value infrastructure across all projects. A report recently released by TRB (SHRP) also provides detailed guidance on including and constructing wider benefits of highways.
   - Another disadvantage is the extensive data requirements, particularly at the subnational level. A greater emphasis on coordinating the collection of subnational data could help address this requirement. It would be convenient to collect micro-level data that could be aggregated in a variety of ways to suit the analysis under consideration.

4. Value transport infrastructure by using a production function approach to estimate the indirect benefits based on the social efficiency of service provision.

   One can also use a general equilibrium approach which widens even further the effects, positive and negative, of highway infrastructure. This approach aims to capture all the benefits related to highways without delineating which benefits are included or how important they are to the total estimated effects.

   - The advantage of this approach is that by assuming it captures all benefits, direct and indirect, household and producer, one can estimate the net marginal social benefits and costs and use these estimates to calculate the optimal investment rules.
   - A disadvantage is that one does not know from the analysis which benefits are actually included in the analysis and their importance to the overall estimates. Because of this lack of identifying the elements, it is difficult to scrutinize the analysis and compare the various elements across studies and more importantly their use across project evaluations.

- Another disadvantage is the extensive data requirements. Furthermore, the data requirements and the model specifications do not lend themselves to estimating these structures at the local level, evidenced by the wide difference in estimates by the various studies.

No one approach has a clear advantage over the others. Two address different questions that are not squarely related to investment decisions. All have extensive data requirements, and despite the years of researching this issue and the hundreds of studies estimating these effects, no one approach captures all the benefits of highways or all the public good and network characteristics of highway infrastructure. Economic theory, in fact, tells us that there is no single estimate of the value of transportation infrastructure, because of its network characteristics and public good aspects. Consequently, one cannot expect to find that one ideal estimate of the effect of transportation infrastructure. However, the richness of the research to date and our clearer understanding of how public infrastructure relates to economic and social outcomes allow us to tailor the estimates to various circumstances.

It appears to be time to take stock in what we do know and follow the lead of the UK and the continued efforts in the US to prescribe procedures to estimate the value of the direct and indirect benefits that are likely to have significant effects. To do this, one starts with an accepted framework of what elements should be included in a benefit cost analysis. Guidelines would be established on the definitions of these elements, what metrics to use, and when and where to include these elements. A detailed methodology would be prescribed for estimating the valuation of these elements based on the best research but also taking into account the practicality of estimating the values for specific projects with the data available. The guidelines would also include the exact data that is necessary to implement the model and where to find it.

Once the guidelines have been determined, a coordinated effort among all levels of government, and even the private sector, is needed to compile data across the highway network at a disaggregate level so that the data can be flexible and used for evaluating projects at the state or metropolitan level and even various segments of highways.

This approach of modeling the effects of transport infrastructure and creating guidelines on how to construct the estimates is still best applied at the project level or perhaps at the subnational level. The macroeconomic approach of estimating production functions or a more general equilibrium approach, as conducted by Nadiri and Mamuneas, is still the best approach for estimating the value of transport capital to the country as a whole or for major regions. The same recommendation holds for the macroeconomic approach as for the microeconomic approach: recommendations as to the best models to be used for what purposes and a concerted effort should be made to provide the best possible estimates of highway capital stock that takes into account the issues of utilization, network characteristics and other characteristics inherent to transport capital stock. Much research has been conducted in estimating the effects of highway capital stock under various model specifications and levels of aggregation of the data, but few have tried to compare these estimates and issues using a consistent set of data, similar to what Eberts

(1999) attempted. Also, transport capital stock estimates have not received the attention needed, particularly at the subnational levels, to provide a credible estimate for of the capital stock. More precise and regionally based measures of highway retirement patterns, efficiency patterns, price deflators need to be developed.

These concerns and recommendations echo that of a conference nearly 15 years ago that agreed that:

- Steps should be taken to ensure that all transportation data would have unquestionable validity and objectivity, so that transportation policy debates would not be marred by unproductive squabbles over the quality of the information,"
- It was much better to reduce data burdens, not by reducing data, but by more closely aligning the intergovernmental transportation goals of the federal, state, and local transportation agencies, and integrating the performance measures of those agencies to meet their similar management goals.
- All the data required should be natural by-products of the data needed for managing their programs effectively, efficiently, and equitably, and being held accountable for program results. Only if managers and their constituencies are relying on those same data to help achieve desired performance and results can others be assured that the data are accurate.[47]

The US is not alone in the need for better and more coordinated data collection. A recent OCED study on the performance of road transport infrastructure finds significant problems with data availability, coverage, quality and comparability across countries.[48] More specifically, the report claims that there is a complete lack of data on some dimensions such as connectivity, partial coverage of data on travel time, for example, or limited comparability for investment and maintenance expenditures. It appears from past and present deliberations on this topic that the profession knows what to do; it is now a problem simply of making the concerted effort to do it. Perhaps the requirements of MAP-21 will be the catalyst.

[47] "Information Needs to Support State and Local Transportation Decision Making into the 21st Century," Transportation Research Board, Conference Proceedings 14, 1997.
[48] Braconier, H., M. Pisu, D. Bloch, "The Performance of Road Transport Infrastructure and its Links to Policies", OECD Economics Department Working Paper, No. 1016 (2013)

APPENDIX: OUTLINE OF RESPONSES TO THE QUESTIONS RAISED BY TASK FORCE

The Task Force posed six questions related to the methodologies and data requirements for the proper valuation of transportation infrastructure. The White Paper addressed these questions but was not organized explicitly by question. This appendix offers a succinct summary of the responses by the White Paper to these questions, although the paper goes into greater detail on many of the points listed here.

1. What are the public and private decisions that would be informed by statistics on the value of transportation?

The public decisions informed by statistics on the value of transportation are divided into macroeconomic decisions and microeconomic decisions. The macroeconomic decisions cover national or state policy and would be most pertinent for the U.S. Congress and state legislatures with respect to:

- The level of financing of infrastructure projects
- Funding/incentivizing specific functions and types of investment
- The optimal tax structure to finance infrastructure projects: user fees, general taxes, tolls, public-private partnerships
- Environmental and social effects, which are external to users.

Microeconomic decisions include decisions that state Departments of Transportation and local Metropolitan Planning Organizations would make regarding:

- The transport projects to undertake, including intermodal
- Asset management decisions
- Performance targeting requirements under MAP-21.

Private decisions relate to those made by the users of transport infrastructure as well as those who produce the rolling stock (cars, trucks, planes, ships, trains) that use the highways. A list of decisions by these groups might include:

- When, where, and how much should direct users use transport capital
- Users of transport infrastructure (auto makers, aircraft makers, shipbuilders)
- Guidance/information technology to improve efficient use infrastructure and reliability of travel time
- Safety technology to help prevent accidents and save lives when accidents occur
- Ensure technology for warning and guidance devices is compatible with transport infrastructure features
- Private-Public Partnerships
- Decide when to enter into P3 concessions
- Monitor revenue and costs, including the use of transport infrastructure (highways) for fee schedule, etc.
- Monitor transport performance and conditions.

2. What is the state of practice for generating value statistics in response to each of the types of decisions?

The state of practice for generating value statistics has not changed much in the past decade, with a few exceptions. Probably the biggest change has taken place with including wider benefits in benefit cost methodologies. Typically, benefit cost analyses focus on the benefits to direct users with respect to travel time and safety. However, guidelines and methodologies have been established recently to include benefits related to externalities and spillovers into the analyses. The UK, with the Eddington Report, and the US, with the SHRP, have spelled out the type of wider benefits that may be appropriate to include in the analyses, under what conditions they should be included, methods and data required to estimate them, and even estimates of the benefits that can be inserted in the analysis. For the macroeconomic models, the general equilibrium approach that includes households and producers has broadened the coverage of benefits to include more of the economic effects. Researchers are still trying to understand how to include spillovers and externalities in econometric specifications, which requires much more detailed data on transport capital stock than is typically collected or generated.

3. What are the criteria for identifying best practice, and how does the state of practice measure up?

The criteria for identifying best practice in valuing transportation infrastructure relates basically to three issues: 1) Do the methodologies include the full set of economic benefits that correspond to the asset (or system) being analyzed; 2) Are the estimates based on credible data; and 3) Can the results be understood by the decision makers?

The state of the use of benefit cost analysis can be summarized by the following:

- Well established approach for assessing single projects but not standardized across states with respect to the benefits included and how to calculate them, particularly wider benefits
- Difficult to use BCA to address value of entire system—too many missing benefits
- Requires a well-defined model that lays out linkages between asset use and types of benefits, which at times is not well-articulated
- Need link to broader econometric models
- Recent guidance is helpful by being more prescriptive and methodologies more detailed
- Still difficult to compare across projects

The state of macroeconomic approaches, such as those based on production function estimation and general equilibrium approaches, is still primarily within the realm of researchers and are difficult for decision makers to understand. One problem is that many econometric approaches do not lay out the various channels of by which transportation infrastructure can influence economic activity, particularly when it comes to describing the wider benefits. Furthermore, many studies still rely on national level data, which are not well suited for estimating specific features of the network effects of transportation systems. More specifically, highway capital stock estimates need to be refined and updated with more location-specific data by state, better estimates of efficiency patterns, and regionally based price deflators. Better measures of physical features of capital and cost per feature would be helpful, not only for macroeconomic methodologies but also for benefit cost analyses.

4. What decisions are not being answered or are being answered poorly by current practice?

To respond to this question, a few issues raised in more detail in the White Paper are listed with respect to asset management, project selection, and optimal investment decisions.

- Asset management
    - Optimal allocation of resources between maintenance and investment could be addressed more completely, particularly addressed across modes
    - Performance measures need to be linked more closely to benefits
    - Better coordination of decisions and harmonization of standards and methodologies within transportation networks (across states and MPOs)

- Project selection
    - Concern that benefit-cost analysis does not capture all relevant benefits
    - Thus, some worthy projects may not pass the BCA ratio
    - Comparisons difficult across projects and across modes, so decisions regarding optimal modal configurations are not being answered

- Optimal investment
    - Benefit-cost analysis does not capture all benefits from transportation network
    - Macroeconomic estimation not well understood by policy makers
    - Typically a "black box" which does not delineate the different channels through which infrastructure investment affects economic activity
    - It is difficult to scrutinize the results and compare the various elements across studies
    - Consequently, questions regarding the optimal investment of transport capital are being addressed poorly

5. What are current data sources for statistics on value, and are those sources being tapped fully?

US Census Sources

- The American Community Survey (ACS) is the primary dataset for social characteristics in the United States. The ACS is based on a survey of one percent of the population. The ACS uses multi-year averages for counties smaller than 50,000 people.
- Quarterly Workforce Indicators (QWI) are based on unemployment insurance records (UI) and contain data on employment, job creation, net job gain, average wages by industry. There is a roughly 12-month lag on the data and the data contain only UI-covered employment (meaning no self-employed).
- On-the-Map is a combination of UI records and ACS records to determine commuting and other characteristics by both place of residence and place of work. This source is the only one that allows user to generate block-to-block commuting.
- The Commodity Flow Survey is a survey of freight shipments for mining, manufacturing, and selected services. The survey is every five years with 2012 the most recent.

- County Business Patterns (CBP) is an annual series that provides subnational economic data by industry. This series includes the number of establishments, employment during the week of March 12, first quarter payroll, and annual payroll.
- Census and Surveys of various business sectors provides information on industry-level output and inputs

Bureau of Labor Statistics (BLS) Sources

- BLS Quarterly Census of Employment and Wages (QCEW) is a UI-records based dataset that contains employment, wages, establishments by industry. The lag is seven months and it contains every county in the United States.
- The Current Employment Statistics (CES) is a business survey that has a lag of less than two months for states and metropolitan statistical areas. Data contain employment and wages by industry.
- The Occupational Employment Survey (OES) contains data on employment and wages by occupation for metropolitan statistical areas and states. Data are for come out yearly and are a three-year average.
- Local Area Unemployment Statistics (LAUS) is a personal survey of labor force status of individuals by place of residence. Data have a six-week lag at the county level.
- America Time Use Survey measures the amount of time people spend doing various activities, such as paid work, childcare, volunteering, and socializing.

Bureau of Economic Analysis (BEA), Department of Commerce

- National income accounts
- Satellite accounts
- Input-Output Accounts
- Tradestats Express (TSE) contains data on imports and exports at the national level and exports at the state level. Data are annual from 1999 to 2013.

6. What methods for estimating value used outside the US might be applied to the US with existing data?

The practice in the UK of identifying and estimating wider benefits is probably the newest practice worth considering and it is already being emulated in the US under the SHRP 2 Capacity project. The UK practice, which was introduced with the Eddington Report under the nomenclature "Value of Money," raises awareness of wider benefits not typically included in benefit cost analyses. The UK Department of Transport developed detailed guidelines for estimating wider benefits (TAG Units), which define the specific effects, describe how to estimate the effects, show how to conduct sensitivity test, list the data required, and show how to incorporate the effects into the decision tool. The TAG Units also provide software tools to help with the analysis. The US has developed something similar to the TAG units under SHRP 2 Capacity Project, which even provides software tools and a database of post-project evaluations.