Economic Development
RESEARCH GROUP

NCHRP Project 2-24
Economic Productivity & Transportation Investment

Task 1 Literature Review, Stakeholder Perspectives and Framework Outline

Prepared for:

National Cooperative Highway Research Program
Transportation Research Board, National Research Council
Washington, DC

Prepared by:

Economic Development Research Group, Inc.
Systems Metric Group, Inc.
University of Leeds
David Simmonds Consultancy, Ltd.
Prime Focus, LLC
Consultants: Roger Vickerman and David Gillen

Revised, February 19, 2013

Table of Contents

Preface and Acknowledgements

Preface. This report is an interim deliverable produced as part of the National Cooperative Highway Research Program, project 02-24, entitled: *Economic Productivity and Transportation Investment Priorities*. The project is intended "to develop a methodology and guide for incorporating productivity gains in analysis and prioritization of transportation investments. The methodology and guide will encourage DOTs and other agencies to apply consistent analysis methods and produce results that facilitate public decision making about transportation improvement priorities within a state or other large region." It covers the first of the following three elements:

1) Conduct a critical review of literature on the links between transportation system performance and economic productivity, including theoretical research and empirical studies and micro- as well as macro-economic perspectives.
2) Develop a methodology for analysis of productivity effects of transportation system improvements.
3) Prepare a guide for incorporating productivity gains into analysis for prioritizing transportation investment projects, with illustrative examples, describing how to collect data, conduct analysis and communicate results to agency leadership, the public and elected officials.

Acknowledgements. This report is the product of a collaborative effort of researchers including:

- Economic Development Research Group, Inc. – Glen Weisbrod (Principal Investigator) and Brian Alstadt;
- Systems Metric Group, Inc. – Chris Williges;
- University of Leeds (UK) – Peter Mackie, James Laird and Daniel Johnson;
- David Simmonds Consultancy, Ltd. (UK) – David Simmonds;
- Prime Focus, LLC – Libby Ogard; and
- Consultants – Roger Vickerman (Univ. of Kent) and David Gillen (Univ. of British Columbia)

This report also reflects guidance, insight and oversight provided by Andrew Lemer of the Transportation Research Board, on behalf of the NCHRP Program, and a project panel consisting of Patrick Morin (Washington State DOT), Barry Padilla (California DOT), Denise Dahlke (Oregon DOT), Robert Russell (Wisconsin DOT), Alexander Heil (Port Authority of NY and NJ), Joshua Rosenbloom (Univ. of Kansas), Rabinder Bains (US DOT) and Leo Penne (American Association of State Highway and Transportation Officials). However, responsibility for any errors in the content lies with the authors.

1 INTRODUCTION

1.1 Objective

Over the last decade, there has been growing interest among US transportation agencies in improving methods and systems for evaluating the economic impacts of transportation projects. Part of this interest can be attributed to federal grant programs that have required applicants to estimate the long-term benefits and impacts of proposed projects from a national as well as local perspective. Recent global economic downturns have also led politicians and decision-makers to demand more information about proposed public expenditures for transportation projects, in terms of the "return on investment or "business case" or expected job and income benefit from funding proposed projects. In a limited capital environment, the private sector is also demanding greater return on their investment as competition increases for capital investment funds.

The interest in *economic evaluation* in general, and *productivity* specifically, comes from two different directions:

- One is the growing recognition that there are "wider economic benefits" associated with reliability, accessibility and connectivity enhancement that are not being fully captured by the narrow measures of user benefit most commonly measured in benefit-cost analysis.
- The other is the growing pressure for more systematic and complete methods for assessing transportation benefits that attempt to quantify elements that have previously been deemed too hard to quantify.

This study, National Highway Cooperative Research Program (NCHRP) Project 02-24, is developing a methodology and guide for incorporating economic productivity gains into the analysis of transportation investments. Some agencies have been addressing the productivity and economic impacts of transportation projects, but they are relatively few and the efforts have been limited to date. They have required substantial resources, often been relatively poorly documented, and generated debate about their accuracy. The goal of this project is to bring the consideration of economic productivity into the mainstream by developing consistent and practical methods that facilitate public decision-making about transportation investment priorities within a state or region. This report provides a review of research and practice to date, as a first step in this effort.

It specifically addresses four questions:

1) How should we define and measure productivity impacts of transportation investments, and their key elements?

2) What is the appropriate use of productivity metrics in economic evaluation to support transportation project prioritization and selection?
3) To what extent is their research confirming how productivity impacts take place, and how these effects can be distinguished from other forms of benefit that are already being counted?
4) How are productivity and wider economic benefits now being considered by transportation agencies, and to what extent have methods been applied (to date) that illustrate their measurement and use?

By addressing these questions, this report lays the groundwork for development of a methodology for incorporating productivity elements into economic benefit and impact assessment.

1.2 Definitions

To understand the role of productivity in transportation decision-making, it is first useful to distinguish three inter-related terms that are commonly confused: "economic impact," "economic benefit" and productivity. Similarities and differences between these concepts summarized below (drawn from Weisbrod, 2007).

- *Economic impact* is commonly defined as effect on total level of activity occurring in the economy of a region (which may be a state or nation). It is commonly measured in terms of change in business output, worker income, jobs, GDP or value added (all of these terms are defined in Ch. 2). Transportation investments lead to broader economic impacts by reducing (a) the cost of living and (b) the cost of doing business in a region. The former can lead to economic impact by shifting consumer spending. The latter increases productivity and hence cost competitiveness of industries in a region, attracting business investment and enabling business expansion and attraction. Economic impact is defined as the resulting gross change in a region's economic activity which includes both effects of local productivity gain and effects of business attraction (which is the spatial relocation of economic activity between regions). Economic impact on a region may be included in project evaluation and ranking, and used as part of the "business case" for transportation investment.
- *Economic benefit* (or the economic value of benefits) represents the social welfare gain and is the numerator in benefit/cost ratios. It encompasses a broader concept of gain than economic impact in that it can include not only income gains but also non-money benefits (represented by a "willingness to pay" value). Hence personal time savings for which households assign a value are conventionally regarded as an economic benefit though they do not directly lead to any an impact on the flow of money in the economy. It also differs from economic impact insofar as it excludes spatial shifts of economic activity.

When Benefit-Cost Analysis (BCA) is used by transportation agencies in the US, it is most commonly implemented by calculating the value of direct savings to users (values of reductions in travel time, travel cost and collisions), though it often also includes valuation of environmental (emissions) reduction. Additional social (quality of life) benefits and wider economic benefits (including effects on business efficiency, competition and labor markets) may also be counted, though that is rarely done in current practice.)

- *Productivity* measures how much output is generated from a given amount of input. The units of input can be workers (which leads to a measure of labor productivity) or investment made in equipment and facilities (which leads to a measure of capital productivity) or total money spent on labor + capital (which leads to a measure of total factor productivity). By comparing the ratio of economic output to inputs, economists can measure the efficiency of production in the economy.

For a given industry in a region, productivity and competitiveness are intrinsically related, for productivity may be viewed as the ratio of [output produced per unit of input cost] and cost competitiveness is measured through the ratio of [input cost per unit of output produced]. Thus, productivity can be viewed as a driver and an indicator of net national economic impact (affecting economic growth net of business relocation effects), and it can be viewed as an element of wider benefit that should be (but in the past has seldom been) included in benefit-cost analysis.

This technical memorandum addresses the aspects of productivity that are most often missing from the standard BCA. It provides a critical review of the literature on sources of wider economic benefits, including economic productivity, and its links with transportation system performance. In this review, the study team provides a synthesis of theoretical research related to economic productivity as well as applied empirical approaches.

1.3 Productivity Processes and Factors

The concept of economic productivity is critical to economic evaluation and assessment. Productivity changes are reflected in effects on the value added or income generated in the economy. From the context of transportation analysis, any benefit that reduces costs or otherwise enables more net income to be generated from existing resources will be seen as a productivity benefit, regardless of whether it is measured per unit of labor or per unit of money invested. And in fact, the technical literature shows that transportation investments can make both labor and equipment investments more productive.

In theoretical terms, all of these effects occur because transportation enhancements can enable more efficient organization and operation of economic activities, through effects on worker commuting patterns, freight delivery patterns and the supporting structure of office, manufacturing, warehousing and delivery facilities.

There are several paths by which productivity effects occur:

- The potential for transportation investments to affect *travel time and expense costs* is well documented, and the associated business cost savings constitutes an important element of productivity benefit.
- Transportation system enhancements can also enlarge customer markets and enable "*scale economies"* of production (which increase sales and reduce unit cost) as well as enable "scope economies" (which increase sales as a result of more highly specialized and differentiated products).
- They can affect the size and density of labor markets, facilitating "*agglomeration economies*" that allow firms to access broader labor pools, hire employees with better matched skills, and innovate from interaction with workers at other firms.[1]
- They can affect *supply chain efficiency*, as more reliable and faster transportation can lower logistics costs by reducing the need for delivery vehicles, warehouse space, and investment in "safety stocks."

The multi-faceted nature of productivity (as clear from the above bullets) presents is a challenge for this NCHRP study. The final guidelines need to provide a clear linkage among the disparate, but linked and important, lines of research related to economic productivity.

Another challenge is the use of ambiguous terms in the United States and abroad. For example, transportation agencies may refer to the focus of this study as economic impacts, economic development, economic benefits, or wider economic impacts. The practice in the United Kingdom (UK) illustrates the complexity of this problem even further. The UK has a well-defined set of procedures for conducting benefit-cost analyses and capturing aspects of the economic productivity impacts of transportation projects. However, use of these terms still varies within the UK. "Wider economic benefits" may refer either to benefits (e.g., labor supply impacts) added to benefit-cost analysis or to measures of the overall impact on the economy (e.g., changes in gross value added). Clear definitions will help provide better guidance for transportation practitioners.

The second chapter of the review provides a more detailed discussion on the definitions and sources of economic productivity. However, all economic definitions of productivity share the same basic idea: *productivity is a measure of economic production relative to inputs*. This can be measured through different geographic scales (e.g., entire nation, state, or metropolitan area), different industrial scopes (e.g., entire economy or specific industries),

[1] In a narrow sense, the term "agglomeration economies" refers to a class of benefits that firms obtain when locating near each other, which revolve around scale effects (access to larger labor and customer markets) and network effects (interactions that provide complementarities). However, transportation improvements can sometimes provide that same class of "agglomeration" benefits by enabling faster travel times, reducing travel time between firms and markets, without requiring firms to be physically closer to each other. See Chapter 3 for a further discussion of agglomeration benefits.

and different time scales (e.g., immediate impacts versus long-term impacts). In addition, economic productivity can arise though several mechanisms, such as learning, matching, scale, or competition. The side box on the previous page defines some of the technical terms economists use to explain these mechanisms, which are found later in this review.

Table 1-1: Classes of Factors Often Missing from Transportation BCA Calculations

Category	Impacts	Inclusion in BCA
Customer Market Access, Gateway/Port Access*	Production scale economies; and matching differentiated products to customer needs	Market Access and Agglomeration
Labor Market Access*	Matching specialized worker skills; knowledge spillovers	
Material Supplier Markets*	Matching differentiated input materials	
Imperfect Markets	Consumers value output > production costs	Output Change
Supply Chain Logistics*	Freight /operations efficiency and trade	Logistics Reorg.
Business & Household Environment	Spatial reorganization efficiencies, relief of housing/land market imperfections, other non-trans compensation	Net private costs

**Note that reliability and connectivity are transportation effects that can also affect both market access and supply chain logistics*

1.4 Literature Review Findings

While the concept of linkages between transport and productivity is relatively clear and straightforward, the frameworks used to assess these linkages become complex because of the multiplicity of impact dimensions spanning freight and passenger transportation. For instance, in the US there has been substantial research on the roles of transportation travel time reliability and intermodal connectivity in affecting logistics costs and supply chain productivity. There has also been research on the role of same-day delivery market access in generating scale economies for distribution channels, as well as manufacturing clusters that further increase productivity. And following the UK lead, there is also a growing base of research on labor market access and associated market agglomeration economies for employers. With all of this research, there are markedly different metrics being developed for representing changes in market access (effective densities), reliability and connectivity, as well as economic responses (elasticities), and resulting productivity impacts.

In particular, the research into the contribution of market access to productivity has come a long way. Over the last decade, significant progress has been made in the estimation of market access or agglomeration effects. The linkage between transportation investment and accessibility, density and productivity is more firmly established. There is also growing acceptance that, conceptually, agglomeration effects can be added to the transportation user benefits found in a standard BCA. While there is reasonably good evidence to provide overall guidance, much work remains to ensure the consistent practical application of the theory to the assessment of transportation projects and programs.

A review of international approaches indicates that the UK is most notable for its formal approach to incorporating economic productivity implemented in the assessment of transportation projects. The UK approach is highly codified and specific guidance is provided online in Transport Appraisal Guidance called WebTAG. Wider economic benefits, such as agglomeration economies, are now routinely included as additional benefits in benefit-cost analyses. And the UK also includes impact on economic growth as a factor in its multi-criteria assessment of the broader business case for transportation investments -- recognizing that productivity increases lead to aggregate growth in Value Added or Gross Domestic Product (GDP).

A variety of US states have also adopted multi-criteria analysis (MCA) as a means for rating competing projects, with economic growth either explicitly or implicitly included as a factor in the decision process. While some states use job growth as the economic impact metric, a few use estimates of GDP growth derived from economic impact models as their factor, thus effectively recognizing productivity effects. And some others accomplish the same effect indirectly, by recognizing market access, intermodal connectivity and/or reliability effects as explicit rating factors in the MCA systems. Yet many others, including a majority of state and regional agencies, still do not incorporate productivity effects into their assessment of transportation project benefits or impacts.

Beyond the US and UK, many other countries have also adopted the approach of incorporating productivity impacts in the assessment process through the use of MCA. For example, the Netherlands has a long tradition of using MCA techniques in decision-making. Under this approach, each factor is given a defined weight to determine a maximum or best decision. In addition, some countries have relied on macroeconomic techniques, such as macroeconomic growth models, to estimate economic impacts. New Zealand and Australia have begun to incorporate practices similar to the UK approach in their benefit-cost methodologies.

1.5 Organization of Report

The rest of this memorandum provides a summary of the literature. It also describes the state of the practice in measuring the economic productivity gains associated with transportation projects. Theory is presented first and then current practice.

The next chapter introduces the economic theory by providing a detailed discussion on the definition of productivity and the drivers by which transportation can affect the rest of the economy. This is followed by chapters covering four key classes of transportation system improvements, which in turn drive the economic productivity gains listed back in Table 1-1. Those elements of transportation system improvement are:

- Labor Market Assess
- Supply Chain and Delivery Markets
- Intermodal Connectivity
- Travel Reliability.

After the theoretical discussion, the literature review provides a description of the current practice in the United States and several other countries. Much of the section on the international practice is devoted to the UK practice, since the UK has one of the most advanced approaches to incorporating economic productivity into transportation assessments. Several practical issues are described, such as why people try to measure economic productivity gains, what is measured, how the measures are used (e.g., in program tradeoffs and alternatives analysis), and in what settings (academic, applied, and commercial).

2 PRODUCTIVITY MEASUREMENT

2.1 Productivity Context

In everyday usage, the term *productivity* means efficiency, or being able to produce a lot with limited resources. Economic definitions preserve this spirit, yet are more precise – clarifying the terms "production" and "resources". As we will see, the types of productivity that are associated with transportation investments have very specific definitions and sources. This precision is important, too, because accurate, defensible, and meaningful policy analysis must be able to articulate a project's economic consequences without over- or under-stating its magnitude (while capturing all the relevant sources).

Yet, in transportation planning and economics, there already exists a rich vocabulary of ways to describe a project's economic consequences. Aside from productivity, projects can be said to generate:

- economic growth or development
- economic impacts
- "wider" benefits or impacts

Therefore, in defining "productivity", it is also necessary to clarify its meaning in relation to these other terms. The next section lays out the different ways of defining productivity before describing its relationship to broader measures of economic outcomes.

2.2 Defining Productivity

All economic definitions of productivity share a single basic idea: *productivity is a measure of economic production relative to inputs*. Productivity is therefore a ratio of economic output to inputs – that captures the efficiency of the production process.

Precise definitions depend on three factors:

1. Scope – the geography and industries being described,
2. The specific measure of "production" (productivity's numerator), and
3. The specific measure of "input" (productivity's denominator).

Geographic and Industrial Scope

Productivity measures always describe a specific "chunk" of the economy, defined by its geographic and industrial scope. Geographically, productivity can be measured for an entire nation, or for a smaller area such as a state, metropolitan area, county, or neighborhood. Within each geographic level, productivity can be either an aggregate measure for all industries, or it can reflect just a part of the economy, such as a broad industry group (for example, manufacturing), a detailed industry (for example, tire manufacturing), or even a single firm.

Measures of Production

There are many ways to measure economic production (the numerator of productivity). At the macroeconomic level, the three most common are *Output*, *Value Added*, and *Labor Income*. The relationship between these three measures is demonstrated in Figure 1, which shows 2010 production levels for the US tire manufacturing industry.

- *Output* is the total value of the goods and services produced by a firm or industry in a year. As such, it is the broadest measure of economic production. For example, in 2010, the US tire manufacturing industry produced roughly $18 billion worth of tires[2].
- *Value Added* measures the industry's contribution to the total value of the output. According to Figure 1, in order to produce $18 billion worth of output, the tire manufacturing industry had to spend roughly $12 billion on intermediate inputs – including rubber, steel, and a variety of other materials, utilities, and services. Value Added is therefore a literal definition of the value an industry adds to the final value of its goods. For tire manufacturing, this was about $6 billion in 2010. Because Value Added isolates each industry's contribution to the final value of the good, it can be summed across industries without double-counting. Gross Domestic Product (or Gross Regional Product for smaller regions) is the sum of Value Added across all industries in the US (or smaller region).
- *Labor Income* measures workers' contribution to total industry output, and is generally the largest component of Value Added. It includes compensation to employees as well as business owners, and typically includes benefits such as employer contributions to health insurance and retirement plans. For the tire manufacturing sector, labor income was about $4 billion in 2010, accounting for about 2/3 of Value Added and 22% of the final value of tires.

[2] Technically, output captures the value of what an industry produces in a year. In most cases this is very close to the industry's annual sales, although small deviations can arise through changes in inventories.

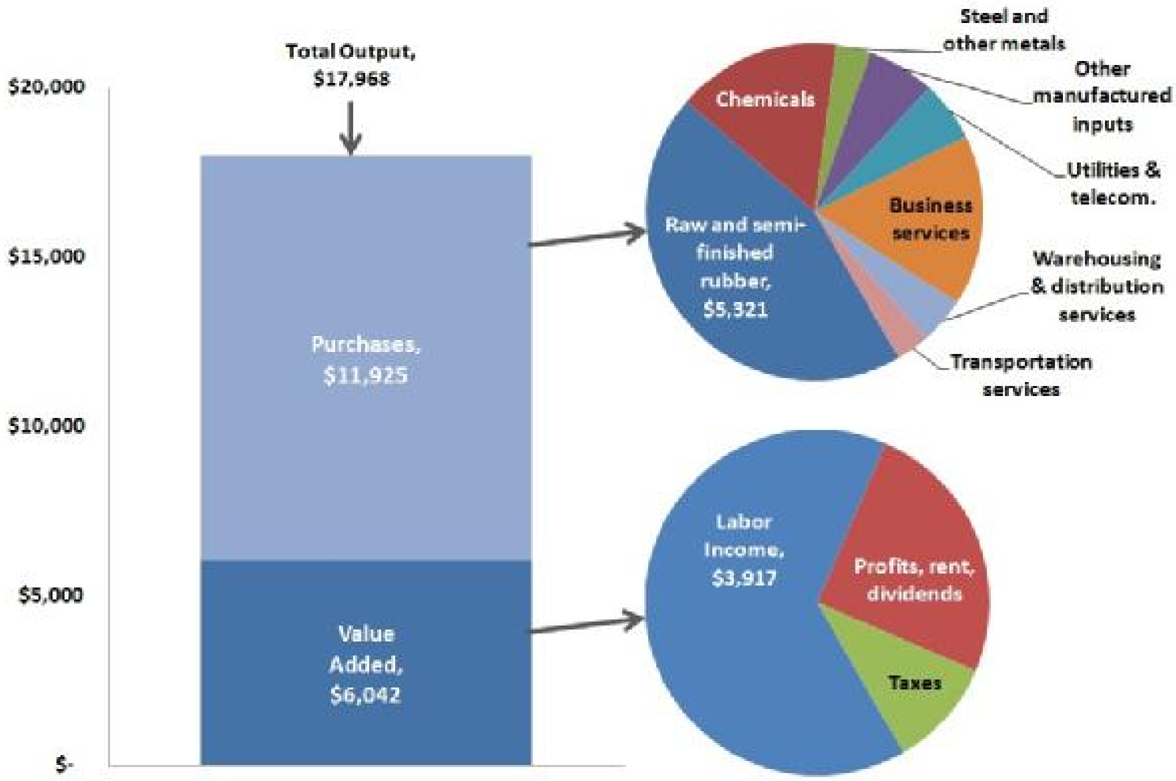

Figure 1-1: Example relationship among Output, Value Added, and Income ($mil. for 2010 US Tire Manufacturing, Source: IMPLAN)

Input Measures

Finally, to complete the concept of productivity, the measures of output described above must be in relation to an economic input. The most common is "labor", which is typically captured as an employment count, although alternative measure of employee-hours or full-time equivalents can be used.

Thus, *labor productivity* is the efficiency of labor in the production process. In 2010, the Tire Manufacturing sector employed about 52,000 workers across the U.S., yielding the following three related measures of labor productivity:

- Output per worker: $18 billion / 52,000 ≈ $346,000 per worker
- Value Added per worker: $6 billion / 52,000 ≈ $115,000 per worker
- Income per worker: $4 billion / 52,000 ≈ $77,000 per worker

Alternatively, *capital productivity* reflects the efficiency of capital inputs – the stock of land, buildings, equipment, vehicles, and computers used by an industry. Labor and capital can also be combined into a single composite measure called *total factor productivity*. Finally, specific industries have more targeted measures of productivity reflecting their unique production methods. In transportation, these include output per truck-mile and air carrier revenue per seat-mile.

At the industry level, labor productivity is the most common measure used in the research reviewed in sections 3-6 for two reasons. First, employment and wage data is readily available at multiple spatial levels and for detailed industry sectors. Second, although skill levels can vary by region, labor is an effective way to normalize productivity measures across industries. Other productivity measures including capital productivity and land productivity can be more difficult to calculate because of more difficulty measuring equipment and land investments in a manner that is consistent across industries and regions.

2.3 Relationship to Other Economic Measures

The previous section clarified that productivity is a ratio of industrial production to inputs. As such, it is a measure of economic *efficiency*. And while productivity growth is closely related to certain measures of economic growth and impacts, they are not equivalent. Moreover, not all the research reviewed in Sections 3-6 use productivity as an exclusive measure of economic outcomes. This section explains the relationship between "productivity" and other terms used to describe the economic consequences of transportation investment.

Productivity and Economic Growth or Development

Economic growth and *economic development* are closely related concepts. Both describe a general increase in the amount of goods and services produced by an economy over time, although economic growth typically has a connotation of larger spatial scales (metro areas, states or the nation), whereas economic development is more commonly used for smaller areas such as cities and towns, or rural areas. Moreover, economic growth is typically measured exclusively through changes in total output or Gross Regional Product (GRP), whereas economic development is a less formal concept that can be also be measured by growth in income, employment, or even the number of firms.

Productivity and GRP Growth. In either case, increasing productivity is widely understood to be one of the main drivers of growth, particularly for mature economies with modest population growth such as the US According to Elwell (2006),

> "Economists have isolated a series of factors, which through accumulation and interaction, are thought to play critical roles for generating steady increases in productivity and sustained long-term [economic] growth. Three factors: physical capital, human capital, and technological knowledge are seen playing a direct role in magnifying the worker's productivity." (p. 6)

Indeed, the purpose of Chapters 3-6 is to identify the specific ways that transportation investment and policy can affect these determinants of productivity growth.

Productivity and Employment Growth. Employment growth is a frequent measure of economic development. Yet it is sometimes argued that there is a tradeoff between productivity and employment. Since employment is the denominator of labor productivity, it would appear that higher productivity would mean *less* employment. Broadly speaking, this is not true. A large body of research has confirmed that when looking at the entire economy, productivity gains are associated with higher employment levels (see, for example, Trehan, 2003).

However, while this positive relationship holds true at aggregated level, a more detailed look at specific industries reveals Schumpeter's famous "creative destruction", where certain industries grow and others decline. In fact, it is both the growth of high productivity sectors and the decline of low productivity sectors that contributes to gross productivity growth.

A number of researchers (for example, Manyika et al, 2011) have noted that this process can create pockets of underemployment, which ultimately necessitates a flexible labor force to be able to adjust skills to match those needed in high growth sectors.

Productivity and Economic Impacts

The preceding section described economic growth and development as an ongoing process driven, to a large degree, by productivity growth, and with the implication that transportation investment can improve prospects for economic growth and development.

Economic Impacts are a formal measure of the consequences of a single policy, investment, or package of investments. They describe the *difference* between an economy with or without a project, using the same measures described above: output, value added, income, and employment. These variables imply labor productivity as well.

The relationship between economic impacts and productivity is not straightforward, and should therefore be an important consideration in any prospective analysis. Because productivity is a ratio of production to inputs, economic impacts can be productivity-enhancing or productivity-neutral (or even productivity-detracting). The findings of sections 3-6 paint a broad picture of transportation investment as increasing productivity – particularly when strengthening metropolitan agglomerations.

However, not all impacts from transportation investment are likely to be productivity-enhancing. In particular, transportation projects can lead to reallocation impacts and stimulus effects that are frequently productivity-neutral. For instance, a transportation investment may increase the competitiveness of one city relative to another. If a business relocates to the more attractive city *but doesn't change any of its business practices*, then national output, value added, income, and employment has not changed; it has simply relocated from one place to another. Yet, if the relocation enables the business to be more efficient – to produce more with the same inputs, then the productivity of the national economy has increased.

Similarly, since the Great Depression, infrastructure investment has been a widely-used means for economic stimulus. Yet, if the additional "stimulated" economic activity is simply a scaling of existing business practices, then national productivity remains unchanged. Output, value added, income, and employment have all increase proportionally (which may be a desirable policy objective in its own right). Yet, if the resulting infrastructure improves economic efficiency, then national productivity increases yield lasting economic impacts after the stimulus effect subsides.

Productivity and Wider Benefits or Impacts

As noted in Section 1, there is some ambiguity surrounding the terms *wider benefits* and *wider impacts*. In some cases (for example, the U.K.), these are used to describe non-traditional benefits for inclusion in benefit-cost analysis. In other cases, the term is simply used to describe economic impacts (i.e., impacts wider than BCA)

In the latter case (which we might call "wider impacts"), the relationship with productivity is precisely as laid out in the previous section. However, in the first case (which we might call "wider benefits"), the relationship with productivity must be made explicit. Benefit-Cost Analysis is a detailed accounting of a project's impact on societal welfare, so any "wider" benefits must be careful to account for only welfare effects without double-counting.

This is typically done by estimating labor productivity or total factor productivity, using Value Added (or perhaps income) for the numerator. Focusing on productivity gain (as opposed to simply Value Added or Income) ensures that the benefits are truly net increases in productive capacity at the national level, and not simply reallocation or scaling of existing economic activity. Focusing on Value Added or Income in productivity's numerator (as opposed to Output) ensures that the estimate of additional value creation in the economy is not double-counted across industries.

2.4 Sources of Productivity Growth

Theoretical Foundation

Productivity benefits can extend far beyond the value of traveler time and vehicle operating cost savings, because they encompass benefits associated with shifting the organization and operation of economic activities. To understand how this occurs, it is useful to consider the economy as a set of material, equipment and labor inputs that are deployed in conjunction with a set of transportation assets to enable various technologies to be used to generate economic (product and service) outputs. (See Figure 2-2.)

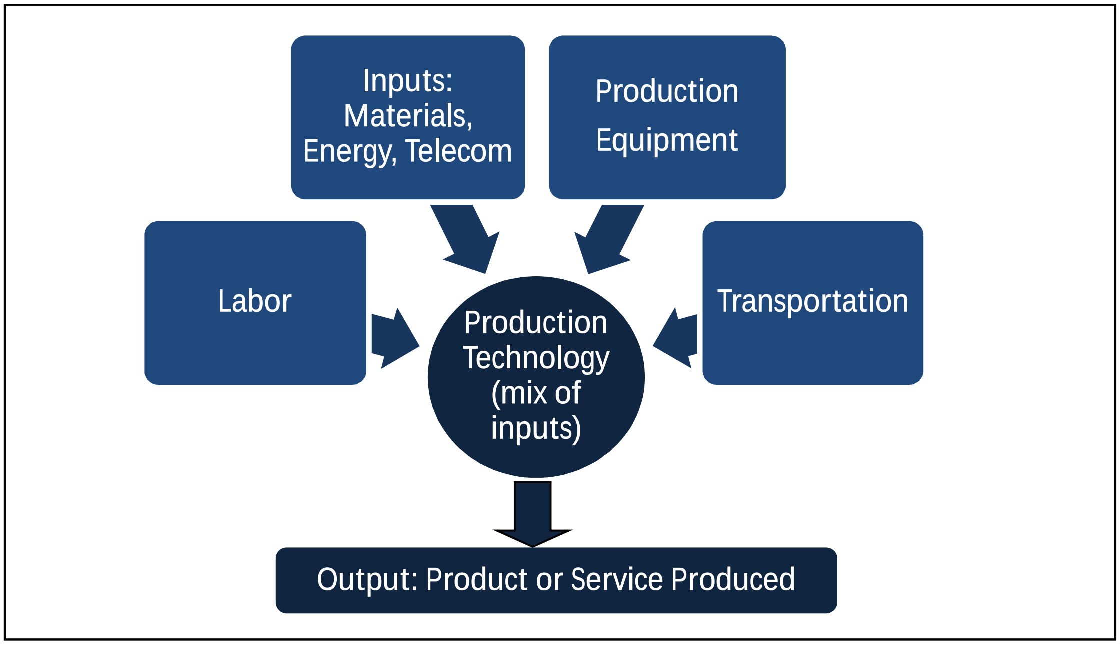

Figure 2-2: Illustrative Schematic Showing Transportation Role in the Economy

Viewed from this perspective, transportation system changes can affect technology use by enabling a different mix of labor, material inputs and equipment to be economically feasible for producing a specific business product or service at lower cost. Fogel (1964, 1979) developed the concept of "social savings" as a way to measure the national income added from such forms of technology change. To illustrate how current transportation investments can affect technology use, cost and income, consider the following examples:

- Transportation improvements may enable a business to serve a wider customer base, thus allowing the business to employ higher capacity equipment and technologies that reduce the unit cost of production. These *scale economies* may be enabled by changes in spatial access patterns or intermodal connectivity, or the frequency and speed of transportation services.
- Transportation improvements may enable new *supply chain technologies* that require less input cost. For instance, more reliable freight delivery may enable "just-in-time" production processes that require less inventory stocking. Or they may enable centralized distribution that eliminates need for satellite distribution centers.
- Transportation improvements may enable access to a broader base of workers that can offer more specialized skills and better match to the needs of new product and service technologies. Or they may enable access to a broader base of suppliers or complementary businesses. Either way, these *agglomeration economies* can make new product or service technologies feasible.

Each of these examples illustrates a situation in which there is a change in technology or industry operation that is enabled by transportation improvement. And in each case, the change leads to productivity benefits beyond traveler time, vehicle expense or safety.

Evolution of Interest in the US

Interest in the connection between transportation investment, productivity and economic growth in the US was raised by Aschauer (1989), who applied statistical analysis with time series data to estimate those relationships at the national level. That work led to a debate about measurement and causality, and subsequently, the US Federal Highway Administration (FHWA) launched a series of studies from 1994 to 2003 to develop new and improved econometric methods to calculate that relationship (see Nadiri and Mamuneas, 2003). Those studies raised further discussion about the many ways in which a developing national transportation network affects productivity over time. Other researchers also conducted studies of these same issues for US regions and other countries over the 1990 – 2004 period (see summary in Baird, 2005).

Yet while this line of research was helpful in showing that transportation investment has affected national productivity and economic growth, it did not provide transportation agencies with a method for discerning how to best prioritize and select among proposed new projects. There was a clear need to bridge between the aggregate studies of regional and national investment benefits and project-level benefit evaluation. A general approach to this issue was presented in the Journal of Transportation and Statistics in 1998, through elasticities linking productivity to localized market access changes (Weisbrod and Treyz, 1998). The concept was further demonstrated through a 2001 NCHRP study measuring costs and benefits of urban traffic congestion based on the relationship of productivity to changes in travel times for commuting and truck delivery trips (Weisbrod, Vary and Treyz, 2001). While it drew on the economic geography framework of Krugman (1991), who recognized the role of market access and associated agglomeration economies, that study also highlighted the need to more systematically categorize and assess the roles of those factors.

Framework for Identifying Causal Factors

Eddington Study. In 2006, the UK's Department for Transport (DfT) published "The Eddington Transport Study". The report sought to "set out the evidence to inform a more comprehensive understanding of transport's role in supporting the productivity of the UK economy and its sustainable growth." (Eddington, 2006, v.1, p.1) It was an ambitious review of decades of research of the ways transportation affects the economy, with the goal of converting research into practice. It raised significant interest in the US as well as the UK, as it portrays the many ways transportation drives economic growth. Specifically, Eddington identified seven "micro drivers" of productivity:

- Business Efficiency: "Transport improvements that deliver time, cost and journey reliability savings, particularly for business and freight traffic, can significantly contribute to GDP through an increase in overall cost savings for business." (p. 24)
- Business Investment and Innovation: "Where direct savings to business lead to a higher rate of business investment there could also be productivity benefits. It could also allow business to benefit from economies of scale – producing more units of goods and services, on a larger scale, at lower cost." (p. 24)
- Clusters and Agglomeration: "Interactions between firms and individuals in [agglomerations] allow the sharing of knowledge and the development of new ideas. They also offer individuals a greater choice of jobs and business access to a larger pool of applicants. These interactions can generate productivity benefits." (p. 25)
- Labor Market: "… transport interventions can play an important role in supporting the overall efficiency and flexibility of labour markets, through better matching of people and skills to jobs. For workers, faster commuting possibilities can permit easier transfer and increase the range over which they can search for jobs, whilst for employers it can improve the size and diversity of the pool of potential applicants." (p. 30)
- Competition: "Competition is a key driver of economic growth. Improved accessibility and faster, more reliable journey times for passenger and freight traffic, can have a similar effect on the economy as a reduction in trade barriers and deliver growth benefits by exposing firms to greater competition." (p. 31)
- Domestic and International Trade: "Trade can directly contribute to productivity and growth. Export growth can enable firms to specialise and benefit from economies of scale. Import growth can stimulate further productivity gains through technological spillovers and increased innovation, as firms compete for custom at an international level. Transport improvements can help reduce costs and therefore barriers to trade, especially as globalisation creates increasingly diverse and far-reaching supply chains." (p. 32)
- Globally Mobile Activity: "Businesses, capital investment and labour are becoming globally mobile. […] Evidence suggests that good transport links, both internationally and domestically, can be important in attracting, retaining and expanding [global] business activity." (p. 33)

A Framework for this Study. Eddington's seven categories provide a foundation for transportation's effect on the economy. Yet, these are not fully independent – there are strong relationships between some of the mechanisms. For example, labor markets and competition are both closely related to agglomeration, and competition is closely related to trade. The remainder of this section presents a more simplified list of sources of productivity from transportation. While some of these are equivalent to Eddington's, others combine several into a more basic concept.

Transportation Efficiency - This source of productivity is equivalent to Eddington's "business efficiency". Investments and policies that reduce transportation costs to businesses can yield direct and unambiguous productivity gains through greater business operating efficiency. For example, if congestion relief increases a trucking firm' schedule from eight to ten deliveries per day, both labor productivity (as measured in value added per driver-hour), and capital productivity (value added per truck) can increase. The same can be true for non-freight vehicles such as repair or construction trucks, or for services such as health care. Different configurations of workers, trucks, equipment and inventory may be possible. In all of these cases, improved transportation can reduce the labor-hours spent driving, and possibly the number of vehicles required, per unit of output.

Business Investment in Growth - This source of productivity is equivalent to Eddington's "business investment". As firms serve larger markets and increase sales volume, they can make more use of fixed assets and spread their costs over a larger number of products sold. This reduces the unit cost of production and represents *economies of scale*. Firms may also leverage existing assets by producing a broader range of differentiated (yet still similar) products. For example, a car maker may lower costs by producing multiple car models from a single body frame. This represents *economies of scope*.

Either way, the result is that a transportation investment reduces firms' production costs and the firms enjoy short-term cash flow improvements in equivalent to the savings. These can be leveraged to generate business growth through investment. This is not a universal response – for example, firms could also retain the savings as profit or pass them on to customers by lowering product prices. However, firms in growing industries and with high demands on new product development have strong incentive to increase investment – by hiring more workers, buying more equipment, or conduct research and development. This response has the effect of enabling greater productivity or new product offerings, and is more likely for traded (non-local) industries and such as manufacturing, information, and professional and business services.

Market Density and Agglomeration - This source of productivity builds on Eddington's "clusters and agglomeration", but also recognizes that access to markets and competition are closely related to agglomeration.

The concept that market scale and density contributes to economic growth has been known at least since Adam Smith, but the specific mechanisms by which agglomeration benefits arise were explicitly laid out by Alfred Marshall (1890). He conceived of benefits arising from three separate consequences of larger markets providing higher economic density: *matching* (of specialized worker skills, products and needs), *sharing* (to spread costs more widely), and *knowledge spillovers* (from greater interaction of businesses and people). His pioneering work has since been generalized, codified, tested, and extended (particularly since 1990 or so) in a body of work sometimes referred to as "New Economic Geography". (Krugman, 1991; Duranton and Puga, 2004).

Trade and Connectivity - This source of productivity is referred to in Eddington's report as "Domestic and International Trade". While clustering and agglomeration focus on interactions within metro areas, trade focuses on interactions between cities (although the two concepts are critically related). Research on trade and economic growth dates back to at least Adam Smith, and has clarified several fundamental mechanisms. Trade enables specialization, economic diversity, and the capitalization of location advantages. Trade also facilitates competition, breaking down spatial monopolies and increasing competition for goods (as described above) and location (described below).

Connectivity is a critical feature to trade, at both domestic and international scales. As will be discussed in Section 5, connectivity unlocks economic potential by enabling trade with a large number of partners (as opposed to just one or two primary partners).

Spatial Competition - This source of productivity is similar to Eddington's "Globally Mobile Activity", yet it recognizes that spatial competition is not limited to global scales. The literature on industrial site location suggests a strong interplay between mobility and spatial competition and economic productivity, and transportation is an important determinant of competitiveness.

Need for a Broader Benefit Framework

A recent study of the US Strategic Highway Research Program (SHRP2 Project C03) conducted detailed interviews and developed case studies for 100 major highway and highway/rail intermodal projects completed within the past decade. It found that many projects had multiple motivations and overall 59% of the projects had been motivated by a desire for some form of access improvement, including 30% citing labor market access, 32% citing truck delivery market access, and over 35% citing access or connectivity to an intermodal terminal such as an airport, rail terminal, or marine port (Economic Development Research Group, 2011). Other projects were motivated by needs for congestion relief, citing reliability as a major concern. Both classes of project benefit – access and reliability – are often not covered by traditional benefit-cost analysis. In addition, both can provide benefits not only to travelers but also to other parties, though the valuation of benefits for the latter group may not be fully reflected by the time valuation of travelers. Yet as noted later in Chapter 7, benefit-cost guidelines for transportation projects in the US and abroad generally recognize the existence of wider productivity benefits and their potential legitimacy in project evaluation. That provides the fundamental motivation for this project, which is to help develop a more formal and comprehensive framework for addressing these issues in the evaluation of proposed transportation projects.

2.5 References Cited: Productivity Measurement

Aschauer, D.A. (1989). "Is Public Expenditure Productive?" Journal of Monetary Economics, 23, 177-200.

Baird, Brian (2005). "Public Infrastructure and Economic Productivity: A Transportation-Focused Review," Transportation Research Record #1932, online:

Duranton, G. and D. Puga (2004). "Micro-foundations of Urban Agglomeration Economies", *in Handbook of Regional and Urban Economics, Vol 4*, eds. V. Henderson and J.F. Thisse, Chapter 48, pp. 2063-2018. Online: http://diegopuga.org/papers/urbanagg.pdf

Eddington, Sir Rod (2006). The Eddington Transport Study, Main report: Transport's role in sustaining the UK's productivity and competitiveness. *Department for Transport, United Kingdom*. Online: http://web.archive.org/web/20080324002356/http://www.dft.gov.uk/about/strategy/transportstrategy/eddingtonstudy/

Economic Development Research Group, et al. (2011). Interactions between Transportation Capacity, Economic Systems, and Land Use: Final Report. Strategic Highway Research Program, Project C03, National Academies Press, 2011.

Elwell, Craig (2006). "Long-Term Growth of the US Economy: Significance, Determinants, and Policy," *Congressional Research Service Report No. 68789*, online: http://fpc.state.gov/documents/organization/68789.pdf

Fogel Robert W. (1964) Railroads and american economic growth: essays in econometric history, The Johns Hopkins University Press.

Fogel, Robert W. (1979). Notes on the social saving controversy, Journal of Economic History, v.39, n.1, 1-54.

Krugman, Paul (1991). Increasing Returns and Economic Geography, Journal of Political Economy, 99: 3

Manyika, J., D. Hunt, S. Nyquist, J. Remes, V. Malhotra, L. Mendonca, B. Auguste, and S. Test (2011). "Growth and renewal in the United States: Retooling America's economic engine," McKinsey Global Institute, online: http://www.mckinsey.com/Insights/MGI/Research/Productivity_Competitiveness_and_Growth/Growth_and_renewal_in_the_US

Marshall, Alfred (Principles of Economics (1890), p. 271.

Metcalfe, J., Ramlogan, R., and Uyarra, E. (2002) Economic Development and the Competitive Process, *Working Paper No. 36*, Centre on Regulation and Competition, University of Manchester (online: http://ageconsearch.umn.edu/bitstream/30612/1/cr020036.pdf).

Mamuneas, Theofanis P. and M. Ishaq Nadiri (2003). Production, Consumption and the Rates of Return to Highway Infrastructure Capital, Federal Highway Administration, US

Department of Transportation.

Puga, Diego (2010) "The Magnitude and Causes of Agglomeration Economies." *Journal of Regional Science, Vol. 50 (1)*, pp. 203-219.

Rosenthal, S. and W. Strange (2004). "Evidence on the Nature and Sources of Agglomeration Economies" , *in Handbook of Regional and Urban Economics, Vol 4*, eds. V. Henderson and J.F. Thisse, Chapter 49, pp. 2019-2172. Online: http://www.core.ucl.ac.be/staff/thisseHandbook/rosenthal%3Astrange.pdf

Schumpeter, Joseph (1934) *The Theory of Economic Development*, Oxford University Press.

Trehan, Bharat (2003). "Productivity Shocks and the Unemployment Rate," *2003 FRBSF Economic Review*, Federal Reserve Bank of San Francisco, online: http://www.frbsf.org/publications/economics/review/2003/article2.pdf

Weisbrod, G. and F. Treyz (1998). "Productivity and Accessibility: Bridging Project Specific and Macroeconomic Analyses of Transportation Investments." *Journal of Transportation and Statistics.* Vol. 1 No. 3.

Weisbrod, G., D. Vary and G. Treyz (2001). Economic Implications of Road Congestion. National Cooperative Highway Research Program, Report 463.

3 MARKET ACCESS

3.1 Introduction to Market Access Issues

This section of the literature review focuses on how transportation system improvements can affect economic growth and productivity by changing access to markets. Much of the research literature focuses on employer access to labor markets (workers), though the same principles hold for access to supplier markets for raw materials and intermediate goods (parts).

The market access literature recognizes that modern economies depend on a high degree of connectivity between suppliers, competitors and labor markets. Firms can benefit– i.e., gain revenue and/or reduce cost -- by being effectively “closer” to their workers, suppliers and customers (where closer may be measured in terms of travel time). The economic benefits from bringing these “economic agents” (businesses and their workers, suppliers and customers) effectively closer together (in time) are referred to as “agglomeration economies.” And they are enabled by transportation investments that enhance the connection between intercity business markets or expand local labor and supply markets. By bringing these economic agents closer together, productivity is raised above and beyond what would be expected from the transportation efficiency saving alone.

In general, transportation improvements can affect productivity in two ways: (1) by reducing the time or expense involved in conducting current travel patterns, and (2) by expanding economic opportunities through enhanced market access or connectivity. Generally, the user cost reduction effect should be picked up in a transportation benefit cost analysis (BCA). Market access effects of transportation investment are distinct from this – arising as a consequence of firms’ activities. They are sometimes referred to as “external benefits” because they are not counted in the traditional valuation of time for travelers, and that occurs because of market imperfections outside of the transportation sector which result in those effects not being accounted for in a BCA based on the transportation sector only.

Alstadt et al. (2012) illustrate this distinction with an example of two projects: (1) adding a lane to a congested highway and (2) building a bridge across a river. For the first project, most benefits arise from reduced transportation costs of existing trips. The second project establishes new linkages between markets and generate new trip making behavior. In the same way, new highway, rail, air and marine linkages can also expand market access. In each case, the new linkages can lead to productivity improvements as businesses gain access to new or expanded labor markets as well as supplier and customer markets. The text which follows focuses on how expanded market access can affect economic productivity.

Conceptual Framework for Agglomeration Economies

Definition. Agglomeration economies have been the main focus of attention in the literature on market access, which is also the key element of "wider economic benefits" recognized in the UK (SACTRA, 1999; van Exel et al., 2002; Laird, Mackie and Nellthorp, 2005; DfT, 2005; Eddington, 2006; Venables, 2007; Graham, 2007; 2009).

The use of "agglomeration" is sometimes misunderstood. The theoretical concept was first introduced by Marshall (1890) to explain the economic advantage of businesses physically clustering in cities, and particularly their central core. Those benefits are largely based the advantage of minimizing travel distances and gaining access to larger size markets for labor, products and services (which lead to what economists call "increasing returns to scale"). A century later, Krugman (1991) introduced a "new economic geography" that built on the same theoretical concept of market access to explain why regions develop differentiated industry mixes. The concept revolves around recognizing "agglomeration economies" – location advantages that depend on the cost of access to labor and business markets.

In this context, "agglomeration economies" refer to the productivity gains associated with increasing market access. It becomes applicable to transportation project evaluation because improved transportation access can bring that same type of advantage (i.e., increasing returns to scale) to any given location – by increasing travel speed, which reduces the "effective distance" between locations (in terms of time) and thus increases the size or "effective density" of markets that can be served from a given location. In this way, speed improvements enable greater interchange among firms and access to larger markets -- without requiring firms to physically relocate into tighter clusters for those advantages to take place.

There is a second line of agglomeration discussion which focuses on the potential for public transportation to encourage higher density development patterns, which can then provide further agglomeration economies. This is a longer term effect that does depend on a change in the location patterns of households and firms.

Agglomeration Benefit Processes. Venables (2007) demonstrated that the benefits of market access improvement from transportation investment are determined by two factors:

- agglomeration economies – supporting growth of business centers by increasing accessibility to markets for firms and workers, as well as improving the effective concentration of complementary industries or worker skills in an area; and
- the elasticity of productivity with respect to agglomeration – i.e., the sensitivity of business productivity to changes in the size or "effective density" of their markets.

Numerous micro-economic linkages between economic agents (businesses, their workers, suppliers and customers), brought closer together in time by the transportation improvement, generate the external benefits which give rise to increasing economic returns or agglomeration economies. Marshall (1890) classified the key sources of increasing returns (or agglomeration economies) as arising mainly through three channels:

- knowledge spillover - interactions between firms facilitate knowledge transfer activities;
- labor markets – improved availability of labor with specialized skills required by specific industries; reduction in search costs for workers and firms improves the quality of the workforce;
- supplier (or input) markets –proximity of firms provides a larger choice of suppliers from which firms can easily and cheaply select the appropriate inputs.

Marshall's classification of agglomeration economies is helpful for identifying empirical measures, but 120 years later, the theory describing the exact micro-economic linkages between economic agents and agglomeration economies is still evolving. Duranton and Puga (2004) later categorized the micro-economic mechanisms underpinning these channels as (1) sharing, (2) matching and (3) learning. Boschma and Martin (2010) added a fourth category: competition.

Sharing benefits are closely tied to economies of scale. Large pools of customers allow for economic activities that would otherwise be unprofitable. A simple example is a skating rink, which is poorly supported by one or two hockey teams, but becomes profitable for large numbers of teams (which require large populations) . These are called "sharing" benefits precisely because demand can be shared, or spread, across a large number of people (or companies). A more subtle version of this effect involves the technology by which firms produce their goods. Large customer bases can support the investment necessary for more efficient production techniques. Said another way, a company with $100 million in annual sales has much more incentive to streamline production than a company with $100 thousand in annual sales. Thus, the sharing of resources facilitates industrial scale, which can enable economic new activity and make existing activity more productive.

Matching benefits are closely tied to economic specialization. They capture the fact that "good economic fits" facilitate productivity. It is widely recognized that specialization is a key factor in economic growth. Indeed, this was one of Adam Smith's primary insights in *Wealth of Nations*. However, diversity and specialization are only part of the story. The true benefits of specialization arise from *matching* specialized products and services to specialized needs. For example:

- *Labor market* – urban areas create large and fluid pools of labor. As the pool of accessible labor grows, odds increase that a firm will find a good fit for their specialized skill needs.
- *Intermediate inputs* – urban areas bring firms and industries near one another. As this pool of firms grows, odds increase that a firm needing a specialized input (for example a manufacturer needing a specific metal alloy) will find it.

- *Final goods market* – cities offer large pools of customers shopping for goods. As this pool grows, odds increase that person seeking a unique good (say, an extra small widget in lime-green) will find a firm that produces or otherwise supplies it.

Ultimately, good matches lead to higher productivity because they are more efficient. In the labor market, one "perfect" employee might substitute for two "adequate" employees. In the intermediate input market, the correct metal alloy may allow a manufacturer to eliminate a downstream production cost. In the final goods market, the right match between product and consumer can trigger a sale that might otherwise not have happened.

Learning benefits (or "knowledge spillovers") are associated with interaction between businesses and workers. As people interact, they share ideas and knowledge. This has been understood at least since Marshall (1890), who noted that information can diffuse quite easily, "as if it were in the air." Recent research has looked at the specific ways that knowledge can accumulate, spread through networks, and be incorporated into the productive process – with a key focus on the relationship between knowledge and innovation (Rosenthal and Strange, 2004; Boschma and Frenken, 2005). From Marshall onward, physical proximity (and the associated economic density of activity) has been viewed as a key to knowledge diffusion, though transportation can effectively increase interaction without physical relocation of activities (leading to the concept of "effective density"). As the effective density of business activity increases, the potential for interaction increases, adding to the pace and breadth of learning and knowledge accumulation. The added knowledge, over time, can be embodied in enhanced worker skills and production techniques to improve firms' efficiency (productivity). Furthermore, diversity and cross-fertilization between industrial sectors, as occurs in large agglomerations, is considered an important (though not required) mechanism for stimulating innovations (Crafts and Leunig, 2006). Foreign direct investment (FDI) has also been viewed as a source of knowledge generation and diffusion within a national or regional economy (Eddington, 2006 p.34; Oxford Economics, 2011, p.9).

Competition provides another means by which business density (or effective economic density) can increase interaction and enable greater innovation. The ides of competition as a driving force for innovation was first championed by Joseph Schumpeter (1934). Later, Boschma and Martin (2010) added it as another aspect of agglomeration effects. The basic idea is that transportation affects competition by increasing effective proximity in terms of travel time. While it has already been discussed that proximity can drive innovation through knowledge spillovers (a form of passive knowledge accumulation), competition caused by business clustering can speed active knowledge growth by forcing firms to innovate or fail, a topic discussed by Porter (1980). Simply put, proximity typically increases the number of firms that directly compete with each other. As the number of market participants increases, two things happen: (1) poor performers are more likely to be driven out of business, and (2) remaining firms feel more pressured to innovate – to actively acquire knowledge (Puga, 2010). Both effects can lead to higher rates of innovation and productivity (Metcalfe et al., 2010).

It is clear that the nature and scale of the external benefit will vary by industry type. One would expect significant effects for industries where specialist inputs are required (e.g. skilled labor and dedicated intermediate goods). Similarly, we would expect significant effects in industrial sectors where research and development is high or face-to-face contact is needed between employees. The expectation to this is that there are few or no agglomeration effects in primary sectors, and a range of effects in industrial and service sectors depending on the above.

Rosenthal and Strange (2004) identified three key dimensions over which agglomeration economies may extend.

- Industrial Scope. This is the extent that agglomeration economies extend across industries. Economies which arise from spatial concentration of activity within a given industry are known as localization economies. Externalities which arise from the size of the city are known as urbanization economies. Urbanization economies are thought to exist as a result of better access to these resources, as well as better public infrastructure, such as road networks, transit systems and public facilities.
- Geographic Scope. Agglomeration economies exhibit distance decay (i.e. with agents in closer proximity, there is more interaction).
- Temporal Scope. Interaction between agents (businesses and workers) that have occurred in the past continue to the present, with awareness and knowledge of markets developing over time.

3.2 Measures of Agglomeration & Productivity

Measuring Market Access

Ciccone and Hall (1996) introduced the use of county level *employment density* as a standardized metric that represents market size differences across counties with different land areas. While this metric can be useful in explaining existing conditions, it is not sensitive to changes in transportation speeds or access patterns.

Isard (1954) introduced the concept of *effective distance* as a way to recognize the role of speed changes in affecting access. It measures the proximity of locations in terms of the travel time or generalized economic cost of travel between areas. This metric is most useful as means for explaining patterns of trade between areas (Krugman, 1991; Fan et al, 2000; Head and Mayer, 2002).

To assess market area access, some studies have extended the effective distance concept to measure the *cumulative opportunities* falling within selected travel time thresholds. The graphic which follows shows isochrones (access time bands) for travel time from Chicago. The left side shows that Minneapolis, St. Louis, Cincinnati and Cleveland are now within a 5-8 hour access range, while the right side shows how high speed rail service would shrinks effective distances so those same cities will fall to a 2-3 hour access range. This type of access representation is most useful for situations in which there is an effective limit to travel times. For instance, in the case of high speed rail, it was argued that same-day trips are feasible only when one-way travel times do not exceed a 2 or 3 hour limit.

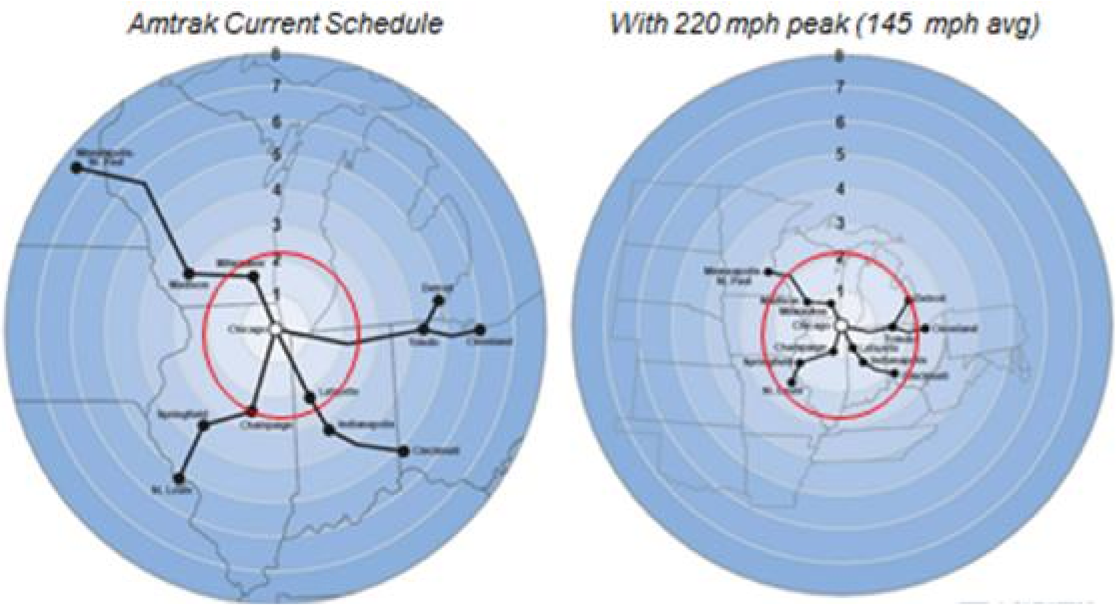

Figure 3-1 Isochrone Representation of Intercity Rail Access from Chicago (hours)
Source: Economic Development Research Group and AECOM (2011)

The same concept of travel time thresholds has been used in other research studies. For instance, a study of the effects of completing the Appalachian Development Highway System used 60 minute thresholds to identify where the highway system completion would significantly expand rural labor and consumer market access (Cambridge Systematics, 2008). Studies of multimodal corridor alternatives for Ontario (URS, 2012) and commuter rail in Massachusetts (Goody Clancy, 2009) used 45 travel time thresholds to assess the magnitude of urban labor market expansion associated with areas gaining new rail service. (Those thresholds were based on US Census commuting statistics). A study of congestion impacts on same-day truck deliveries identified 3-hour one-way travel time thresholds to assess how traffic slowdowns shrink the size of delivery areas, a value based on legal limits to driving hours for truck drivers and estimated time required for loading and unloading at both ends (EDR Group, 2005). The advantage of this approach is that it recognizes threshold effects, though the arbitrariness of thresholds can lead to instability in measurement.

Another approach is to use the *gravity model concept* (involving a time or distance decay factor) to calculate the "effective density" of opportunities enabled by transportation improvements. While the gravity function dates back to Hansen (1959), Rice and Venables (2005) and Graham (2005) introduced "effective density" measures to capture accessibility to economic mass, where the effective density of an area is calculated by counting employment in and surrounding an area, with a zonal weighting factor that decays with spatial distance.

This concept aims to capture the scale and proximity of activity accessible to a location, (i.e. a measure of employment which is accessible to firms located in a particular region). Effective density measures serve as a proxy for the factors that cause clustered firms to be more productive. One form of effective density of region *j* in period *t* is:

Effective density = $$ED_{j,t} = \sum_{k,t} E_{k,t} \times D_{j,k,t}^{-a} \qquad (1)$$

where:

- Ek,t = Workplace based employment in k areas around and including area j
- Djkt = Distance between areas j and k
- α = A decay parameter

Effective density is analogous to the concept of "market potential" referred to in the new economic geography literature. The larger the decay parameter α, the more rapidly effective density falls. So, for example, if α =1, the weight is precisely inverse to distance. Travel times or generalized cost can be used instead of distance, as they reflect the effects of transportation improvements. This metric has the advantage of providing a continuous measurement of access differences, though there has been debate about (a) how to determine the decay parameter, and (b) whether it is better to use effective distances based on travel time rather than physical distances to reflect localized differences in the density of network routes. Critical discussion of the full range of market access metrics is provided in Vadali (2011, 2012).

Measuring Productivity

There are different ways to measure the changes in productivity stemming from changes in agglomeration. Graham (2005) specifies firm level production functions in land use, capital, labor and an agglomeration measure to estimate the effect of agglomeration on firm level total factor productivity. Often, however, as pointed out by Rosenthal and Strange (2004), these approaches are constrained by lack of appropriate measures of land use and capital, employment and materials. This makes an effective implementation of this approach extremely challenging. Other more indirect approaches include measures of productivity such as employment growth, creation of new establishments (e.g. Rosenthal and Strange, 2003) and land rents (e.g. Dekle and Eaton (1999).

Another approach is to use wages as a measure of labor productivity (e.g., Glaeser and Mare, 2001 and Wheaton and Lewis, 2002). This uses basic economic theory which shows that under the assumption of competitive markets, workers are paid the value of their productivity, so, wages will rise as workers in an area become more productive. Of course, there are many other factors not related to labor productivity that also cause wage disparities among regions. These include labor and household mobility constraints as well as location attractiveness factors such as differences in quality of life, culture, crime, etc. Yet at the margin (holding all of these other factors constant), an increase in labor productivity in a given region would still be expected to cause a corresponding rise in demand for workers there, and thus be expected to eventually bid up local wage rates.

3.3 Relationship to Productivity

Statistical models are used for estimation of the extent of the linkage between agglomeration measures and productivity. The agglomeration measure is regressed on some measure of productivity to obtain a ratio of "agglomeration elasticity," defined as:

$$\left\{\frac{\text{\% change in productivity}}{\text{\% change in agglomeration}}\right\}$$

As mentioned above, the productivity can be calculated through a wage equation, but more often it is done through a firm level production function. Mackie et al (2011) encapsulate this through an equation representing firm output as a function of: (1) factor inputs, (2) their corresponding productivity levels, and (3) the extent to which agglomeration economies are experienced by the firm. Models then seek to estimate the extent to which the third factor has a significant and positive effect.

There are various estimation issues associated with such regression type approaches. First, as Graham (2009a) shows, there is evidence for reverse causality in the relationship between agglomeration and productivity, i.e. areas which are more productive will attract higher concentrations of skilled workers (and better firms). If this relationship is not treated by models, they are not necessarily identifying a true causal linkage, and estimates of agglomeration elasticities are subject to bias and inconsistency. Put more starkly, we cannot tell for sure that the increased accessibility arising from transport investments will necessarily raise productivity. To correct for this issue, "instrumental variable" approaches are used, whereby researchers attempt to utilize additional variables which are correlated with agglomeration but not with productivity, such as time lagged values of population or population density, eg Ciccone and Hall (1996) and Rice et al (2006). Rosenthal and Strange (2008) and Ciccone (2002) use geographical instruments.

Clearly, correct estimation of the relationship between productivity and agglomeration requires the identification of appropriate exogenous variables (i.e. the Zs in equation 2), otherwise, the estimated elasticities may include effects on productivity of other, unobserved factors. Examples cited in the literature include labor heterogeneity, i.e. unobserved labor quality or human capital. This is crucial as while transport investments change accessibility to economic mass, they do not change labor quality, and if not controlled for, productivity increases which arise from higher levels of human capital may be attributed to increases in agglomeration.

Empirical Evidence

In NCHRP Report 463, Weisbrod, Vary and Treyz (2001) applied Krugman's new economic geography concepts to calibrate a flexible production function model (with input substitution), utilizing data on firm locations, industry and worker occupation mix, and variation in commute distances and travel times within the Chicago area. The analysis showed that a 10% reduction in region-wide commuting travel times yields a productivity benefit of 0.31 – 0.42% (indicating a productivity elasticity of 0.03 – 0.04). This was the predecessor of access benefit computations included in both the REMI and TREDIS regional economic impact models (Weisbrod, 2008), though both have since evolved and the latter model now has a new set of published elasticities (Alstadt et al, 2012).

Later studies adopted effective density measures as a basis for calculating agglomeration and then calculated their relationship to productivity. Rosenthal and Strange (2004) provided a literature summary of findings around the world on elasticities of productivity with respect to agglomeration.

There is a wide variance in estimates of agglomeration elasticities. This is due to a number of factors. Firstly, the industrial category: service industries generally exhibit higher elasticities as these are more present in concentrated urbanized locations. It is thus appropriate to estimate different elasticity values for different economic sectors.

Rosenthal and Strange (2003) found elasticity estimates typically lie between 0.03 and 0.08 (meaning that a 100% increase in effective market size yields a 3 – 8% increase in output). For example, Ciccone and Hall (1996) find an elasticity with respect to employment density for the manufacturing industry of 0.06 in US states, and Ciccone (2002) finds an elasticity of labor productivity of 0.045 in EU regions. According to the Eddington Report (2006), 'the broad consensus is that a doubling of city size (reflecting a 100% increase in effective market scale or density) is associated with an increase in productivity of 4-11%', while Venables et al. (2006) reports an increase of 3.5%.

Graham's (2009a) estimates, which further controlled for endogeneity (measurement error due to multiple correlated variables) and labor quality, are slightly smaller than elsewhere -- ranging from 8% for business services, to 2% for manufacturing and consumer services for a doubling of city size.

Melo et al (2009) conducted a meta analysis of estimates of urban agglomeration economies, based on 729 estimates from 34 studies between 1965 and 2002 to understand the factors underlying the divergent values. Summary statistics from their sample are reproduced in the table that follows, showing segmentations by region, agglomeration and productivity measures and by industry group.

These results show that estimates vary systematically by country, by industry sector (higher for service industries), agglomeration specification (lower results for those which use measures of localization and urbanization economies) and labor quality (lower for those studies that control for education levels). They also show the wide range of minimum and maximum values associated with different industry sectors – with higher elasticities for service industries as well as some manufacturing based industries. Higher values are also found amongst those studies focusing on market potential measures of agglomeration, i.e.

the effective density measures, as opposed to studies that used the wage measure of productivity.

Table 3-1: Summary of Agglomeration Elasticities from Melo et al (2009)

Sample	Obs.	%	Mean	Median	Std Dev	Min	Max
Model Estimates	729	100	0.058	0.041	0.115	-0.800	0.658
Empirical Studies	34	100	0.043	0.037	0.055	-0.088	0.194
By country/region							
Brazil	20	2.74	0.046	0.024	0.052	0.003	0.180
Canada	14	1.92	-0.003	0.028	0.151	-0.310	0.300
China	2	0.27	0.013	0.013	0.028	-0.007	0.033
Europe	21	2.88	-0.038	0.045	0.258	-0.800	0.280
France	54	7.41	0.039	0.035	0.022	0.012	0.143
India	18	2.47	0.017	0.007	0.179	-0.204	0.658
Italy	43	5.9	0.041	0.031	0.032	0.002	0.109
Japan	115	15.78	0.048	0.040	0.060	-0.079	0.300
Sweden	4	0.55	0.017	0.018	0.002	0.014	0.019
UK/GB	254	34.84	0.102	0.083	0.145	-0.277	0.503
US	184	25.24	0.036	0.036	0.064	-0.366	0.319
By measure of agglomeration							
Market potential or Distance band	279	38.27	0.101	0.076	0.143	-0.277	0.658
Density	158	21.67	0.030	0.039	0.099	-0.800	0.300
Size	292	40.05	0.032	0.030	0.076	-0.410	0.319
By measure of productivity							
Labor productivity	342	46.91	0.053	0.038	0.095	-0.366	0.503
Output	264	36.21	0.076	0.057	0.156	-0.800	0.658
Wages	123	16.87	0.034	0.032	0.030	-0.096	0.143
By industry group							
Economy	168	23.05	0.031	0.034	0.099	-0.800	0.250
Manufacturing	427	58.57	0.040	0.036	0.095	-0.366	0.658
Services	134	18.38	0.148	0.142	0.148	-0.219	0.500

There have also been some specific studies that have focused on elasticities of productivity with respect to agglomeration, developed with the impact of the transport infrastructure specifically in mind. Graham (2007) estimated agglomeration economies for a range of industries to understand the variation across sectors. Using firm level data for productivity measures, together with finely disaggregated measures of differences by industry, he estimates the effect of agglomeration on firm productivity across eight sectors, as shown in the table below. Highest elasticities are observed in Transport, distribution & storage, Banking, finance & insurance and Business services, with the lowest in Manufacturing and Construction sectors.

Table 3-2: Estimated elasticities of productivity with respect to agglomeration (Graham 2007)

Industry	Elasticity
Manufacturing	0.077
Construction	0.072
Distribution, hotels and catering	0.153
Trans. Storage and communications	0.223
Real estate	0.192
Information Technologies	0.082
Banking, finance and insurance	0.237
Business services	0.224
Whole economy	0.119

Graham et al. (2009b) also estimated the effective density decay parameter α, (see equation 1 in Section 3.2) based on firm level panel data and an estimate of "total factor productivity" for broad sectors of the economy. With this specification of effective density they find the distance decay parameter to be around 1.1 for manufacturing, 1.8 for consumer and business service sectors and 1.6 for construction, implying agglomeration measures fall more rapidly for service sectors than for manufacturing. However, they also found lower elasticities for manufacturing industries.

Alstadt and Weisbrod (2012) examined the relationship between productivity and various types of travel time based access and connectivity measures capturing not just labor market access, but also regional delivery markets and access to intermodal facilities, airports, intermodal facilities, seaports and international land borders. Using a database of economic and location access measures for county locations across the U.S., they applied a system of simultaneous equations to jointly determine the impact of these measures on industrial employment, labor productivity and foreign exports in 54 industrial sectors. They found the labor market measure to be less of a factor in manufacturing, construction and utilities, as these sectors are heavily reliant on supply chain factors, available utilities and cost. Their range of elasticities vary from 0.01-0.04 for manufacturing to 0.05 to 0.1 for professional service industries.

Gibbons et al (2010) is an important study because it is the only known one relying on "ex-post" (after-the-fact) observation. They estimated the effect of road infrastructure improvements on total factor productivity and employment using British datasets of firms and employees. These are geographically linked to actual road transport improvements that occurred between 1998-2003. They measured the extent to which these projects changed effective density and find that firms close to these locations exhibited relatively higher productivity improvements than those in areas less affected – though in all instances the increase in productivity is much smaller than would have been expected from predictions based on cross-sectional analysis such as Graham (2007) and Graham et al. (2010). They did not find significant employment effects though. The observed effects may have been weakened through the choice of businesses sampled which, while in the proximity of the motorway, may not have actually received many direct benefits.

3.4 Implementation Challenges

Modeling Issues

Modeling the economic impacts of transport infrastructure investment, including those of productivity, within a holistic framework is a complex issue that crosses several disciplines and is at the cutting edge of regional science. Unsurprisingly, there is, therefore, a large body of literature covering wider economic impacts (e.g. Vickerman, 1991, Rietveld and Bruinsma, 1998) and also to their various methodological approaches and applications (Oosterhaven et al., 1998, Rietveld and Nijkamp, 2000, and Oosterhaven and Elhorst, 2003). The various modeling approaches include the following:

Surveys of firms: These can be general surveys to elicit location factors or impacts of specific factors on firms' behavior. Such approaches can lead to biased responses and do not capture agglomeration impacts well.

Estimation of production functions. These macro-economically based modeling approaches capture impact on business output (production) relative to labor, capital and infrastructure spending or investment. These models require detailed time series and cross-sectional data, and they have generated discussion regarding causality (regarding whether business growth drives infrastructure investment, or vice versa). This aggregate approach spans both labor market productivity and supply chain productivity.

Partial equilibrium potential models are more spatially disaggregated than the production functions, and utilize changes in effective density measures (described above) to estimate transport infrastructure investment impacts. (See Rietveld and Bruinsma, 1998, for an overview). These methods typically calculate the changes in accessibility brought about by the transport improvement from a transport model and then apply fixed response coefficients (elasticities) to calculate the change in productivity. The UK approach to estimating agglomeration benefits of transport investments has been based on this approach. Brocker (1995) argued that spatial impacts could be better modeled using a spatial economic model, though this increases modeling complexity.

Regional and national macro-economic models are structural equation approaches attempting to capture a multi-sector comprehensive picture of regional or national economies. (See Rietveld and Nijkamp, 2000, for an overview.) These require a detailed transport model to generate impact of the transport investment and do not have a spatial dimension – which is a definite weakness when assessing the impacts of transport infrastructure investments. Oosterhaven and Elhorst (2003), therefore, argue that spatially disaggregated models are the most appropriate way to model economic impacts of transport investments. There are two broad types of models: Land-use/transport interaction (LUTI) models and Spatial Computable General Equilibrium (SCGE) Models.

Land Use Transport Interaction (LUTI) models are linked transport and land use models developed specifically for different areas. (See Wilson, 1998; Wegener and Fuerst, 1999; and Bramley et al., 2008, for overviews.) Households and firms interact with each other in various goods and services, labor and property markets. Transport influences the decisions of households and firms through accessibility changes on key land using activities, transport systems and through the linkage to other markets. Land use is affected by other factors as well as transport (e.g. demographics and development).

Spatial-economic models are economic forecasting and simulation models that represent the spatial patterns of trade and location occurring between regions. These models estimate the wider impacts of transport investments by linking household and firm level production functions to more aggregate economic outcomes that occur as transport conditions change. REMI and TREDIS are the examples of regional models for the US and Canada. An overview of European models is provided in Brocker and Mercenier (2011). They include the RAEM model (Ivanova et al, 2007; Tavassy et al., 2011) and the CGEurope Model (Brocker, 1999). In Australia, there is TRESIS-SGEM (Hensher et al., 2012), which has since evolved to the TRESIS-TREDIS model.

The modeling choices therefore faced by the analyst are thus between partial equilibrium approaches such as application of fixed elasticity values (as used in the UK transport appraisal guidance), or much more complex resource intensive approach based on land use or spatial economic models.

Data Issues

A number of practical data related issues also exist in the modeling of the impact of transport improvements on labor market access and productivity, for which economic theory and existing empirical research offer few, if any, insights.

Choice of elasticity. Melo et al. (2009) questioned the transferability of elasticities from one area/sector to another, implying that local data is needed. Additionally, many of the elasticities reported in the literature do not use an agglomeration measure that is sensitive to transport policy (e.g. they use city size). Even Graham's work, which is much cited in the transport literature, does not use an agglomeration measure sensitive to transport policy – as his work is based on an effective density measure calculated using Euclidean distance. Inevitably, some approximations have to be made. How sensitive the results are to these approximations has not been explored to date in the literature.

Spatial, modal, journey purpose and temporal aggregation. Accessibility measures (e.g. generalized cost) are typically calculated at a zonal level by time, trip purpose, vehicle type and mode. Such levels of disaggregation are typically too fine for the effective density calculations. Generalized costs need to be aggregated across time periods, journey purposes, and modes and sometimes zones. In the absence of empirical research defining the importance of different time periods, modes, vehicle types, journey purposes to the productivity of an agglomeration a mechanistic approach has to be adopted.

Economic data. While transport data is typically available at a reasonably disaggregate spatial scale, the same cannot be said for economic data. For sampling reasons and confidentiality reasons, wage data is often only available at a municipality level. Clearly, this is inadequate as wages at firms located in the CBD (central business district) are higher than those in the suburbs. Some method of approximating the wage gradients observed in cities is therefore necessary.

Current issues

While cross-sectional analysis can demonstrate a relationship between agglomeration and productivity, there is a conceptual leap to then interpret this to mean that transport policy can affect the size of an agglomeration in any meaningful way. The ex post work of Gibbons et al. (2010) certainly questions whether improvements in transport accessibility are having the expected impact on total factor productivity expected by the literature. For such impacts to happen, transport investments need to stimulate changes in the wider economy. Time savings and other user surpluses must feed through into the final markets. This may not always be the case – i.e., the business traveler may take extra leisure or the freight vehicle may not have time to make any extra deliveries (Mackie et al. 2011). Other factor supply conditions such as land rents or sticky wages may also prevent the 100% 'passing through' of transport cost savings to final output.

There is also the issue of whether these agglomeration elasticities, which are average sensitivities typically estimated across time for large areas, are robust enough to portray the effect of typically small changes in agglomeration arising from transport investments. For this they need to be independent of the magnitude of change and constant over different levels of agglomeration. To date this has not been tested.

Another issue is the behavior of the administered sector of the economy — does public administration, or even the university sector, respond to agglomeration economies in the way predicted for the market sector? Also, there is need for consistency. For example, if transport investment centralizes activity in a regional capital, drawing activity from second level cities, the negative, as well as positive, agglomeration effects must be considered.

3.5 References Cited: Market Access Benefits

Alstadt, B., G. Weisbrod and D. Cutler (2012). The Relationship of Transportation Access and Connectivity to Local Economic Outcomes: A Statistical Analysis, Transportation Research Record, 2012.

Boschma, R. and Frenken, K. (2005). The Spatial Evolution of Innovation Networks: a Proximity Perspective. Papers in Evolutionary Economic Geography, No. 09.05, Utrecht University Urban & Regional Research Centre (http://econ.geo.uu.nl/peeg/peeg0905.pdf).

Boschma, R. and Martin, R. (2010). The Aims and Scope of Evolutionary Economic Geography. Papers in Evolutionary Economic Geography, No. 10.01, Utrecht University Urban & Regional Research Centre (online: http://econ.geo.uu.nl/peeg/peeg1001.pdf).

Bramley, G., Simmonds, D. and Dobson, A. (2008). Using Land Use Transport Interaction Models to Assess the Sustainability of Strategic Planning and Infrastructure Proposals: the Potential Scope and Illustrative Applications, Evaluation in Planning, 7th International Workshop: Towards methodological innovation in planning evaluation, Edinburgh.

Brocker, J. (1999). Trans-European Effects of ‘Trans-European Networks’: A Spatial CGE Analysis, University of Technology, Dresden.

Brocker, J. and Mercenier, J. (2011). General Equilibrium Models for Transportation Economics, in De Palma et al., eds., Handbook in transport economics, Edward Elgar Pub.

Cambridge Systematics, EDR Group and HDR Decision Economics (2008). Economic Impact Study of Completing the Appalachian Development Highway System, Appalachian Regional Commission, 2008.

Ciccone, A. and Hall, R. E. (1996). Productivity and the Density of Economic Activity. American Economic Review, 86, 54–70.

Ciccone, A. (2002). Agglomeration Effects in Europe. European Economic Review, 46, 213–227.

Crafts, N. and Leunig, T. (2006). The Historical Significance of Transport for Economic Growth and Productivity. In: R. EDDINGTON, (ed). The Eddington Transport Study, Annex A – Research. Norwich: Her Majesty’s Stationery Office.

Dekle, R. and Eaton, J. (1999). "Agglomeration and Land Rents: Evidence from the Prefectures," Journal of Urban Economics 46: 200-214.

Deutsch, Karl W. and Isard, Walter (1961). A Note on a Generalized Concept of Effective Distance, Behavioral Science, 16: 4, October (308-311)

Department for Transport (2005). Transport, Wider Economic Benefits and Impacts on GDP. London: Department for Transport.

Economic Development Research Group (2005). The Cost of Congestion to the Portland Region, prepared for the Portland Business Alliance, Port of Portland, Portland Metro and Oregon DOT, December 2005.

Economic Development Research Group and AECOM (2011). The Economic Impacts of High Speed Rail: Transforming the Midwest, Midwest High Speed Rail Association.

Eddington, R. (2006) The Eddington Transport Study. Norwich: Her Majesty's Stationery Office.

Fan, W., Treyz, F. and Treyz, G. (2000). An Evolutionary New Economic Geography Model, Journal of Regional Science, 40:4, 671-695.

Gibbons, S., Lyytikäinen, T., Overman, H and Sanchis-Guarner, R. (2010). Productivity and Employment Impacts of Agglomeration: Evidence from Transport Improvements, LSE Discussion Paper, London, UK

Glaeser, E.L., and D. C. Mare (2001). Cities and Skills, Journal of Labor Economics 19(2): 316-342.

Goody Clancy et al (2009). Economic Impact of South Coast Commuter Rail Alternatives, Massachusetts Dept. of Transportation.

Graham, D. J. (2000) Spatial Variation in Labor Productivity in British Manufacturing. International Review of Applied Economics, 14, 323.

Graham, D. J. (2005) Transport investment, Agglomeration and Urban Productivity. Imperial College of London.

Graham, D. J. (2007) Agglomeration, Productivity and Transport Investment. Journal of Transport Economics and Policy, 41(3). 317–343.

Graham, D. J. and Kim, H. Y. (2008). An Empirical Analytical Framework for Agglomeration Economies. Annals of Regional Science, 42, 267–289.

Graham, D.J. (2009a). Identifying Urbanisation and Localisation Externalities in Manufacturing and Service Industries. Papers in Regional Science, 88(1). pp. 63-84.

Graham, D.J., Gibbons, S. and Martin, R. (2009b). Transport investment and the Distance Decay of Agglomeration Benefits, Imperial College London for the Dept. for Transport.

Graham, D.J. and van Dender, K. (2012), Estimating the Agglomeration Benefits of Transport Investments: Some Tests for Stability, Imperial College London, Joint Transport Research Centre of the OECD and the International Transport Forum

Hansen, Walter G. (1959). How Accessibility Shapes Land Use. Journal of the American Planning Association, 25:2, 73-76.

Head, Keith and Mayer, Thierry (2004). "The Empirics of Agglomeration and Trade," in: J. V. Henderson & J. F. Thisse (ed.). Handbook of Regional and Urban Economics, v.4, chapter 59, 2609-2669, Elsevier.

Hensher, D.A., P.T. Truong, C. Mulley and R. Ellison (2012). Assessing the Wider Economy Impacts Of Transport Infrastructure Investment with an Illustrative Application to the North-West Rail Link Project in Sydney, Australia, Journal of Transport Geography, forthcoming.

Isard, Walter (1956). Location and Space-economy; a General Theory Relating to Industrial Location, Market Areas, Land Use, Trade, and Urban Structure. MIT Press.

Ivanova, O. et al. (2007). RAEM Version 3.0. Transport Mobility Leuven, Netherlands.

Krugman, Paul (1991). Increasing Returns and Economic Geography, Journal of Political Economy, 99: 3

Laird, J.J. (2008). Modelling the Economic Impact of Transport Projects in Sparse Networks and Peripheral Regions. Ph.D. thesis, University of Leeds.

Laird, J.J., Mackie,P.J. and Nellthorp, J. (2005). Network Effects and Total Economic Impact in Transport Appraisal, Transport Policy, 12(6), 537-544.

Mackie, P.J., Graham, D.J., and Laird, J.J. (2011) The Direct and Wider Impacts of Transport Projects: A Review; in R. Vickerman and E. Quinet,eds., Handbook on Transport Economics.

Marshall, Alfred (1890). Principles of Economics. London: Macmillan.

Melo, P.C.,, Graham, D.J. and Noland, R.B.(2009). A Meta-Analysis of Estimates of Urban Agglomeration Economies, Regional Science and Urban Economics 39 (2009) 332–342

Oosterhaven, J., and Elhorst, J.P. (2003). Indirect Economic Benefits of Transport Infrastructure Investments, in Dullaert, W., Juorquin, B. and Polak, J.B. (eds) Across the Border: Building Upon a Quarter of a Century of Transport Research in the Benelux, De Boeck, Antwerpen.

Oxford Economics (2011). Economic Benefits from Air Transport in the UK.

Porter, Michael E. (1980). Competitive Strategy, Free Press, New York.

Rice, P., A. J. Venables, and E. Patacchini (2006). Spatial Determinants of Productivity: Analysis for The Regions of Great Britain. Regional Science and Urban Economics 36, 727–752.

Rietveld, P. and Bruinsma, F. (1998). Is Transport Infrastructure Effective? Transport Infrastructure and Accessibility: Impacts on the Space Economy, Springer, Berlin.

Rietveld P. and Nijkamp P. (2000). Transport Infrastructure and Regional Development. In: Polak J.B., Heertje A., eds. Analytical Transport Economics.An International perspective, Cheltenham, Elgar, 208-232.

Rosenthal, S. S. and W. C. Strange (2003). "Geography, Industrial Organization, and Agglomeration," Review of Economics and Statistics, 85 (2): 377-393.

Rosenthal, S.S. and Strange, W.C. (2004). Evidence on the Nature and Sources of Agglomeration Economies. In: Henderson, J.V., Thisse, J.F. (Eds.). Handbook of Urban and Regional Economics, vol. 4. Elsevier, Amsterdam.

SACTRA - Standing Advisory Committee for Trunk Road Assessment (SACTRA) (1999). Transport and the Economy, London: The Stationery Office.

Sturm, J.E. (1998). Public Capital Expenditure in OECD Countries: The Causes and Impact of the Decline in Public Capital Spending, Cheltenham, Elgar

Tavassy, L.A., M.J.P.M. Thissen, J. Oosterhaven. 2011. "Challenges in the Application of Spatial Computable General Equilibrium Models for Transport Appraisal." Research in Transportation Economics, 31, pp. 12-18.

van Exel, J., S. Rienstra, M. Gommers, A.D. Pearman and Tsamboulas, D. (2002). EU Involvement in TEN Development: Network Effects and European Value Added. Transport Policy, 9, pp. 299-311.

Vadali, Sharada (2011). Spatial Representation in Economic Impact Models. International Transportation and Economic Development Conference, Charleston, WV

Venables, T. (2007). Evaluating Urban Transport Improvements: Cost Benefit Analysis in the Presence of Agglomeration and Income Taxation. Journal of Transport Economics and Policy 41, 173–188.

Vickerman, R.W., ed. (1991). Infrastructure and Regional Development, Pion, London.

Wegener, M. and Franz Fürst, F. (1999). Land-Use Transport Interaction: State of the Art, Deliverable 2a of the project TRANSLAND, (Integration of Transport and Land Use Planning) of the 4th RTD Framework Programme of the European Commission

Weisbrod, G., D. Vary and G. Treyz (2001). Economic Implications of Road Congestion. National Cooperative Highway Research Program, Report 463.

Weisbrod, G.E. (2008). Models to Predict the Economic Development Impact of Transportation Projects: Historical Experience and New Applications, Annals of Regional Science, 42:519-543, 519-543.

Wheaton, W. C. and M. J. Lewis, (2002). "Urban Wages and Labor Market Agglomeration," Journal of Urban Economics 51, 542-562.

Wilson, A.G. (1998). Land-Use / Transport Interaction Models: Past and Future, Journal of Transport Economics and Policy, 32, 3-26.

4

4.1 Introduction to Supply Chain Issues

A "supply chain" is the sequences of steps whereby a product moves from raw material and suppliers to producers and finally to end users or customers. It can involve interactions between producers, shippers, transportation and logistics providers, intermodal transfer agents, warehousing, distribution channels, freight recipients and customers.

"Logistics" refers to the process by which firms are organized and their resources are managed to facilitate the flow of goods between the various origins and destinations (as part of the supply chain). Logistics activities encompass transportation, warehousing, inventories, administration, order processing, financial management and customer service. Logistics cost is an important element of total productivity because logistics may account for 10% or more of the delivered cost for some products and sometimes up to 30% of the total delivered cost (Roberts, 1999). And transportation costs are a particularly critical factor, as they can account for around 40% of total logistics costs, depending on the type of product.

Transportation system performance characteristics can affect logistics costs (and hence productivity) through changes in travel time, reliability, and allowable vehicle sizes and weights. That, in turn, can affect supply chains by changing the spatial pattern of business locations, the timing of work shifts, inventory stocking practices and vehicle fleet deployment. Many of these mechanisms are discussed in Weisbrod and Fitzroy (2011), which provides the summary graphic below.

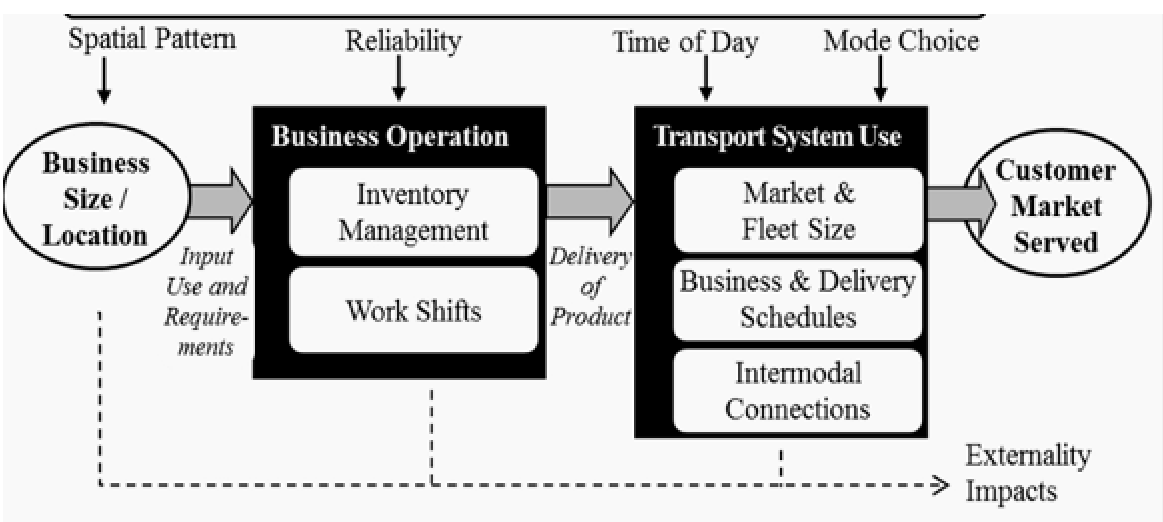

Figure 4-1 Mechanisms by which transportation can affect supply chains
(from Weisbrod and Fitzroy, 2011)

4.2 Defining Logistics Cost Elements

The FHWA *Freight Benefit Cost study* (ICF et al, 2001, 2004) was a multi-year effort involving a team of consultants to develop an overall methodology for identifying and measuring the wider (non-traveler) economic benefits of freight transportation improvements, focusing on productivity changes. This study highlighted the fact that traditional benefit-cost analysis for transportation projects was valuing time and cost savings only for drivers and vehicles, effectively assigning no value to cargo time savings and hence making no distinction between empty and full freight vehicles. By recognizing that freight shippers and recipients (rather than truck drivers) are the true "users" of freight transportation systems, this study provided a new perspective for recognizing that wider economic benefits accrue to those parties.

The study developed a framework for relating changes in travel times and variability (reliability) into effects on warehouse inventories, delivery costs and other logistics costs, leading to broader impacts on business organization and productivity. The chart below, taken from that report, illustrates the dimensions of these impacts.

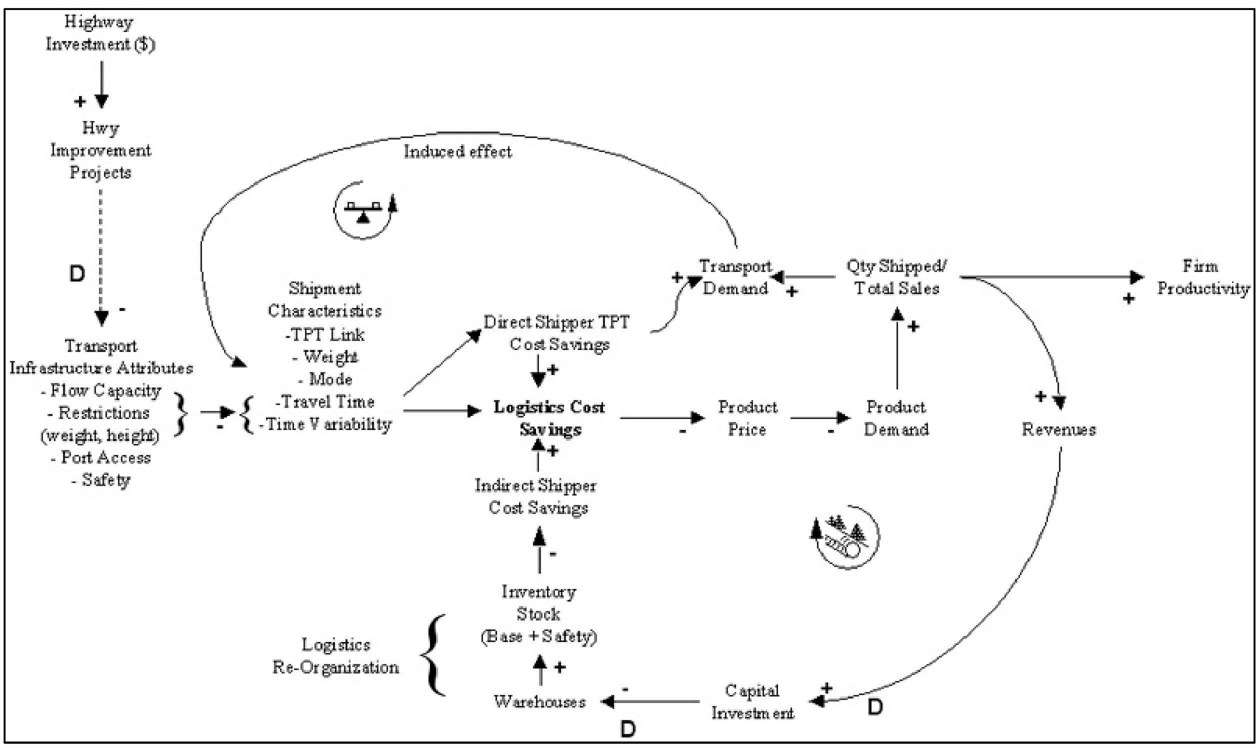

Figure 4-2 Transportation effects on supply chains and productivity

(from ICF et al, 2001)

That freight benefit methodology built on earlier lines of research establishing that firms will reorganize their production and distribution activities to minimize the cost of freight movement (Mohring and Williamson, 1969). This concept was formalized through the "inventory-theoretic framework" laid out by Baumol and Vinod (1970) for measurement of total logistics costs. It showed how transportation conditions can change mode choices, by shifting the tradeoff that firms make between incurring transportation costs and incurring inventory costs in order to minimize total logistics costs.

The graph which follows illustrates this basic logistics cost tradeoff. Simply stated, it shows that transport costs fall with increasing shipment size (due to economies of scale), while inventory carrying costs rise with the number of warehouses. So for any specific type of freight and market, there is an optimal mix of shipment size and warehousing that can minimize costs. Traffic speed and reliability improvements can make it economically feasible for a firm to rely on larger shipments and fewer warehouses, while traffic congestion causes firms to adopt the more costly strategy of relying on smaller shipments and more warehouses. Just-in-time inventory systems become economically feasible only when travel times become highly reliable and schedule variability essentially disappears.

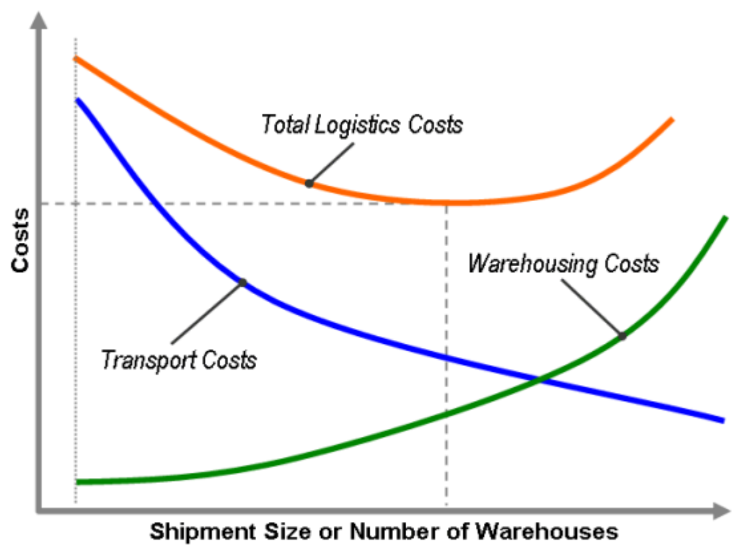

Figure 4-3 Optimization of total logistics cost
(adapted from McKinnon, 2003)

In practice, the total logistics cost function is more complex, as transportation costs can include not only direct transit costs, but also loading & unloading costs as well as loss & damage costs. And inventory costs can include costs of order processing, in-transit inventory carrying cost, holding cycle stocks, safety stocks and "stock-out" costs (penalties for shortages). These elements are portrayed in the figure which follows, drawn from NCHRP 8-85 Report (DecisionTek, 2012).

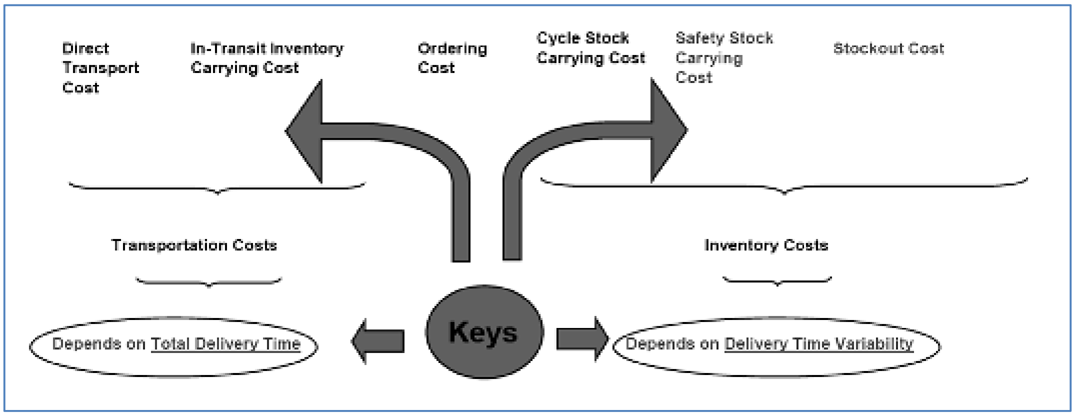

Figure 4-4 The differing effects of delivery time and travel time variability

(from DecisionTek, 2012)

The total logistics cost framework has since been applied to transportation modeling as discussed in reviews by Tyworth (1991), Chow and Waters (1993) and Blauwens et al (2006). And this same logistics cost tradeoff framework has been used for a wide variety of more recent analytic studies. Paul Roberts (Transmode, 1994) originally used it to develop a truck-rail, rail-truck modal diversion model based on cost minimization. Tyworth and Zeng (1998) used it to estimate effects of carrier time performance on total logistics costs. Swan and Tyworth (2001) used it to analyze shipper sensitivity to rail carload markets. And Dullaert et al (2007) used the framework to show the impact of different transport modes on inventory levels and service. Using information on cost minimization tradeoffs, the FHWA study (HLB, 2001) developed case studies illustrating an elasticity of logistics cost with respect to travel time savings, building initial research conducted in a study for NCHRP (HLB, 1995).

4.3 Measuring Supply Chain Performance

Issues of freight transportation, supply chains and logistics costs are now given more attention in the US, as state DOTs are now required to prepare long-range statewide freight plans. Nevertheless, the many dimensions of supply chains do make for complex relationships to economic productivity, particularly because the supply chain process used by each company is unique, as each business is different and the logistics network depends on the nature of the business, its location, markets and products shipped.

Researchers have not agreed on the definition for management of supply chains. Terms such as “network sourcing”, “value chain management” and “supply pipeline management” have been used interchangeably with the term “supply chain management” (Bichou and Gray 2004; Sydor 2012). Most papers define supply chain management to be a one-way process, where the product or service is distributed from the raw material stage to the end-customer stage (Beamon 1999; Bichou and Gray; Sydor 2012). However, supply chains can involve two-way directions, since purchases often also involve after-sales repair and maintenance services which may also involve moving the product from the final customer back to the factory-level.

Supply chains involve multiple parties and regions. Many facilities and procedures may be involved in between each supply chain stage, which adds to the complexity of the whole system (Beamon, 1999). These value chains usually involve strategic partnerships, process integration, and co-operative arrangements across the upstream and downstream organizations in order to produce value in delivering the good or service to the end-customer (Bichou and Gray 2004). Globalization has boosted international trade flows, and many production activities within a supply chain have been segregated and located across various sites in multiple locations (DeBacker and Yamano 2012; Globerman 2012; Sydor 2012).

Supply chain designs are also multi-dimensional and their designs are often influenced by other factors including "globalization, increasing logistics complexity, rising risk, increasing labor costs in the developing world, sustainability, and growing volatility" (Industry Canada, 2011). These logistic processes are affected by container traffic, intermodal mix and connectivity, infrastructure development, and government policy including customs and security inspections (InterVISTAS, 2007). And as supply chains become more globalized, gateways, corridors, and port operations play increasing roles in supply chain design (Bichou and Gray 2004; InterVISTAS 2007). A gateway also requires intermodal connectivity which may include marine, road, and/or rail operations to help extend international trade flows beyond the immediate catchment area.

Businesses have in recent years been relying more on logistics and transportation providers to improve and streamline the distribution process in order to lower inventory and other transport-related costs (Industry Canada, 2011). Successful supply chains also heavily depend on on-time and reliable deliveries (Industry Canada 2011; InterVISTAS, 2007).

Yeung (2006) conducted statistical analysis of the export performance of Hong Kong-based manufacturers and trading companies, and its relationship to the timeliness and pricing of third party-logistics service providers. His analysis showed that timeliness is most important (and statistically significant) as a positive factor explaining users' export performance relative to major competitors. That analysis also indirectly shows that supply chains and productivity are related, since export numbers enter into the output component of the productivity measure.

Bilateral (two-way) relationships are also shown to exist for supply chains, as increases in international trade also help stimulate economic growth while productivity also raises demand for global supply chains (Industry Canada 2011). And greater demand for global supply chains tends to be associated with greater investment in distribution centers.

Despite evidence that supply chain and productivity appears to be associated, finding the link between these two variables is complex. As noted above, supply chains involve more than just transport modes. Supply chains also involve qualitative measures such as customer satisfaction, information flow, supplier performance, and risk management (Beamon, 1999), as well as interdependencies across the supply chain partners – factors which cannot easily be expressed in numerical forms.

The relationship between supply chains and productivity measurement is also affected by decisions regarding how productivity is measured. In general, productivity can be measured relative to different inputs such as labor, capital, energy, and materials (Alstadt et al. 2012; Stainer 1997). Many productivity studies use a single factor productivity measure such as labor productivity (output per labor hours worked) or capital productivity (output per unit of capital) for their analysis. However, in the supply chain context, all four input types tend to interact with each other – so input measure (denominator in the productivity ratio) should be a weighted index comprising of the four categories. And then total productivity can be defined as presented in Stainer (1997):

$$= \quad * \quad \overline{\qquad} \; *$$

which equals to: $= \quad \overline{\qquad} * \overline{\qquad} * \overline{\qquad}$

The output produced by supply chains or their gateways is also complex. In the transportation context, a single firm can produce multiple outputs. The same good that gets transported to different geographical regions would be considered as different outputs; and each of the commodities transported by rail would be considered as different outputs because each item has a different cost structure. This complication is further magnified in a supply chain context for international gateways, since gateways involve multiple carriers handling multiple goods over multiple locations.

To tackle this problem, InterVISTAS (2007) and Iacobacci and Schulman (2009) suggest using an output index weighted either by the mass of the goods, by the value of the goods, or by the revenue shares of each of the outputs produced. However, they also note that any weighting methodology can be problematic due to the following reasons:

- The mass-based approach can fail to recognize the value to the economy of gateway output.
- The value-based approach can produce volatile results because the value of the goods can be affected by factors not related to gateway performances (for example, the price of the goods can be affected by supply-shortage which can be entirely not related to the supply chain process).
- The revenue-based approach is commonly used for firm's productivity performance measure; but retrieving revenue data is challenging as businesses fear disclosing sensitive / confidential information.

Furthermore, the output measure is incomplete especially under the supply chain context. As noted above, supply chains consist of time and reliability (service quality) components. In typical productivity analysis, the gross domestic product (GDP), firm income, or sales figure has been used for the output component of the productivity measure. However, any of these measures may exclude service quality aspects that most likely are not incorporated into the typical output measures..

4.4 Linking Productivity and Supply Chains

A variety of research papers have been written on the relationship of public investment with productivity, and the relationship of intermodal connectivity with productivity. Since infrastructure investment and intermodal connectivity are factors contributing to supply chain performance, results from these areas of research can provide some indirect evidence on how supply chains relate to productivity.

As noted above, infrastructure development is one of the contributors to supply chain performance. In general, a favorable infrastructure can lower transit time, reduce logistics (trade) cost, improve service levels, and thus increase productivity (Limao and Venables, 2001). Globerman (2012) argued that firms can enjoy more efficient global supply chains via improvements in transportation infrastructure, which facilitates trade integration with other global economies. Reduction in trade barriers encourages more trade activities across the economies and has positive implications on productivity growth.

Ambiguity about the link between public infrastructure and productivity also exists at a disaggregated level. Brox (2008) showed that manufacturing firms enjoy reduction in production cost associated with greater public infrastructure development. Harchaoui and Tarkhani (2003) found similar results using disaggregated data of 37 industry sectors in Canada for the period 1961-2000. Harchaoui and Tarkhani (2003) found that the transportation industry experiences the most cost reduction for every additional investment in public capital, which allow firms to set prices lower to achieve competitive advantage. Brox (2008) and Harchaoui and Tarkhani's (2003) found results consistent with the argument that firms reliance on logistics innovations in order to improve and streamline their supply chain processes to help reduce inventory and transport-related costs. Supply chain management is important to the manufacturing sector especially when a lot of the production processes are segregated across various geographical regions along with growing volumes of international trade flows.

Using a model different from the production function or the cost function approach, Shirley and Winston (2004) did not find highway spending by itself to substantially raise productivity, though they do conclude that highway spending can raise productivity via improvements in cost, speed, and reliability of highway transportation, which enable 0reductions in inventories. Those authors modified their "Economic Order Quantity" (EOQ) model to estimate the effect that different supply chain factors have on raw material inventories. The modified EOQ model sets the expected inventory level as a function of expectations of and variation in demand; order, handling, and stockout costs; and other transportation system attributes.

From the connectivity perspective, some indirect evidences suggest that supply chain performance positively relates to productivity growth. Roson and Soriani (2000) noted that new methods and increased reliability in handling cargo, improved productivity of port operation, reduction in time spent by ships in seaports are stimuli to promote the adoption of intermodal services. In other words, intermodal connectivity is important for supporting good supply chain processes because the performance of these value chains depends on timeliness and reliability.

Focusing on urban business location and its relationship to truck delivery times, Weisbrod et al (2001) developed a flexible production function model (with input substitution), utilizing data on firm locations, industry classifications, and truck origin-destination patterns within the Chicago and Philadelphia areas. Their analysis focuses on the benefits of reducing urban traffic congestion. The analysis model shows that a 2.5% average reduction in area-wide delivery costs (reflecting both travel time and reliability effects) yields a productivity benefit of 0.23 – 0.38% (indicating a productivity elasticity of .09 – 0.15). However, the productivity effect is shown to be substantially larger for services located in central business districts, which are particularly sensitive to incoming deliveries.

Focusing on aviation, Pathomsiri et al. (2006) found that time and reliability are important factors for an airport's success. Freight movements measured in terms of cargo throughput and reduction of delayed flights contribute to more efficient use of airports (i.e. increase in airport productivity).

Alstadt et al. (2012) also explored how market access and business productivity are related. Their models include variables that act as proxy for supply chain management, and these variables include:

- Employment accessible within 3 hour (one-way) driving distance: a proxy for same day truck delivery opportunities.
- Population accessible within 40 minute (one-way) driving distance: a proxy for effective labor market or consumer shopping market.
- Access time to major marine port, major commercial airport, major international freight airport, intermodal rail terminal and border crossings (weighted by their activity levels).

The study showed that productivity benefits derived from the accessibility measures do differ widely depending on the industry sector, but the overall results are consistent with supply chain practice. The same-day delivery variable was found to be particularly important for supply chain process, in particular for the manufacturing sector, because on-time shipment of goods is important to meet increasing customer service level requirements. Consistent with expectations, the study found that the manufacturing industry benefits most from same-day delivery access.

Retail and natural resource industries are also relying on supply chain processes and logistics innovations to streamline their processes. Global trade management is also commonly included in supply chain designs. Expansion of international trade flows, such as exports of natural exports or imports of retail goods, has encouraged the development of gateways and corridors. The performance of these gateways and corridors depend on rail and truck traffic (InterVISTAS , 2011). And consistent with that assertion, Alstadt et al, (2012) found that industries that export or import natural resource and retail products derive more productivity benefits from intermodal freight terminal access.

In terms of connectivity, some of the model parameters in Shirley and Winston (2004) also indirectly suggest that supply chain and productivity are positively related. As shown above, the authors link firm productivity with reductions in logistics and inventory costs. Cost savings allow firms to become more competitive and encourage more business investments. Their EOQ inventory model shows the following results:
Highway congestion raises inventory cost. Logistics cost increase by $1 billion for every 10% increase in vehicle-miles traveled. Improvement in delivery times and reliability resulting from good supply chain management can reduce the number of freight movements on the road.

Inventories for raw materials can rise for a number of reasons, including delivery schedule variability, as well as materials demand variability and work-in-progress inventories. Shirley and Winston argue that faster and more reliable transportation system enables firms to lower reorder point due to less uncertainty over when the orders will arrive. Increased reliability in speed and cost also facilitates just-in-time inventory management, which helps lower inventory and warehousing-related costs.

4.5 References Cited: Supply Chain Benefits

Alstadt, B., G. Weisbrod & D. Cutler (2012). The Relationship of Transportation Access and Connectivity to Local Economic Outcomes. Transportation Research Record.

Baumol, W. and H. Vinod. (1970). "An Inventory Theoretic Model of Freight Transportation Demand." Management Science, 16(7): 413-421.

Beamon, B. M. (1999). Measuring Supply Chain Performance. International Journal of Operations & Production Management , 19 (3), 275-292.

Bichou, K., & Gray, R. (2004). A Logistics and Supply Chain Management Approach to Port Performance Measurement. Maritime Policy & Management , 31 (1), 47-67.

Blauwens, G., N. Vandaele, E.V. Voorde and F. Witlox (2006). "Towards a Modal Shift in Freight Transport? A Business Logistics Analysis of Some Policy Measures" Transport Reviews (March), 26,2, pp. 239 - 251.

Brox, J. A. (2008). Infrastructure Investment: The Foundation of Canadian Competitiveness. IRPP Policy Matters , 9 (2).

De Backer, K., & Yamano, N. (2012). International Comparative Evidence on Global Value Chains. Trade Policy Research 2011 - Global Value Chains: Impacts and Implications , 103-126.

DecisionTek and Economic Development Research Group (2012). The Comprehensive Costs of Highway-Rail At-Grade Crossing Crashes, NCHRP Project 8-85, National Cooperative Highway Research Program, Transportation Research Board.

Dullaert, W., B. Vernimmen, E. Aghezzaf and B. Raa (2007). “Revisiting Service-level Measurement for an Inventory System with Different Transport Modes” Transport Reviews, 1 - 11.

Gillen, D. (2000). Public Capital, Productivity, and the Linkages to the Economy: Transportation Infrastructure. Wilfrid Laurier University.

Globerman, S. (2012). Global Value Chains: Economic and Policy Issues. Trade Policy Research 2011 - Global Value Chains: Impacts and Implications , pp. 17-42.

Harchaoui, T. M., & Tarkhani, F. (2003). Public Capital and its Contribution to the Productivity Performance of the Canadian Business Sector. Economic Analysis (EA) Research Paper Series , 11F0027MIE - No. 017.

Iacobacci, M., & Schulman, J. (2009). The Productivity Performance of Canada's Transportation Sector: Market Forces and Governance Matter. Ottawa: Conference Board of Canada.

ICF Consulting, HLB Decision Economics and Louis Berger (2001). "Benefit/Cost Analysis of Highway Improvements in Relation to Freight Transportation: Microeconomic Framework," Freight Benefit/Cost Study, White Paper, Federal Highway Administration.

ICF Consulting and HLB Decision-Economics (2004). FHWA Freight BCA Study: Summary of Phase II Results, Federal Highway Administration. http://ops.fhwa.dot.gov/freight/freight_analysis/bca_study_phase2/index.htm

Industry Canada. (2011). Global business strategy and innovation: A Canadian logistics perspective. http://www.ic.gc.ca/eic/site/dsib-logi.nsf/eng/h_pj00528.html.

InterVISTAS. (2007). Gateways and Corridors and Productivity Measurement in a Supply Chain Management Environment. from http://www.intervistas.com/publications/publications.php

Limao, N., & Venables, A. J. (2001). Infrastructure, Geographical Disadvantage, Transport Costs, and Trade. The World Bank Economic Review , 15 (3), 451-479.

McKinnon, Alan (2003). "The Effects of Transport Investment on Logistical Efficiency", Logistics Research Centre, Heriot-Watt University, Edinburgh.

Mohring, H and H.F. Williamson (1969). F. "Scale and Industrial reorganization economies of transport improvements," Journal of Transport Economics and Policy, Sept. 1969.

Shirley, C., & Winston, C. (2004). Firm Inventory Behaviour and the Returns from Highway Infrastructure Investments. Journal of Urban Economics , 55, 398-415.

Stainer, A. (1997). Logistics - A Productivity and Performance. Supply Chain Management: An International Journal , 2 (2), 53-62.

Swan P. and J. Tyworth (2001) “Shipper Sensitivity To Unreliable Service in Carload Markets” Transportation Journal, Spring; 40, 3, 16 - 25.

Sydor, A. (2012). Global Value Chains: Impacts and Implications Editor's Overview. Trade Policy Research 2011 - Global Value Chains: Impacts and Implications , 1-15.

Transmode Consultants Inc. (1994) Truck-Rail, Rail-Truck Diversion Model Users Manual. Report prepared for the US Department of Transportation (December).

Tyworth, John E. and Amy Zhaohui Zeng. (1998). "Estimating the Effects of Carrier Transit-Time Performance on Logistics Cost and Service." Transportation Research Part A (Policy), 32A, no. 2 (February): 89-97.

Weisbrod, G., Vary, D., & Treyz, G. (2003). Measuring the Economic Costs of Urban Traffic Congestion to Business. Transportation Research Board , 1839, 1-23.

Weisbrod, Glen and Stephen Fitzroy (2011). Traffic Congestion Effects on Supply Chains: Accounting for Behavioral Elements in Planning and Economic Impact Models , in Sanda Renko, ed, Supply Chain Management - New Perspectives", InTech Publishers.

Wylie, P. (1995). Infrastructure and Canadian Economic Growth. Canadian Business Economics , 40-52.

Yeung, A. C. (2006). The Impact of Third Party Logistics Performance on the Logistics and Export Performance of Users: An Empirical Study. Maritime Economics & Logistics , 8, 121-139.

5 INTERMODAL CONNECTIVITY

5.1 Introduction to Connectivity Issues

Intermodal connectivity can be considered a cross-cutting element affecting productivity, since it can affect both market access and supply chain characteristics. This occurs in the following ways:

- *Market effects:* Whereas existing studies of market access largely focus on travel times and distances relevant for a single mode, intermodal connectivity can be seen as opening up new extensions of labor or customer markets. (For instance, express train services can extend labor market areas beyond the area normally achieved via road systems. And aviation services can enable local industries to expand into new export markets).
- *Supply chain effects:* Whereas existing studies of supply chains largely focus on inventory and vehicle deployment strategies that depend on scheduling for existing modes, inter-modal connectivity can be seen as opening up new scheduling and reliability solutions that involve mode switching. (For instance, air services can enable new forms of truck/air interchange and support growth of just-in-time processing. And new rail, sea or air services can require changes in surface travel schedules, and impose new penalties for failure to arrive at terminals before departure deadlines).

There are also unique factors distinguishing intermodal connectivity. One is that intermodal connectivity is typically defined in terms of the characteristics of the network node at which inter-modal interchange occurs (e.g., airports, marine ports, passenger train stations or intermodal freight terminals). These are specific location points, as opposed to the areas or delivery route systems that are the object of market access and supply chain analyses.

5.2 Defining Inter-modal Connectivity

Definition. Effects of intermodalism (i.e., availability of transportation utilizing intermodal connections) tend to vary depending on the model selection and data disaggregation. Authors such as Jennings and Holcomb (1996) and Debrie and Gouvernal (2006) noted that the term "intermodal" is not standardized across studies. Berrittella (2010) defined intermodal transport as the door-to-door movement of goods that involves two or more modes of transportation. Alstadt et al. (2012) defined connectivity as "the ease, time or cost of traveling between different transportation route systems or modal systems." Those same authors further defined intermodal connectivity in terms of the link between surface transportation (highway or rail) routes and terminals or interchanges for accessing other modes (which may involve surface, air or marine travel). This definition encompasses the connection between road transport and the interchange point or terminal for any other mode such as an airport or seaport.

More generally, research studies on the benefits of intermodal connectivity focus tend to focus on the following specific types of facilities:

- *Airports* - interchange between road (car, bus, truck) and aviation modes; a few airports also have interchange between passenger rail and aviation modes; most airports serve mixed passenger and cargo activities.
- *Marine ports* – interchange between road (car, bus, truck) and marine modes; many cargo ports also have interchange between freight rail and marine modes; most are either passenger only (ferry terminals or cruise ports) or cargo only.
- *Rail terminals* –interchange between road (car, bus, truck) and rail modes; most are either passenger facilities (train stations) and or cargo only (intermodal freight terminals);
- *Border crossings* – interchange between the road or rail systems of different nations.

Connectivity Measurement. For any of the above types of intermodal nodes, the most common metrics used to characterize them are:

a) Size/capacity of terminals
b) Level of activity: daily or annual vehicle (aircraft/train/ship) arrivals + departures
c) Throughput (use): daily or annual passengers, cargo tons or container TEUs
d) Frequency of Service: average wait time between arrivals or departures
e) Breadth of connections provided (number of different destinations served).
f) Travel time to/from specified employment or population centers

At least two studies have developed connectivity indices based on these factors:

- ICF (2012) developed a tool for rating and evaluating intermodal connectivity for the US Strategic Highway Research Program. Their tool calculates a connectivity rating for all road, air, marine and rail terminals in the US, based on a database of information on their levels of activity (scheduled arrivals and departures) , throughput (passenger volumes), breadth of connections (number of origins and destinations served) and average access times from the surrounding population base.
- The International Air Transport Association (IATA) developed an index for comparing the international aviation connectivity of major airports and countries (see Oxford Economics, (2011, p.24). This connectivity index reflects total passenger seat capacity for nonstop flights from that airport to every destination (based on frequencies of service and seats per flight to that destination), weighted by the relative importance of each destination in the global air transport network (calculated on the basis of total seats available from that airport to anywhere else in the world).

There are also some studies that have focused on only one or two of these dimensions of connectivity. For instance, Targa (2005) related business concentrations at the zip code level to travel time for accessing rail transit stations and airports. Cambridge Systematics et al (2008) develop measures of the impacts of highway network improvements on highway drive times to the closest airport, marine port and intermodal rail terminal. Alstadt et al (2012) presented a gravity model that related business concentration to both airport access time and airport activity level. They also repeated the analysis, using only information on access time, for marine and rail terminals.

The use of these types of basic intermodal characteristics is consistent with the finding of Shepherd et al. (2011), who noted that the dimensions of intermodalism fall into basic dimensions, including:

- quantity and quality of the infrastructure (corresponding to above elements a, b and c in the preceding list of connectivity metrics);
- private sectors' ability to coordinate intermodal linkages (corresponding to elements c and d); and
- the network of links (i.e. roadways, railways, air/sea routes) and nodes (i.e. port terminals and airports), and their flows (corresponding to elements e and f).

A favorable intermodal connectivity is associated with reductions in business operating costs (transport and logistics expenses), improvements in supply chain management, and expansion of trade and foreign direct investment opportunities (Shepherd et al. 2011). Any one of these factors can contribute to reducing cost or increasing returns to scale, and thus positively relate to business output and productivity holding all else constant).

5.3 Modeling Connectivity-Productivity Linkages

Multimodal Productivity

Targa et al. (2005) used an econometric model to show that statistically significant association exists between business activity and various transport access measures. The authors find that the magnitude for the coefficient capturing primary highway facilities is substantial relative to other transport access variables. The positive coefficient suggests that more roadway access translates to higher number of business establishments per square kilometer, holding all else constant. The authors obtained mixed results for airport access – the variable capturing access time to Dulles airport (IAD) had a negative coefficient, while access time to Washington National (DCA) and to Baltimore-Washington (BWI) airports had positive coefficients. The authors suggested that the proximity to local economic centers may influence the sign of the airport access time coefficients. Targa et al. (2005) also found positive and statistically significant coefficient for rail transit access variable. These findings seem consistent with those of Notteboom (2008) and Rodrigue (2012), who showed that road and rail transport are complementary and are critical components to favorable intermodal connectivity.

Berrittella (2010) used a multi-country economic forecasting and simulation model to analyze the macroeconomic impacts that investment in intermodal connectivity in Europe have on the European Union and on the other economies. The paper looked specifically at the construction of the four major corridor rail lines in Europe: the North-South corridor; the Betuwe corridor (between Netherlands and Germany); the France-Italy corridor; and the East European corridor. The simulation results showed that increase in investments in combined transport (intermodalism) contributes to negative trade balances (higher imports), positive economic growth (higher GDP), and larger welfare for the European nations. However, the study showed that this intermodal investment in Europe benefits the directly served home regions rather than foreign regions, as the model showed losses for the U.S., Japan and South America. Berrittella's (2010) findings appear consistent with Chandra and Thompson's (2000) results, which showed that economic activity tends to increase for counties in which highways directly pass through, while it decreases for adjacent counties.

Some studies find mixed results regarding intermodalism. Black (1974) used a multivariate time series methodology and finds a negative relationship between Interstate highway construction and passenger enplanement (which is a proxy for air transport services) for non-hub airports in Indiana. The construction of the Interstate highway was intended to increase accessibility, and the author suggested that benefits would be derived only for large airports. Small airports would lose passengers, as the passengers are willing to substitute highway travel for a portion of the trip. Black (1974) also found that the measures of connectivity used in his model, such as the number of routes connected to airport, number of routes passing through the terminal, number of trunk lines using the terminal, are more influential than expected.

Buckley and Westbrook (1991) used a cost function approach to explore the relationship between truck and rail and obtain a high measure of substitutability between the two modes of transport. The elasticity measures imply vigorous competition between the two modes of transport, which seems contrary to the objective of intermodal connectivity. Lim and Thill (2008) concluded that intermodalism enhances average accessibility and their model shows that all other things held constant, accessibility gains are on average higher for regions with poor highway accessibility.

Some research has looked specifically at how one mode of transportation influences productivity growth. However, as noted above, studies such as Shepherd et al. (2011) do show that the overall performance from multimodal transport is greater than the performance from any of the individual transport mode. As such, results derived from models looking specifically at how one transport mode influences productivity growth would be underestimated.

International Trade

Export Volumes. To evaluate the relationship between exports and transport infrastructure, Shepherd et al. (2011) used a gravity model, together with data on total exports from APEC (Asia Pacific Economic Cooperation) members to up to 229 overseas markets. The authors calculated a multimodal transport variable using "principal components analysis," where this variable incorporates the air, maritime, land transport, and logistics competence indicators.[3] Elasticity measure for that multimodal transport indicator were greater than the elasticity measure for any single transport mode[4]. They also concluded that gains from reforming multimodal transport translate to an average $500 billion increase in exports per APEC member region (or 4% export growth), and "economies that are open, highly integrated into world markets, and with strong multimodal connectivity gain even more" (page 646).

In other words, intermodalism contributes more to exports than what any single mode of transport can do. Shepherd et al. (2011) found that the multimodal transport variable has a higher impact on trade than variables capturing single transport modes because the overall performance is strongly influenced by how effectively the transport modes work together. This explanation implies complementarity between the transport modes. Shepherd et al. (2011) also argues that trade performance depends a lot on the quality and competence of private logistics services than on the other aspects of multimodal transport, which suggests that the multimodal result is more demand driven than supply side driven. After correcting for reverse causality via the use of an instrumental variable, the same paper finds the elasticity of exports with respect to multimodal transport index to be at 1%. With favorable intermodal connectivity, output is anticipated to go up due to larger export numbers, holding all else constant.

International Trade and Transport Costs. Limao and Venable (2001) and Micco and Serebrisky (2006) also used a gravity model to show that international trade and transportation infrastructure are strongly linked. Micco and Serebrisky (2006) found that greater investment in airport infrastructure helps lower overall transport cost; and Limao and Venable (2001) found that poor infrastructure accounts for 40% of transport costs for coastal countries and up to 60% for landlocked countries. Transport cost negatively influences trade volumes. Furthermore, landlocked countries are disadvantaged in terms of

[3] The air indicator is a weighted average of the number of primary airports and the number of secondary airports in each member economy; the maritime indicator is a weighted average of the number of ships, container-carrying capacity, vessel size number of services, and the number of companies deploying containerships to and from an economy's ports; the land indicator is a weighted average of the road infrastructure density and rail infrastructure density; and the logistics environment indicator is based on survey responses given by logistics professionals around the world relating to competence and quality of logistics services. All are calculated based on the principal components analysis (Shepherd et al. 2011).

[4] According to Shepherd et al. (2011), the elasticity of exports with respect to multimodal transport is 3.2%; with respect to maritime transport is 1.2%; with respect to air transport is 0.9%; and with respect to land transport is 0.5%.

trade due to accessibility issues, but they could overcome some of this by improving their own infrastructures (Limao and Venable 2001).

International Connectivity and National Productivity. Besides the connection to international trade levels and transport costs, other research studies have examined the relationship between the IATA index of airline connectivity among nations and levels of national productivity. Although causation is not established, several studies have shown a statistically significant relationship although elasticity estimates vary (Oxford Economics, 2005; Intervistas, 2006).

5.4 5.4 Individual Ports and Terminals

Port/Terminal Function. Airports, marine ports, bus and railroad terminals (including intermodal rail yards) serve two types of function: (1) as a transfer point for freight or passenger movements within the same mode, and (2) as a transfer point between modes. With the first type of function, the facility is a network node that has transfer properties enabling it to expand the effective network size and density, or to represent a bottleneck in the network. With the second type of function, the facility can serve as a gateway to access broader markets served by the other mode. This can be illustrated by the graphic in Figure 5-1, which shows how an airport expands the effective market for same-day business travel by opening up travel to/from other cities. (In this case, the illustration shows areas accessible within 2 hours travel time from Boston via direct driving or hourly air shuttle service).

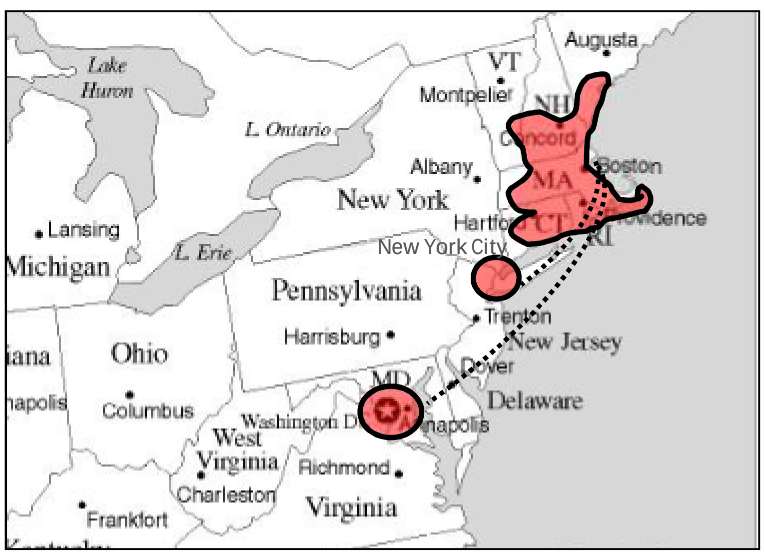

Figure 5-1 Illustration of Port/Terminal as a Gateway to Markets

(cities within 2 hours total travel time from downtown Boston, based on driving a car or flying to destinations that have hourly or more frequent air service during business hours)

Port/Terminal Transfers. It is important to distinguish the productivity of a port/terminal from the productivity of carriers using it, and its effects on the productivity of the surrounding regional economy. It is logical that if the port/terminal is serving as a gateway to and from surrounding areas, then the productivity of the terminal can directly affect the productivity of area businesses that depend on it for incoming or outgoing movements of passengers and freight. On the other hand, if a port/terminal is primarily serving as a transfer hub for movements that start and end outside the local area and just pass through it, and transportation carriers are also based outside the region, then effects on the local economy may be limited to just support for the port/terminal operation. Of course, a port/terminal can provide a combination of both uses.

It is also important to distinguish productivity from gross economic impact. The choice by a global transportation carrier to move the location of one of its hubs may have only a small net effect on that carrier, but a significant gross impact on the economy of the affected area losing hub service (depending on the extent to which it serves local customers).

Ground Access. The role and importance of a port or intermodal facility for a region's economy can also depend on the quality of ground access feeder networks. The importance of this relationship is supported by studies showing that inland accessibility does influence a port's competitiveness, and that competitiveness can be enhanced if port access to the hinterland[5] is efficient (Notteboom, 2008; Notteboom and Rodrigue, 2005; OECD/ITF, 2008). A port's competitiveness can also have direct implications for a region's overall productivity and economic growth because of the direct relationship between regional productivity and competitiveness that was noted back in Section 1.2.

Alstadt et al. (2012) examined the relationship of local business productivity to variation in highway ground access to intermodal terminals. They calculated the mean travel time to airports, marine ports, intermodal rail terminals and international gateways for 3200 locations across the US. They then applied non-linear regression techniques to relate those intermodal access metrics to observed ratios of output per worker and export share of output among 54 industry sectors. Their findings, similar to those of earlier studies by Fernald (1999) and Harchaoui and Tarkhani (2003), showed that market access and intermodal connectivity do influence the productivity benefits derived by the various industry sectors, though that relationship differs depending on the industry sector.

Reliability of transportation on regional access routes serving a port/terminal can also affect the amount of cargo going inbound and outbound through that terminal. In the case of freight movement, cargoes may divert to other nearby ports if the reliability of the total route is poor, which would affect export and import numbers, thereby influencing productivity growth. Numerous papers such as Debrie and Gouvernal (2006), Notteboom

[5] According to Rodrigue and Notteboom (2010), geographers have not agreed upon the definition of hinterland. The authors suggest that early works defined the term, "hinterland" as follows: "the area of which greater part of the trade process passes through the port" (page 2).

(2008), OECD/ITF (2008) have recommended connecting port operations with rail transport as a mean to relieve congestion, to retain control and extend current hinterlands, and to open up more market opportunities to maintain competitive advantage over competitors. Multimodal transport connectivity, such as complementarity between road and rail transport, is important for both the port's success and for economic development (Notteboom 2008; Rodrigue 2012).

5.5 References Cited: Intermodal Connectivity

Allroggen, F., & Malina, R. (2010). Causal Relationships between Airport Provisions, Air Traffic and Economic Growth. *12th WCTR*, (pp. 1-18). Lisbon, Portugal.

Alstadt, B., Weisbrod, G., & Cutler, D. (2012). The Relationship of Transportation Access and Connectivity to Local Economic Outcomes. *Transportation Research Board, Annual Conference*, (pp. 1-18).

Antunes, P., Beckman, K., & Johnson, J. (2010). *The Economic Impact of Public Infrastructure in Ontario.* Ottawa: Conference Board of Canada.

Aschauer, D. A. (1989). Is Public Expenditure Productive. *Journal of Monetary Economics , 23*, 177-200.

Baird, B. (2005). Public Infrastructure and Economic Productivity: A Transportation-Focused Review. *Transportation Research Record: Journal of the Transportation Research Board , No. 1932*, 54-60.

Baltagi, B. H., & Pinnoi, N. (1995). Public Capital Stock and State Productivity Growth: Further Evidence from an Error Components Model. *Empirical Economics , 20*, 351-359.

Beamon, B. M. (1999). Measuring Supply Chain Performance. *International Journal of Operations & Production Management , 19* (3), 275-292.

Berrittella, M. (2010). A Macroeconomic Analysis of the Public Investments in European Combined Transport. *Empirical Economics , 39*, 167-181.

Bichou, K., & Gray, R. (2004). A Logistics and Supply Chain Management Approach to Port Performance Measurement. *Maritime Policy & Management , 31* (1), 47-67.

Black, W. R. (1974). Intermodal Impacts: Interstate Highways and Airport Viability. *Journal of Transport Economics and Policy , 8* (2), 136-147.

Brox, J. A. (2008). Infrastructure Investment: The Foundation of Canadian Competitiveness. *IRPP Policy Matters , 9* (2).

Buckley, P., & Westbrook, M. D. (1991). Market Definition and Assessing the Competitive Relationship between Rail and Truck Transportation. *Journal of Regional Science , 31* (3), 329-346.

Cambridge Systematics, EDR Group and HDR Decision Economics (2008). Economic Impact Study of Completing the Appalachian Development Highway System, Appalachian Regional Commission.

Chandra, A., & Thompson, E. (2000). Does Public Infrastructure Affect Economic Activity? Evidence from the Rural Interstate Highway System. *Regional Science and Urban Economics , 30*, 457-490.

Chow, G., Heaver, T. D., & Henriksson, L. E. (1994). Logistics Performance: Definition and Measurement. *International Journal of Physical Distribution & Logistics Management , 24* (1), 17-28.

Davidson, R., & MacKinnon, J. G. (2004). *Econometric theory and methods.* New York: Oxford University Press.

De Backer, K., & Yamano, N. (2012). International Comparative Evidence on Global Value Chains. *Trade Policy Research 2011 - Global Value Chains: Impacts and Implications* , 103-126.

Debrie, J., & Gouvernal, E. (2006). Intermodal Rail in Western Europe: Actors and Services in a New Regulatory Environment. *Growth and Change , 37* (3), 444-459.

Fernald, J. G. (1999). Roads to Prosperity? Assessing the link between public capital and productivity. *The American Economic Review , 89* (3), 619-638.

Gillen, D. (2000). *Public Capital, Productivity, and the Linkages to the Economy: Transportation Infrastructure.* Wilfrid Laurier University.

Globerman, S. (2012). Global Value Chains: Economic and Policy Issues. *Trade Policy Research 2011 - Global Value Chains: Impacts and Implications* , pp. 17-42.

Gu, W., & MacDonald, R. (2009). The Impact of Public Infrastructure on Canadian Multifactor Productivity Estimates. *The Canadian Productivity Review , 15-206-X* (21).

Harchaoui, T. M., & Tarkhani, F. (2003). Public Capital and its Contribution to the Productivity Performance of the Canadian Business Sector. *Economic Analysis (EA) Research Paper Series , 11F0027MIE - No. 017*.

Helling, A. (1997). Transportation and Economic Development: a Review. *Public Works Management Policy , 2* (1), 79-93.

Iacobacci, M., & Schulman, J. (2009). *The Productivity Performance of Canada's Transportation Sector: Market Forces and Governance Matter.* Ottawa: Conference Board of Canada.

ICF International (2012). "Intermodal Connectivity Tool," in Economic Development Research Group et al, Development of Tools for Assessing Wider Economic Benefits of Transportation, Strategic Highway Research Program, Project C11, Transportation Research Board.

Industry Canada. (2011). *Global business strategy and innovation: A Canadian logistics perspective.* http://www.ic.gc.ca/eic/site/dsib-logi.nsf/eng/h_pj00528.html.

InterVISTAS. (2007). *Gateways and Corridors and Productivity Measurement in a Supply Chain Management Environment.* From http://www.intervistas.com/publications/publications.php

Jennings, B., & Holcomb, M. C. (1996). Beyond Containerization: The Broader Concept of Intermodalism. *Transportation Journal , 35* (3), 5-13.

Johansen, S. (1994). The Role of the Constant and Linear Terms in Cointegration Analysis of Nonstationary Variables. *Econometric Reviews , 13*, 205-229.

Lau, Paul, S.-H., & Sin, C.-Y. (1997). Public Infrastructure and Economic Growth: Time Series Properties and Evidence. *The Economic Record , 73* (221), 125-135.

Limao, N., & Venables, A. J. (2001). Infrastructure, Geographical Disadvantage, Transport Costs, and Trade. *The World Bank Economic Review , 15* (3), 451-479.

Micco, A., & Serebrisky, T. (2006). Competition regimes and air transport costs: The effects of open skies agreements. *Journal of International Economics , 70*, 25-51.

Mirza, S. (2007). Danger Ahead: The Coming Collapse of Canada's Municipal Infrastructure. *A Report of the Federation of Canadian Municipalities.* Ottawa.

Notteboom, T. (2008). The Relationship between Seaports and the Intermodal Hinterland in light of Global Supply Chains. *Joint Transport Research Centre Round Table. Discussion Paper 2008-10.* Paris: OECD / International Transport Forum.

Notteboom, T., & Rodrigue, J.-P. (2005). Port Regionalization: Towards a New Phase in Port Development. *Maritime Policy and Management , 32* (3), 297-313.

OECD / International Transport Forum. (2008). Port Competition and Hinterland Connections. *Joint Transport Research Centre Round Table*, *Discussion Paper 2008-19.* Paris.

Pathomsiri, S., Haghani, A., Dresner, M., & Windle, R. J. (2006). Role of Freight Transportation Services and Reduction o Delayed Flights on Productivity of US Airports. *National Urban Freight Conference*, (pp. 1-18). Long Beach, CA.

Rodrigue, J.-P. (2012). *The Containerization of Commodities: Integrating Inland Ports with Gateways and Corridors in Western Canada.* Calgary: Van Horne Institute.

Romer, D. (2006). *Advanced Macroeconomics* (3rd ed.). New York: McGraw-Hill Irwin.

Roson, R., & Soriani, S. (2000). Intermodality and the Changing Role of Nodes in Transportation Networks. *Transportation Planning and Technology , 23*, 183-197.

Shepherd, B., Serafica, R. B., Bayhaqi, A., & Jing, H. (2011). The Trade Impact of Enhanced Multimodal Connectivity in the Asia-Pacific Region. *Journal of Economic Integration , 26* (4), 624-650.

Shirley, C., & Winston, C. (2004). Firm Inventory Behaviour and the Returns from Highway Infrastructure Investments. *Journal of Urban Economics , 55*, 398-415.

Stainer, A. (1997). Logistics - A Productivity and Performance. *Supply Chain Management: An International Journal , 2* (2), 53-62.

Sydor, A. (2011). Global Value Chains: Impacts and Implications Editor's Overview. *Trade Policy Research 2011 - Global Value Chains: Impacts and Implications* , 1-15.

Targa, F., Clifton, K. J., & Mahmassani, H. S. (2005). Economic Activity and Transportation Access: An Econometric Analysis of Business Spatial Patterns. *Transportation Research Record: Journal of the Transportation Research Board , No. 1932*, 61-71.

Tatom, J. (1991). Public Capital and Private Sector Performance. *St Louis Federal Reserve Bank Review , 73*, pp. 3-15.

Wylie, P. (1995). Infrastructure and Canadian Economic Growth. *Canadian Business Economics* , 40-52.

Yeung, A. C. (2006). The Impact of Third Party Logistics Performance on the Logistics and Export Performance of Users: An Empirical Study. *Maritime Economics & Logistics , 8*, 121-139.

6 TRAVEL TIME RELIABILITY

6.1 Introduction to Reliability Issues

Reliability refers to the variability of travel times relative to their average levels. It can also be considered a cross-cutting element affecting productivity since it can also affect both market access and supply chain characteristics. This occurs in the following ways:

- *Market effects:* Market access studies discussed in Chapter 3 typically define transportation changes as affecting labor and customer markets through changes in effective distance, effective density or market size – all driven by shifts in average travel times. However, consideration of travel time reliability can be seen as introducing an additional factor that can potentially expand or contract the effective size and scale of labor and delivery markets.
- *Supply chain effects:* Whereas supply chain studies typically define inventory and vehicle deployment strategies on the basis of expected schedule frequency, capacity and travel times, reliability considerations introduce uncertainty leading to schedule padding (reducing delivery stops) and increases in carrying of inventory safety stocks.

There are also unique factors distinguishing reliability. Reliability is typically defined in terms of bottlenecks at specific links in transportation networks, rather than the area-wide effects (in the case of market access) or route effects (in the case of supply chains).

6.2 Defining Reliability

In general, reliability is defined as "the extent to which an experiment, test, or measuring procedure yields the same results on repeated trials" (Merriam-Webster 2012). In the context of the transportation system, this means users experiencing similar conditions from one trip to the next. While these similar results or certainty could refer to many aspects of the transportation, such as pavement quality, availability of certain routes, or absence of an accident, most researchers and transportation professionals have focused on the issue of how variations in travel time affect users. In this sense, "reliability" is the ability of the transportation system to provide consistent travel times. The Strategic Highway Research Program (2001) was initiate by the US Congress with a reliability goal to "provide reliable travel times by preventing and reducing non-recurring congestion."

In recent years, there has been a growing recognition in the transportation community that consistent or reliable travel times are important to travelers and the movement of goods. Figure 6-1 illustrates how travel time reliability and travel time represent distinct concepts. In economic analysis, they can be represented as separate benefits to users. These two measures are analogous to risk and return as defined in the landmark Markowitz (1952) paper that established modern portfolio theory.

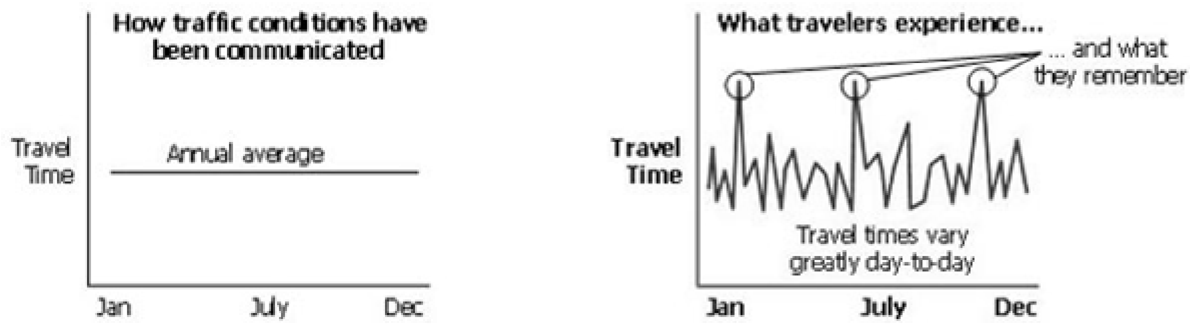

Figure 6-1: Travelers Experience More than Average Travel Times
Source: Texas Transportation Institute and Cambridge Systematics (2006)

In addition, the public's "demand" for reliability has been increasing. The Joint Transportation Research Centre (JTRC) of the Organization for Economic Co-operation and Development (OECD) and the International Transport Forum (ITF) attributed this to more complex scheduling. Improvements in regional, state, national, and global transportation networks have facilitated the development of just-in-time supply chains that increase the importance of reliable travel times for freight transportation. These changes have been mirrored on the passenger side as changes in personal lifestyle and employment patterns have increased the importance of scheduling (JTRC, 2010).

A critical factor that has been increasing interest in reliability effects is the continuing growth of road traffic, which not only slows speeds, but also dramatically increases travel time variability. As traffic volumes approach road capacity, travel speeds slow due to "recurring delay," but travel time variability grows even faster due to an exponential increase in "non-recurring delay" triggered by transient events. In plain English, this means that while a small traffic incident usually has negligible effect on traffic movement in an uncongested road, it is likely to lead to major backups (queues) on congested roads. Thus, there is a direct relationship between road congestion and travel time variability.

While unreliable travel has obvious costs by increasing user frustration and stress, it has not been incorporated into benefit-cost analysis until recently. This omission is glaring, because if travel time reliability is important to businesses and people, it certainly affects the economy. Individuals can respond to unreliability by planning for delays and adding extra buffer times to their schedules. This extra time reduces labor productivity, the size of the labor pool accessible to particular businesses, and personal consumption.

In supply chain research, it is well established that businesses respond to unreliability by changing their pattern of operations, by holding additional safety stock, increasing warehouse space, and/or investing in systems that provide traffic flow information to reduce the impact of unreliability. These additional investments may help businesses cope with unreliable travel times, but they reduce the return on capital.

6.3 Empirical Estimation of Effects

To incorporate travel time reliability into the economic analysis of transportation infrastructure, the following information is needed:

- Measure for travel time reliability
- Value of reliability
- Methods for predicting future reliability and estimating changes in reliability due to transportation improvements (Williges, 2010).

There is a wide body of research on the appropriate probability distribution to use for modeling travel times. Fosgerau and Fukuda (2010), Taylor (2009), and (Susilawati et al. 2010) provided three such examples. SHRP2 Project L03 identified a number of different reliability performance metrics, shown in Table 6-1 on the next page (Margiota, 2010). Nearly all were derived from the distribution of travel time, so any of these metrics can be derived if the underlying travel time data or the appropriate statistical moments (e.g., mean and variance) are known.

Table 6-1: Alternative Reliability Performance Measures

Reliability Performance Metric	Definition(s)	Units
Buffer Index (BI)	• The difference between the 95th percentile travel time and the average travel time, normalized by the average travel time • The difference between the 95th percentile travel time and the median travel time, normalized by the median travel time	None
Failure/On-Time Measures	• Percent of trips with travel times less than 1.1 × Median Travel Time *or* 1.25 × Median Travel Time • Percent of trips with space mean speed less than 50 mph; 45 mph; or 30 mph	Percent
80th Percentile Travel Time Index	80th percentile travel time divided by the free-flow travel time	None
Planning Time Index	95th percentile travel time divided by the free-flow travel time	None
Skew Statistic	The ratio of (90th percentile travel time minus the median) divided by (the median minus the 10th percentile)	None
Misery Index (Modified)	The average of the highest 5 percent of travel times divided by the free-flow travel time	None
Standard Deviation of Travel Time or Travel Rate*	Standard statistical definition	Minutes

Source: SHRP2 Project L03 Final Report, 2010.

In general, research on this topic has focused on two theoretical frameworks for measuring reliability:

- Mean-variance theory – Transportation users are expected to optimize their decisions across both measures. Travel time impacts are measured by the mean of the travel time distribution, while travel time reliability impacts are measured by the standard deviation of the distribution. Benefits can be summed in an economic analysis.
- Scheduling theory – Transportation users are assumed to have a preferred arrival time and chose a departure time that allows them to arrive at the preferred time. Travelers incur "disutilities" (negative value) for early or late arrival. Transportation impacts are measured by travel time, early arrivals, and late arrivals.

Significant research has been conducted on both approaches. Vickery (1969) and Small (1982) provided the early work on scheduling theory and this research underlies most estimates of the value of time. Jackson and Jucker (1982) introduced the mean-variance theory to transportation research, but the approach has a much older basis in the financial economics literature in the form of risk-return models (see Markowitz 1952). Carrion and Levinson (2012) provided a detailed overview of the two theoretical approaches and recent research extensions. Researchers have preferred the scheduling approach because it allows for "asymmetrical disutilities" – i.e., disproportionately larger negative effects associated with late arrival than benefits associated with early arrival.

Some analysts and researchers prefer the mean-variance approach for incorporating travel time reliability into benefit-cost models because it fits neatly into the existing economic frameworks. Travel time benefits correspond to the mean. Travel time reliability can be added as an extra user benefit measured by the standard deviation (the square root of the variance), which is in the same units as travel time. Fosgerau and Karlstrom (2010) showed that scheduling delay models can be approximated by mean-variance models under certain conditions (i.e., travelers know the distribution of travel times on their travel corridors and have early and late preferences), so the two approaches are compatible.

With the mean-variance approach, the value of travel time reliability is typically expressed as a proportion of travel time. This proportion, called the "reliability ratio," indicates how the value of travel time reliability relates to an economic value that has already been established - the value of travel time. As with the value of time, reliability ratios can be estimated from stated preference (SP) or revealed preference (RP) approaches. Liu et al. (2007) developed an alternative to SP and RP for estimating the value of travel time reliability. Liu et al. took a time-dependent approach that assumes travel time preferences regarding travel time and its reliability are related to departure time. They used a statistical model to estimate route choice using three randomly distributed variables (i.e., travel time, reliability, and monetary cost) and found that values of reliability are close to their respective values of time using data from State Route 91 in Orange County, California.

Carrion and Levinson (2012) reviewed the reliability ratios estimated in several studies. As shown in Figure 6-2, there vary though many researchers find values of reliability roughly equal to the value of time (i.e., reliability ratio of 1.0). Carrion and Levinson explored the potential causes of variation in estimates and found that the time of day when data is collected as well as the location are significant, while the data collection method (SP or RP) is not. Although not explored by Carrion and Levinson, the value for reliability is likely to vary greatly by individual, income, travel time, and trip purpose (which may not be same classification as used in travel demand models), and monetary advantage from better scheduling in the case of freight. Few studies have estimated reliability ratios or other reliability values for freight travel.

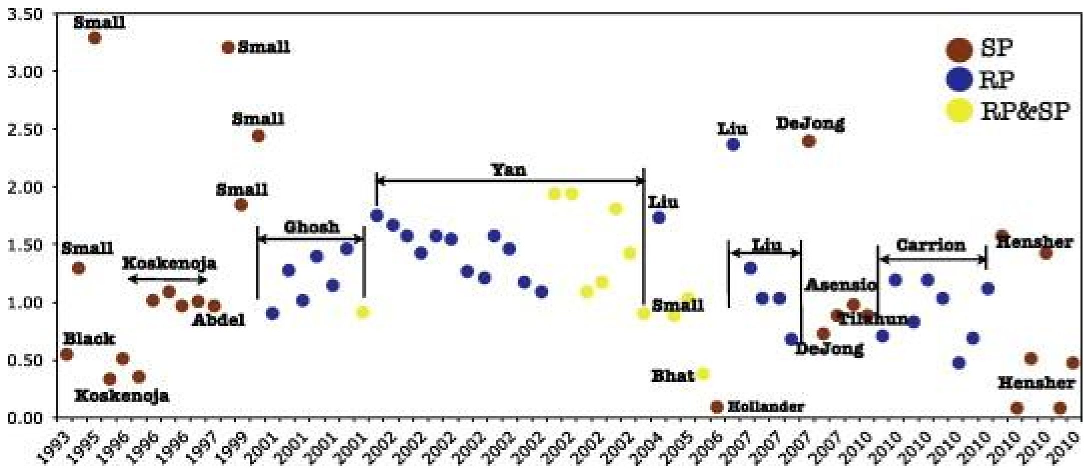

Exhibit 6-2: Reliability Ratio of Selected Studies

Source: Carrion and Levinson (2012)

As noted in the SHRP2 workshop on travel time reliability (Cambridge Systematics and ICF, 2012), several countries have adopted specific reliability ratios to use in benefit-cost analysis:

- Australia – 1.3 for cars (Australian Transport Council, 2006)
- Netherlands – 0.8 for cars (Kauppila, 2011)
- New Zealand - 0.8 for cars, 1.2 for commercial vehicles, and 0.9 for typical mixed urban traffic (NZ Transport Agency, 2010)
- Sweden – 0.9 for cars and freight (Eliasson, 2009)
- United Kingdom – 0.8 for highway travel (UK Department for Transport 2009).

There are a few large-scale stated preference studies underway or recently completed in Europe. The Research Council of Norway's Institute of Transportation Economics (TØI) is conducting two studies on the value of reliability (Samsted et al., 2009). The first study attempts to value time, reliability, comfort factors, traffic safety, and the environment for passenger transportation using a stated preference survey. The second study focuses on freight transport and the value of time and reliability for producers, retailers, as well as road and rail carriers, but is not completed. A stated preference survey similar to the Norwegian one has since been initiated in the Netherlands (Warffemius 2009).

6.4 Application in Analysis of Productivity

Until recently, transportation professionals in the United States have used proxy methods for incorporating travel time reliability in economic analysis. The most typical approach is to use a higher value of time for “unexpected” or non-recurring delay that results from traffic congestion. To implement this concept in economic impact or benefit-cost analysis, it is necessary to calculate both a value for the average expected addition of non-recurring delay (in minutes) and then apply a time valuation (penalty cost factor), which is set to be a multiple of the normal value of time.

For example, the Intelligent Transportation Systems Deployment Analysis System (IDAS) benefit-cost model uses a value of time three times the standard value for delays associated with traffic incidents (Margiotta, 2009). The Cal-B/C benefit-cost model uses the same ratio, since it was adopted from IDAS (System Metrics Group, 2004). The HEAT model used in Montana has an even higher value of time for non-recurring congestion. These more valuable delays are included in the user benefits inputted into the regional economic model (Wornum and Hodge, 2005).

Through SHRP2, the US government has conducted extensive research on reliability. Four projects provide analysis tools useful for incorporating reliability in economic analysis:

- Project L03 (Analytic Procedures for Determining of Reliability Mitigation Strategies) examined congestion by source using traffic, incident, weather, and geometric data to capture valuations in travel times. The project provides models to predict travel time reliability measures and distributions using only volume data as well as including more detailed incidents, weather, and work zone data (Cambridge Systematics et al., 2011).
- Project L07 (Evaluation of the Costs and Effectiveness of Highway Design Features to Improve Travel Time Reliability) developed a spreadsheet tool for analyzing the reliability benefits of design treatments on freeways in peak periods. The tool estimates a benefit-cost ratio using only travel time and travel time reliability user benefits (MRI Global and HDR, 2012).
- Project L08 (Incorporation of the Non-Recurrent Congestion Factors into the Highway Capacity Manual Methods) updates the Highway Capacity Manual to include travel time reliability calculations. It also updated the FREEVAL spreadsheet tool to include reliability on freeways and developed a new spreadsheet tool (STREETVAL) to evaluate changes in travel time reliability on signalized roadways (Kittelson, 2012).
- Project C11 (Development of Improved Economic Analysis Tools Based on Recommendations from Project C03) developed a sketch-planning corridor

spreadsheet to predicts the travel time percentiles, buffer time indices and dollar values of travel time reliability benefits for use in benefit-cost analysis. The C11 project also addressed other wider economic benefits, such as connectivity and accessibility (Margiotta et al. 2012).

One of the outcomes of the L03 and C11 research has been refinement of the "buffer time index" calculation models, building on a concept developed from earlier FHWA and AASHTO research (Cambridge Systematics, 2005 and 2008). Buffer time represents the added time would need to be padded into travel schedules to allow for on-time arrival 95% of the time. There is a distribution of travel time variation in which the mean-variance ratio and buffer time index can yield equivalent results for use in benefit-cost analysis. However, the buffer time concept has been recognized as being behaviorally intuitive to the public and also useful for calculation of business productivity based on cost savings associated with inventory management and worker shift schedules.

Building on the SHRP L03 analysis, there is now an option for derivation of buffer times based on volume/capacity data for both BCA and economic impact analysis in the TREDIS system (Alstadt and Weisbrod, 2008). That approach has been utilized for studies estimating the benefits and costs of congestion reduction in Portland (OR), Vancouver (BC) and Chicago (IL).

Travel demand models can be used to estimate either buffer times or standard deviations of traffic delay. The Dutch use a network-based travel demand model and run Monte Carlo simulations of input variables (e.g., travel demand and capacity) to model the potential ranges of travel time reliability (Van der Waard 2009). New Zealand also uses travel demand models to estimate standard deviation from network skim matrices (New Zealand Transport Agency 2010). Incorporating travel time reliability into benefit-cost modeling can capture economic productivity benefits through either direct productivity estimation or the standard US approach (of using a benefit-cost model in combination with a regional economic model).

Outside the United States, a number of countries are also moving towards incorporating travel time reliability in their national benefit-cost analysis methods. Both Australia (Australian Transport Council 2006) and the New Zealand (New Zealand Transport Agency 2010) already include travel time reliability in benefit-cost analysis, but use simple methods. The Netherlands, Sweden, and Norway are engaged in active reliability research. Since the Eddington (2006) Study, the UK Department for Transport has worked on developing guidance for incorporating travel time reliability in project evaluations. WebTAG (Transport Analysis Guidance) Unit 3.5.7 provides the current appraisal guidance (UK Department for Transport, 2009).

The UK Department for Transport has developed an Incident Cost-Benefit Assessment (INCA) spreadsheet that provides an estimate of travel time reliability using an incident history. INCA operates as an add-on to existing modeling to estimate the delays due to queuing and the variability of these delays. The model has not been included in UK benefit-cost analysis due to unresolved theoretical issues. For example, it is unclear how the incident parameters should be modified for more innovative operational strategies, such as shoulder operations (Chiang 2009).

The Dutch have taken two approaches to modeling reliability. The first approach models travel time variation from the user perspective using the Simulation Model for Analyzing the Reliability of Accessibility (SMARA). The model uses output from a network travel demand model. The variations of travel times are estimated by applying Monte Carlo simulation of input variables, such as travel demand and link capacity. The output is presented as the percentage of trips on time. A post processing tool can calculate the reliability indicators using relationships with output variables (Van der Waard 2009).

A second Dutch approach addresses the alternative definition of reliability (availability of infrastructure) by examining the vulnerability of the network from a system perspective. A "robustness scanner application" allows planners to determine the number of alternative routes and the remaining capacity on the alternative routes (Van der Waard 2009). Sweden has taken taking a similar vulnerability approach to identify the impact of critical links. After critical links are identified using maps, the consequences of a breakdown on a critical link are examined in no build and build scenarios using an activity-based approach (Eliasson 2009). The Centre for Transport Studies Stockholm applied this modeling approach to estimate the traveler costs of unplanned disruptions using empirical data from the I-35W bridge collapse in the Twin Cities, Minneapolis (Jenelius et al. 2010).

6.5 References Cited: Travel Time Reliability

Alstadt, B. and G. Weisbrod (2008). "Generalized Approach for Assessing Direct User Impacts of Multimodal Transport Projects," Transportation Research Record: Journal of the Transportation Research Board, v. 2079, 119-126.

Australian Transport Council (2006), National Guidelines for Transport System Management in Australia, Appraisal of Initiatives, 2006 www.atcouncil.gov.au/documents/files/National_Guidelines_Volume_5.pdf

Cambridge Systematics and Texas Transportation Institute (2005). Effective Practices for Congestion Management: Final Report, NCHRP Report 20-24(63), prepared for the American Association of State and Highway Transportation Officials.

Cambridge Systematics and Resource System Group (2008). Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation, Federal Highway Administration.

Cambridge Systematics, Texas A&M University, University of Washington, Dowling Associates, Street Smarts, H. Levinson, and H. Rakha (2011). SHRP 2 Project L03: Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies.

Cambridge Systematics and ICF International (2012). Value of Travel Time Reliability: Synthesis Report & Workshop Working Paper. Prepared for SHRP2 Workshop on the Value of Travel Time Reliability, Washington, DC.

Carrion, C. and D. Levinson (2005). "Value of Travel Time Reliability: A Review of Current Evidence." Transportation Research Part A: Policy and Practice, Vol. 46, pp. 720-741.

Chiang, P. (2009). The UK Approach to Reliability & CBA. Presented at International Meeting on Value of Travel Time Reliability and Cost-Benefit Analysis, Vancouver, BC.

Eddington, R. (2006). The Eddington Transport Study. HM Treasury, London, UK.

Eliasson J. (2009). Reliability in Swedish CBA – Current Practice and What Needs to Be Done. Presented at International Meeting on Value of Travel Time Reliability and Cost-Benefit Analysis, Vancouver, British Columbia.

Texas Transportation Institute and Cambridge Systematics (2006). Travel Time Reliability: Making It There On Time, All The Time, Federal Highway Administration. www.ops.fhwa.dot.gov/perf_measurement/reliability_measures

Fosgerau, M. and D. Fukuda (2010). Valuing Travel Time Variability: Characteristics of the Travel Time Distribution on an Urban Road. Unpublished. http://mpra.ub.uni-muenchen.de/24330/.

Fosgerau, M. and A. Karlstrom, A. (2010). "The Value of Reliability." Transportation Research Part B , Vol. 44, pp. 38–49.

Jackson, W. and J. Jucker (1982). "An Empirical Study of Travel Time Variability and Travel Choice Behavior." Transportation Science, Vol. 16, pp. 460–475.

Jenelius, E., L. Mattsson, and D. Levinson (2010). "The Traveler Costs of Unplanned Transport Network Disruptions: An Activity-Based Approach." Fourth International Symposium on Transportation Network Reliability (INSTR), Minneapolis, MN.

Joint Transport Research Centre (2010). Improving Reliability on Surface Transport Networks. Organization for Economic Co-operation and Development (OECD) and the International Transport Forum.

Kauppila, J (2011). "State-of-Practice in Incorporating Reliability into Cost-Benefit Analysis." Presented at the 2011 TRB Summer Meeting, Transportation Economics Committee, Boston, MA.

Kittleson & Associates, ITRE, and Cambridge Systematics (2012). "SHRP 2 Project L08: Incorporation of Travel Time Reliability into the Highway Capacity Manual." Presented to the SHRP2 Project L38 Expert Task Group.

Liu, H.X., X. He, and W. Recker (2007). "Estimation of the Time-Dependency of Values of Travel Time and Its Reliability from Loop Detector Data." Transportation Research, Part B, Vol. 41, pp. 448-461.

Margiotta, R. (2009). “Reliability and Cost-Benefit in the ITS Deployment Analysis System.” Presented at International Meeting on Value of Travel Time Reliability and Cost-Benefit Analysis, Vancouver, British Columbia.

Margiotta, R., Z. Tao, G. Weisbrod (2012). ”Adapting the Project L03 Methods for Sketch Planning: the C11 Tool.” Presented to the SHRP2 Project L38 Expert Task Group.

Harry Markowitz, H. (1952). Portfolio Selection, Journal of Finance, 7 (1): 77-91, March.

MRI Global and HDR. (2012). “Highway Design Features to Reduce Nonrecurrent Congestion.” Available at http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/Pages/RFP_L38_Resources_and_Reference_Material_628.aspx

Merriam-Webster (2012). http://www.merriam-webster.com/dictionary/reliability. (As of September 11, 2012).

New Zealand Transport Agency (2010). Economic Evaluation Manual (Volume 1). First Addition, Amendment 0.

Samstad, H. et al. (2009), Value of Time, Safety and Environment in Passenger Transport. Institute of Transport Economics (TØI), Oslo, Norway, TØI report 1053/2010.

Small, K. (1982). “The Scheduling of Consumer Activities: Work Trips.” American Economic Review, Vol. 72, pp. 467–479.

Strategic Highway Research Program (2001), Future Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life, Transportation Research Board.

Susilawati, S., M.A.P. Taylor and S.V.C. Somenahalli (2010). “The Distributions of Day To Day Variability in Travel Times on Urban Roads –Some Empirical Evidence.” Presented at the Fourth International Symposium on Transportation Network Reliability (INSTR), Minneapolis, MN.

System Metrics Group (2004). Cal-B/C Technical Supplement to User’s Guide. Volume 2: Transportation Management Systems (TMS), Operational Improvements, Pavement Rehabilitation, and Economic Value Updates.

Taylor, M.A.P. 2009. “Reliability and Benefit-Cost Analysis in Australia and New Zealand.” International Meeting on Value of Travel Time Reliability and Cost-Benefit Analysis, Vancouver, BC.

United Kingdom Department for Transport (2009). Transport Analysis Guidance. The Reliability Sub-Objective: WebTAG Unit 3.5.7.

Van der Waard (2009). “Role of Reliability in Policy, System Planning and Investment Decisions,” Presented at International Meeting on Value of Travel Time Reliability and Cost-Benefit Analysis, Vancouver, British Columbia.

Vickrey, W. (1969). “Congestion Theory and Transport Investment.” The American Economic Review, Vol. 59, pp. 251–260.

Warffemius, P. "Preliminary Results of the Dutch Valuation Study." International Meeting on Value of Travel Time Reliability and Cost-Benefit Analysis, Vancouver, BC.

Williges, C. (2010). Research on Freight Valuation and Travel Time Reliability. Unpublished. Prepared for the California Department of Transportation.

Wornum, C. and D. Hodge. (2005). Montana Highway Reconfiguration Study: Final Report, Montana Department of Transportation, FHWA/MT-05-003/8164.

7 US PERSPECTIVE ON PRODUCTIVITY

7.1 Introduction: US Planning Context

> *"Economic impact is like the pepper on top, in other words, the special sauce on a Big Mac."*
>
> –statement by a state planning official, succinctly summarizing the importance of economic growth effects in transportation planning

For those who desire further explanation, this section describes the practice of considering economic productivity effects in transportation program and project assessment the North America. It describes the extent to which productivity considerations are currently recognized in transportation planning and funding processes that take place at three different levels: federal, state/province and local (metropolitan). It draws findings from a review of current practice and a set of interviews conducted with representatives of state and metropolitan agencies across the US.

In the US, the federal role involves distribution of formula grants to states and metropolitan planning organizations, plus 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 playing a dominant role in multimodal planning for urban areas. The same three-levels of transportation planning (federal-provincial-metropolitan) also exist in Canada, although there is no highway trust fund and the federal government has a relatively smaller role in funds distribution to lower levels of government.

The importance of this arrangement is that it gives wide latitude to states, provinces and metropolitan planning organizations (MPOs) to decide upon their own procedures for prioritization and selection of projects. And each level of government faces a different set of criteria and considerations for setting transportation investment priorities. As a result, a variety of different forms of benefit-cost analysis, multi-criteria analysis and economic impact analysis are utilized for project prioritization and funding decisions – and some of them do incorporate economic productivity considerations.

Interviews conducted for this study with state and metropolitan-level planners found wide recognition of the importance of considering wider economic benefits and productivity impacts, though there was also wide variation in how those factors are being considered in transportation planning. Often the choice was dictated by the type of data available for measurement or estimation, or else requirement specified in a legislated mandate. As a result, a variety of different terms are used to describe measured impacts pertaining to productivity, including changes in: GDP, Value Added, jobs, GDP per capita, average wage, unemployment rate, economic return on investment, economic return on jobs, economic productivity, freight productivity and supply chain productivity.

7.2 Federal Perspective

Since the US Dept. of Transportation is divided into modal agencies, each makes its own rules regarding project evaluation criteria for grant funding. For highways, federal programs have been divided into special purpose categories (such as safety, congestion mitigation and air quality, rail-highway crossings, national highway performance and metropolitan planning), and each has its own cost-effectiveness criteria for project selection based on the purpose of that program. In addition, some federal discretionary grant programs have BCA requirements to ensure that only projects passing that efficiency test are funded.

At the federal (US DOT) level, there is existing BCA guidance pertaining to highway asset management (FHWA, 2003), freight project investment (FHWA, 2008), rail transit new starts (FTA, 2008), aviation improvement (FAA, 1999) and ground transportation discretionary grants (US DOT, 2011). In general, each recognizes user cost savings though only three of the five also recognize the inclusion in BCA of wider productivity benefits associated with market access, connectivity and reliability. They are summarized below:

- Highway Freight Investments. FHWA's freight benefits guide recommends procedures for evaluating proposed freight projects. It recognizes that a primary mechanism for productivity improvement occurs as freight shippers respond to changing reliability and transportation costs by adjusting inventories or shuffling logistical activities. It also provides a "Highway Freight Logistics Reorganization Benefits Estimation Tool" (FHWA, 2008).
- Airport Improvement Projects. FAA's capital grant program requires submission of BCA to support every request for grants above $5 million. The BCA guide (FAA, 1999) recognizes that productivity improvements can occur as freight shippers respond to lower transportation costs by adjusting inventories or shuffling logistics activities. The FAA now allows productivity to be included in BCA for grant applications, and that was the basis for approval of a runway extension at Rock County Airport in Wisconsin. The project was justified largely on the basis of a labor and capital productivity gain associated with reducing down-time for just-in-time delivery for the automotive parts supply chain. (Wisconsin DOT, 2000).
- Ground Transportation Grants. In 2010, US DOT initiated the TIGER (Transportation Investment Generating Economic Recovery) program, which provided grants for multimodal surface transportation projects that pass a BCA test and aid the economic development of communities. A new set of BCA guidelines, published in the Federal Register (US DOT, 2011), allow monetization of a wider range of non-user benefits I TIGER grant applications. The USDOT guidance also specify that one of the outcome metrics used to justify a TIGER Grant is *economic competitiveness*, defined as

> "contributing to the economic competitiveness of the United States over the medium- to long-term." (US DOT, 2011). Productivity is a major element of economic competitiveness, though not the only one since proximity to natural resources and markets can also matter.
>
> The Federal Register goes on to clarify that: "In weighing long-term economic competitiveness benefits, applicants should describe how the project supports increased long-term efficiency and productivity. Priority consideration will be given to projects that: (i) Improve long-term efficiency, reliability or cost competitiveness in the movement of workers or goods (including, but not limited to, projects that have a significant effect on reducing the costs of transporting export cargoes), or (ii) make improvements that increase the economic productivity of land, capital or labor at specific locations" (US DOT, 2011).

The inclusion of productivity gains associated with reliability adds recognition to freight projects, while the inclusion of productivity associated with access changes allows potential recognition of agglomeration effects from urban transportation investments. However US DOT staff report that, to date, only a small portion of applicants have actually calculated productivity benefits for their TIGER Grant applications." While the TIGER grant program will not continue, similar benefit definitions and perspectives are expected to remain in new programs authorized by Congress under the MAP-21 program and other future legislation.

Two other economic benefit guides are of note. One is the pair of benefit estimation tools and methods sponsored by the American Public Transportation Association through the National Cooperative Transit Research Program (Reno and Weisbrod, 2009, Chatman et al, 2012). Both cited documents provide guidance on the estimation of economic benefits associated with market access and agglomeration economies, and are designed for use by public transportation agencies. The other notable guide is the Canadian benefit-cost guide, which also recognizes industry-level productivity benefits (Transport Canada, 1994).

7.3 Interviews of State and Local Officials

Interview Purpose. The research team interviewed representatives of state DOTs, metropolitan transportation organizations and specialized transportation agencies. The process was not intended to provide a comprehensive survey of practice, but rather, it was intended to illuminate similarities and differences in their perspectives regarding when and how they consider productivity effects and economic impacts in their project prioritizing and project selection decision-making.

Interview Selection. The study team interviewed 23 public and private agencies to identify their current use and interest in the use economic productivity measures in transportation project prioritization and selection. The perspectives of six others were also reviewed, based on prior discussions between study team members and leaders of those agencies.

Staff of ten state DOTs were interviewed, which represented a broad geographic distribution of both growing and mature economies. Staff of nine Metropolitan Planning Organizations were also interviewed; they represented both medium and large urban areas as well as key multimodal transportation gateways that support transit networks and freight corridors.

While the focus of the interview process was on governmental bodies, the study team also conducted interviews with private and quasi-public independent authorities. Two port authorities, one airport and one Class 1 railroad were also selected to identify the state of practice in linking transportation project prioritization and selection to economic outcomes.

Interview Topics. Six subject areas were discussed in the interviews:

1. Current economic analysis activities
2. The motivation for economic analysis
3. Key questions requiring economic input
4. Economic impact metrics and methods
5. Areas needed improvement to facilitate economic assessment for transport projects.
6. Benchmarking question about current leaders.

The agencies interviewed are listed in Table 7-1. The interview topics are shown on the page which follows.

Table 7-1 Agencies Interviewed

<u>State DOT staff interviewed</u> Georgia Dept. of Transportation Illinois Dept. of Transportation Indiana Dept. of Transportation Michigan Dept. of Transportation Missouri Dept. of Transportation New York State Dept. of Transportation North Carolina Dept. of Transportation Wisconsin Dept. of Transportation Vermont Agency of Transportation Wisconsin Dept. of Transportation <u>Other Programs and projects reviewed (based on prior work; no new interviews)</u> Kansas Dept. of Transportation Maine Dept. of Transportation Ontario Ministry of Transportation Oregon Dept. of Transportation Metro - Portland, Oregon Virginia Dept. of Transportation	<u>MPO staff interviewed</u> Metropolitan Transportation Commission (San Francisco) Southern California Association of Governments (Los Angeles) Chicago Metropolitan Agency for Planning Pikes Peak Area Council of Governments (Colorado Springs) Houston-Galveston Area Council Puget Sound Regional Council (Seattle) Central Transportation Planning Staff (Boston) Delaware Valley Regional Planning Council (Philadelphia) Southeast Michigan Council of Governments (Detroit) <u>Others agency staff interviewed</u> Chicago Dept. of Transportation (Aviation) Port of Portland Port of Alabama Norfolk Southern Railroad

Interview Topics

1. Do you currently conduct economic analysis or assess the economic impacts of current or proposed transportation investments? If not, are you planning to do so in the future?
   - If so, what does economic analysis mean to you or your agency?
   - What terms do you use? (e.g., economic impact, benefit-cost analysis, economic development, productivity, wider economic benefits)
   - How are economic impacts and benefits measured within your agency?
   - How would you define economic productivity?

2. What is your motivation for conducting economic analyses?
   - Prioritization (ranking) of projects for funding
   - Selection (yes/no) decisions for project funding and implementation
   - Support the planning process (e.g., alternatives analysis or EIS)
   - Answer other questions from decision makers, legislators, transportation commission, etc.
   - Complete funding grant applications (e.g., TIGER grant applications)
   - Seek private sector partners

3. What types of questions are you trying to answer?
   - What is more important to you, job impacts or spurring income growth?
   - Is the emphasis more on selecting or prioritizing projects?
   - Or, are you trying to measure overall economic outcomes?
   - Do you include measures for job creation or economic development in your project selection process? If so, what are they?

4. What methods do you use to estimate economic impacts or economic productivity benefits?
   - Benefit-cost analysis
   - Regional economic models
   - Multi-criteria rating systems
   - Wider economic benefit elements (direct estimation of access and logistics effects)
   - Combinations, relying on outside consultants or specific software to do the analysis

5. Where or how would you incorporate better estimates of economic productivity impacts of transportation projects?
   - Would better productivity estimates change the overall project prioritization process?
   - Would it be used mostly to evaluate investments in large-sale projects?
   - Would it be used to better complete federal funding grant applications?
   - Does your interest in productivity calculations differ by type of project (e.g., facility capacity expansion, new routes and lines, intermodal freight, public transit or road investments)?
   - Do you envision a time where public private partnerships might include consideration of the ties between transportation performance and economic activity?

6. Who else should we talk to?
   - Which states, MPOs, or other agencies are the best at measuring the economic impacts of transportation projects or tying transportation to economic development?

7.4 State-Level Perspectives

Motivation

At the State DOT level, there is a wide array of interest in economic productivity and measurement, spanning three functions: (A) statewide long-range plans, (B) alternatives analysis for major corridor studies, and (C) project ranking and selection. Examples of each type of use are described below.

It is worth noting that the state DOTs vary in terms of their legislated mandates and responsibilities to make uniform recommendations, which makes national standards for transportation funding decisions nearly impossible. In some states, only the highways are state-owned and operated, while railroads are privately owned and local authorities own public transportation, airport and marine port facilities. In others, the state DOT may also own and operates short-line railroads, airports, marine ports and/or public transportation properties.

The use of economic analysis also varies from required to voluntary. In some states (e.g., Vermont), there is a statutory requirement to conduct benefit cost analysis to show that all major programs and projects have costs that do not exceed their benefits. In other states (e.g., Wisconsin), certain state-to-local grant programs require benefit-cost analysis, as do certain types of federal-to-state grant applications, while many other projects are subject to agency-developed ratings. In many states, staff reported that they conduct economic impact analysis, sometimes also recognizing wider economic benefits (particularly insofar as they affect business cost competitiveness), as an internally driven initiative to formalize their decision-making and better communicate funding justifications to legislators and the public. A few states also reported that a new and emerging motivation for the identification of business productivity benefits is that it helps open up funding via public private partnerships. This process can be helpful when identifying investment grade opportunities to attract private industry investment.

A – Statewide Long Range Plans

Some States are limited in their ability to assess productivity; others are directed or mandated to undertake economic assessments. Most state DOTs develop medium and long-range transportation plans, and many hire consultants to assess the economic benefits of those plans. The studies typically compare alternatives in which higher or lower levels of investment take place. These studies nearly always utilize network models to portray the impact on travel conditions (speeds, delay) and often they also utilize regional economic models to portray the impact on growth on job and economic output or GDP growth (which indirectly reflect productivity changes). There are two classes of such studies:

- *Multi-modal vision plans,* in which there is a 5 to 30-year strategy for investment in road and rail surface transportation, and sometimes also air and port investment. For instance, Virginia DOT and Maine DOT developed a five-year and thirty year vision plans incorporating all four modes, and then evaluated their benefits for job and GDP growth (compared to a baseline of current spending levels). In both cases, the analysis considered highway and rail network connectivity between cities (market access) and intermodal connectivity to airports and seaports. These studies were aimed at educating legislators and the general public about the economic stakes involved in transportation infrastructure investment decisions.

- *Statewide investment policy studies* - A variety of state DOTs apply economic impact models to demonstrate the economic importance of continued investment in transportation. For instance, Oregon DOT conducted a statewide study of the economic impact of allowing road bottleneck delays to grow over time, due to a combination of aging roads and insufficient capacity. A key element of the impact was the variability of travel time and economic impacts on the supply chain. Both Kansas DOT and Michigan DOT conducted statewide studies of the economic impact of funding highway preservation, as opposed to the alternative of allowing pavement and bridge conditions to deteriorate over time. Both studies examined impacts on business costs and productivity related to truck size/weight restrictions as well as speed slowdowns. Michigan also recently examined the economic consequences of raising transportation fees and also tradeoffs between investing in transit vs. highway maintenance.

Most of these economic impact studies are aimed communicating to the business community, general public and elected officials regarding the importance of transportation funding and investment to maintain a competitive economy. Some are also intended to help convince leaders of these groups of the importance of focusing on statewide economic issues rather than lobbying for pet local projects. In some cases economic benefit has also been used to increase transportation related fees to support increasing transportation investment.

B – Corridor Studies

Major corridor studies compare alternatives for addressing a corridor-specific transportation need. Montana DOT, Indiana DOT, Michigan and Wisconsin DOT have processes in place that can be used to evaluate economic costs and benefits for all major highway corridor projects. Many other states initiate economic impact or benefit-cost studies only for very large investment projects, which fall into three categories.

- *Multimodal Corridors* - Productivity factors tend to be considered most prominently for projects that involve multiple modes. For instance, Ontario Ministry of Transport conducted studies for both the Toronto-Detroit and Toronto-Buffalo inter-city corridors, which considered combinations of highway and rail investments to alleviate congestion. In both cases, a regional economic model portrayed impacts on job and GDP growth by considering differences in market access (agglomeration) and supply chain (logistics) productivity. The Massachusetts DOT conducted the South Shore Corridor Study to evaluate bus and rail options for the Boston-Fall River corridor, linking an economically depressed region of the state to the most economically vibrant area. Since a major objective of the proposed corridor upgrade is to improve job market access and grow a technology industry cluster, the analysis focused on labor market access effects on economic competitiveness (which were implicitly based on productivity benefits).

- *Inter-City Rail* - Access for labor markets and same-day business and tourism travel are also a prominent factor in studies of the economic impacts of high speed passenger rail investments, including studies for California, Illinois and Florida agencies.
- *Inter-State Bridges and Highways* - Supply chain logistics, as well as intermodal connectivity (components of productivity), tend to be major considerations for bridge projects spanning between two states, such joint studies by Kentucky DOT with Ohio DOT for the Ohio River Bridges at Louisville, Washington State DOT with Oregon DOT for the I-5 bridge replacement over the Columbia River, and Minnesota DOT with Wisconsin DOT for the bridge replacement over the St. Croix River at Stillwater. Supply chain productivity factors are similarly important considerations for economic impact evaluations of improvements to inter-state highway routes, including a 13-state study of I-95 inter-modal connectivity and a 5-state study of truck movement along I-70.

Interviews with state DOT representatives confirmed that that states tend to be concerned about geographic equity and thus interested in transportation strategies and alernatives that can support economic growth in distressed areas. The see measurement of "economic productivity" factors, such as market access and competitiveness, as helping tell the story and this consideration is increasingly used to help "make the case for project selection" among available alternatives. Representatives from some of the more economically mature states reported that there is less interest in economic productivity due to the fact they can barely cover required asset management activities required to support existing infrastructure.

C - Project Prioritization and Selection

Every US state and Canadian province has some process for evaluating and prioritizing requests for enhancement of individual roads and rail transportation facilities, which may be submitted to the state by local communities, regional agencies, or district offices of the state DOT. And in many but not all cases, some aspect of economic productivity, competitiveness or job growth is considered as a factor in project prioritization or selection. In general, the prioritization rating systems fall into four classes:

- *Multi-Criteria Analysis (MCA),* which involves of rating projects along a variety of factors. MCA allows for qualitative and quantitative factor ratings to be considered together in a summary table. Ohio DOT (2008), Wisconsin DOT (2007), Missouri DOT (2009) and Virginia DOT use variants of this method, with formally specified weights applied to each factor so that an overall total score can be computed for each project. These DOTs all calculate GDP or employment impacts from a regional economic impact model (REMI or TREDIS) that directly calculates productivity and economic growth impacts. The states then assign a weight to that predicted benefit. They also add weight to other factors affecting local productivity, such as connectivity (to intermodal terminals, key state-wide corridors and export gateways) and spatial development (supporting regeneration, cluster and in-fill development).

- *Benefit Cost Analysis.* This is typically done through a two-step process of quantitative BCA calculation and qualitative factor ratings. First, BCA is calculated considering only user benefits and costs, following guidelines of the Association of State Highway and Transportation Organizations (AASHTO, 2003). Then qualitative factors are considered that reflect non-user benefit categories including regional and local economic competitiveness and development, environmental and social impacts. Minnesota DOT (2009), California DOT and Vermont Agency of Transportation (Vtrans, 2008) adopt this approach.
- *Composite Scoring Systems.* Kansas DOT (2010) developed a composite scoring method, which calculates GDP impact using the TREDIS economic analysis framework to account for labor market and freight market access impacts. The GDP impact rating is then combined with engineering rating and a "local consultation" rating (from community meetings) to provide a composite score. North Carolina DOT also takes this general approach. The Vermont Agency of Transportation (Vtrans) has a different point system for rail and aviation projects. The rail rating gives points to projects that increase use of the mode and reduce transport costs for the state's industries. The aviation rating considers effects on job creation as well as activity levels and percentage of surrounding population served. There is also a rating for highway projects, which gives extra weight to projects that recognize impacts on productivity for the state's trucking industry, which will in turn also reduce overall costs of doing business for Vermont manufacturers.
- *Informal Systems.* Some state DOTs rely on appointed expert panels to periodically review proposed projects and rank them on the basis of stated program goals.

Table 7-2, shown on the next page, shows the elements of productivity and localized economic growth recognized by selected federal and state agencies for project selection decision-making.

Table 7-2. Economic Development Criteria Used in Project Rating Systems

Rating Criteria	BCA	MCA			Rating
	USDOT	OH	WI	MO	KS
Traveler Benefit and Environment					
Travel time, operating cost, level of service	X	X	X	X	X
Safety (accident rate)	X	X	X	-	X
Pollution emissions	X	X	X	X	-
Transportation Drivers of Business Productivity Gain					
Intermodal facilities & multi-modal access	*(x)*	X	*(a)*	X	*(a)*
Reduce congestion, traffic bottlenecks, vol/capacity	*(x)*	X	X	X	X
Connectivity to key statewide corridors	*(x)*	-	X	X	*(a)*
Labor market access	*(x)*	-	*(a)*	-	*(a)*
Predictability (reliability) of travel times	*(x)*	-	*(a)*	-	*(a)*
Connectivity to export markets or global gateways	*(x)*	-	X	-	*(a)*
Concentration of trucks for goods movement	*(x)*	X	*(a)*	X	X
Industry productivity /competitiveness of freight costs	*(x)*	-	X	-	*(a)*
Transportation Drivers of Localized Economic Growth					
Industry site access for business development	-	X	*(a)*	-	*(a)*
Location in economically distressed area	-	X	-	X	-
Supports cluster development /in-fill/redevelopment	-	X	-	X	X
Supports local economic development initiatives	-	-	-	X	X
Local public support	-	-	X	-	X
Leveraging local private investment	-	X	-	-	-
Economic Growth Outcomes					
Jobs(support job growth/reduce unemployment)	-	X	X	-	-
Gross Regional Product (income generated)	-	-	-	-	X

"X" = factor explicitly included as an element of the rating system;
"(x)" = factor implicitly allowed via calculation of additional productivity impact
"(a)" = factor implicitly included as a component of the economic model calculating job or GRP impacts;
" - " = factor not formally recognized as a separate element of the rating system, but may still be considered through other elements of the broader project selection process
Abbreviations and Sources: BCA = Benefit-Cost Analysis; MCA = Multi-Criteria Analysis; USDOT = US Dept. of Transportation (2011), OH = Ohio DOT (2008), WI = Wisconsin DOT (2007, 2009), MO = Missouri DOT (2009), KS=Kansas DOT (2010)
Source: Weisbrod (2009)

7.5 Metropolitan Planning Organizations

Overview of Practice

Metropolitan planning organizations in the US are required to develop a "Transportation Improvement Program" (TIP) every six years. The TIP represents a schedule regionally agreed-upon list of priority transportation projects that will be eligible for public funding, as required for obligation of federal funds to state and local projects. Many MPOs also develop goals for a longer-term future.

In selecting projects for these plans, a growing number are using forms of multiple criteria analysis, which involve rating projects using a combination of quantitative and qualitative factors. While productivity per se is never an explicit factor in these rating schemes, key aspects of productivity -- including market access, connectivity, reliability and economic competitiveness – often are included.

For instance, the Chicago Metropolitan Agency for Planning (CMAP) includes factors such as labor market access and infill development , location in economically distessed areas, as well as job and income growth outcomes among the factors affecting selection of projects for their long-range plan (Chicago MAP, 2010). Boston's MPO rates projects in terms of factors including integration with land use and economic plans, support for sustainable land development, service to existing activity centers and connecting links for economic activity (Boston MPO, 2009). The San Francisco MPO includes access to airports and seaports, as well as ability to accommodate growth in movement of both people and freight, for their regional plan (Metropolitan Transportation Commission, 2009). While the factors vary among areas and agencies, reflecting differences in local values and priorities, they share a common attempt to place value on projects that can affect job and income growth by increasing busienss productivity.

At the MPO level, economic productivity is primarily considered as an indirect element in project selection (as a competitiveness factor) though it is often part of grant application requirements for specific state or federal funding sources. Staff of seeral MPOs reported that they are trying to embrace private sector participation and find if they "speak the language" of the private sector, it can help build relationships and can foster data exchange and private sector participation. That consideration applied when the Portland, Oregon MPO (Metro) co-sponsored a study with the Portland Business Alliance, which examined the economic productivity and competitiveness benefits of investing in the long-range transportation plan rather than merely spending on transportation facilities and infrastructure at current levels. More recently, the San Francisco MTC has initiated studies of the business productivity and agglomeration benefits of adopting a long-range land use and transportation plan that extends BART rapid transit lines and focuses development around those station areas.

7.6 Interview Findings on Use of Productivity Metrics

Use of Terms. Interviews with staff of state DOTs and MPOs revealed a wide interest in economic productivity and measurement. In many cases, they do not use the term "productivity" but effectively address it through key elements of productivity, including market access, logistics, connectivity and reliability effects. The impacts may be measured through terms including statewide total GDP, GDP per capita, gross state product, wage income, unemployment rate, economic development, business attraction, return on investment, economic productivity, freight productivity, supply chain productivity or job creation.

While many interviewees did use the term "economic productivity" in speaking, the definition of the concept. State DOTs typically are looking at productivity as a factor in industry attraction, while the MPO were more focused on job creation. In fact, nearly all of those interviewed said that job creation was more important than income growth though staff of many state DOTs went on to say that both were important.

A growing number of state DOTs are adopting terminology focusing on ROI – "return on investment," as part of an effort to engage private sector partners by adopting the "business case" viewpoint. Vermont's benefit-cost system also gives specific attention to the measurement of trucking industry costs and efforts to reduce them, based on the concept that this will tend to make all manufacturing industries in the state more competitive. Wisconsin DOT evaluates economic productivity by measuring project effects on the cost of production. Georgia DOT likewise monetizes the effects of projects on cost savings to logistics providers, in addition to considering travel time, cost and safety for commuters.

Audience. State and MPO staff reported that they care about economic productivity to help "make the case" to leadership and to voters when it comes to project selection and funding. In both cases, the most important use of economic productivity and job creation metrics was reported to be justification of project selection. Staff of nearly every agency interviewed felt that public funds are getting tighter, so private sector partners will be increasingly called upon for matching investments in future public-private partnerships. And that will make business productivity measures even more important in the future.

State of Practice. While staff of nearly every government agency interviewed understood the term economic productivity, the challenge is that many of them still feel that it is difficult to quantify with the current tools available. Nevertheless, many states are using REMI or TREDIS economic models, because they both yield calculations of gross GDP and net productivity impact metrics, as well as job impact metrics. The idea of leveraging transportation performance in the strategic allocation of limited transportation investment resources is also gaining ground at the MPO level. The more projects which can be clustered together the greater the economic productivity outcome.

In general both levels of government are frustrated by the inability to compare projects across modes and they struggle to capture network or synergistic benefits created by bundling projects. Many States recognize that corridors are essential yet on many levels the states are competing with each other for job creation. Working across state lines can be difficult due to differences in data collected and key measurements. At the MPO level, data to capture market access benefits is difficult, especially for freight projects. Social and environmental benefits are also hard to quantify in terms of economic productivity. At the MPO level job creation and job quality is a key motivator. Most states and MPOs rely on multiple measures to support project selections. In every case 'jobs created' by project is a measure every agency is trying to develop.

Specific Interests and Challenges. In a resource constrained environment everyone is struggling to make strategic transportation decisions that will support growth and spur job creation. Many states are struggling with time honored allocation traditions and are facing networks which must be pruned. Economic productivity assessments helps inform decision makers about what impacts strategic investment decisions might have. Not all projects are being assessed to determine economic impact due to the time and staff cost to develop. Some agencies have developed their own models so that staff can assess more projects; other states are creating project benchmarks so that similar projects can be assumed to have similar impacts, therefore reducing the burden to evaluate each project.

Several MPOs and several DOTs mentioned the interest in including economists on staff and/or interest in developing strong University partnerships to help improve economic productivity assessments. Other MPOs have joined with the regional economic development agency efforts with transportation study efforts, and in the case of Chicago, have linked economic development and transportation project selection activities. In Houston many projects are focused on improving clusters defined by the economic development agency.

Some government groups hope to be able to use economic productivity assessments to be able to identify areas for public private partnerships. A few agencies expressed interest in evaluating tolling and other fee based activities which might be able to raise additional revenues to be used for transportation improvements with economic productivity analysis.

Improved Tool Development. A number of states have developed their own software systems for evaluating the wider economic growth consequences of proposed highway and public transportation projects and plans. This includes Indiana, Montana and Ohio. In each case, the software draws upon a regional economic impact model. All of these systems are now over a decade old and each state is in the process of either updating their system or evaluating options for updating it. A few agencies, including SEMCOG (Southeastern Michigan Council of Governments) are now investing in enhancing their capabilities to address these issues. Other state DOTs (including Michigan, Kansas, North Carolina and Wisconsin) have developed hybrid combinations of spreadsheet tools linked to regional economic models (REMI or TREDIS) that can isolate productivity effects.

All of the interviewees noted the importance of data and tools, and the need for economists on staff. Several noted that to make a noticeable impact on statewide productivity, investment in new capacity and connectivity is required. Yet many states are faced with more infrastructure than they can support and find themselves more concerned with needs to focus on supporting existing travel and retaining existing industries and jobs.

7.7 Areas for Improvement

Interviewees noted that a glaring weakness with the evaluations now being done is that they tend to focus on investment in individual modes, rather than fully examining opportunities for inter-modal complementarities. Several noted that it is "hard to buck" a state allocation process which separates modal decisions and awards too many, too small awards in order to make people happy across the state. One referred to this as "crop dusting" and another referred to it as "spreading the peanut butter."

Other difficulties were also noted. One is the difficulty attempting to justify investment in international and national logistics networks when the impacts are so diffused. This is particularly problematic for investment in border crossing and port links. Another issue is the need to better link the benefits of market access and productivity for business with the resident benefits of improved livability for residents. Both are planning requirements yet it is hard to integrate them. And finally, it is difficult to both measure and interpret differences in productivity among different sectors of the economy.

Finally, Interviewees suggested issues that could be addressed by the guidebook to be developed for this project. They concern:

- How to measure changes in accessibility and network connectivity
- How to better understanding supply chain impacts
- How productivity changes will affect business investment and attraction
- How to compare projects spanning different modes
- How to recapture private sector benefits that result from transportation investment
- Tools that are sensitive to small scale projects such as highway interchanges
- How to better communicate to audiences so as to attract more investment and raise revenue to support strategic transportation investments

7.8 References Cited: North American Practices

Boston Regional MPO (2009). Journey to 2030: Amended Regional Transportation Plan, Central Transportation Planning Staff. www.ctps.org/bostonmpo/3_programs/1_transportation_plan/2030Tranplan_toc.pdf

Chatman, D.G. (2012). Methodology for Determining the Economic Development Impacts of Transit Projects, Transit Cooperative Research Program, Web-only document #56. http://www.trb.org/Publications/Blurbs/167284.aspx

Chicago Metropolitan Agency for Planning (2010). "GO TO 2040 Major Transportation Capital Program Element." www.cmap.illinois.gov/transportation-capital-projects

Economic Development Research Group (2008). Use of Freight and Business Impact Criteria for Evaluating Transportation Investments, prepared for the Port of Portland and Portland Business Alliance. www.flypdx.com/PDFPOP/Trade_Trans_Studies_EDR_Report.pdf

FAA (1999). FAA Airport Benefit-Cost Analysis Guidance, Federal Aviation Administration, Office of Aviation Policy and Plans. www.faa.gov/regulations_policies/policy_guidance/benefit_cost/media/faabca.pdf

FHWA (2003). Economic Analysis Primer, Federal Highway Administration, Office of Asset Management. www.fhwa.dot.gov/infrastructure/asstmgmt/primer.cfm

FHWA (2008). Cost Benefit Analysis, Federal Highway Administration, Office of Operations. http://ops.fhwa.dot.gov/freight/freight_analysis/cba/index.htm

FRA (1997). "Methodology for Comparisons of Benefits And Costs," Chapter 6 in High Speed Ground Transportation for America, Federal Railroad Administration www.fra.dot.gov/downloads/RRDev/cfs0997ch6.pdf

FTA (2008), Reporting Instructions for the Section 5309 New 26 Starts Criteria, Federal Transit Administration www.fta.dot.gov/documents/FY10_Reporting_Instructions_FINAL_7_7_2008(1).doc

Kansas DOT (2010). Expanded Highway Project Selection Process, Briefing Paper. www.kansastlink.com/downloads/Project%20Selection%20Process%20White%20Paper.pdf

Metropolitan Transportation Commission (2009). Transportation 2030, San Francisco. www.mtc.ca.gov/planning/2030_plan/

Minnesota DOT (2009). "Implementation of Minnesota Statewide Transportation Plan Cost-Effectiveness Policy," Technical Memorandum No. 09-13-IM-01. http://dotapp7.dot.state.mn.us/edms/download?docId=770804

Missouri DOT (2009). Engineering Policy Guide; Section 121.2, "The Planning Process," Table 121.2.5.4 - Prioritization Process. http://epg.modot.org/index.php?title=121.2_the_planning_process

Ohio DOT, (2008), "TRAC – Transportation Review Advisory Council Policies & Procedures," Columbus, p.8. www.dot.state.oh.us/trac/Documents/TRACPoliciesandProcedures-December-18-

Reno, Arlee and Glen Weisbrod (2009). Economic Impact of Public Transportation Investment, TCRP Project J-11 (7),Transit Cooperative Research Program. www.apta.com/resources/reportsandpublications/Documents/economic_impact_of_public_transportation_investment.pdf

Transport Canada (1994). Guide to Benefit-Cost Analysis in Transport Canada, Report TP11875E, Ottawa. Online at www.tc.gc.ca/finance/bca/en/TOC_e.htm

US DOT, (2011). "Interim Notice of Funding Availability for the Department of Transportation's National Infrastructure Investments Under the Full-Year Continuing

Appropriations," Federal Register, Vol. 76, No. 127, July 1, 2011, pages 38719 - 38740.

Vtrans (2008). Transportation Project Prioritization and Project Selection, Vermont Agency of Transportation, Policy and Planning Division www.aot.state.vt.us/planning/Documents/Planning/Project Prioritization.pdf

Wisconsin DOT (2000). Benefit-Cost Analysis for the Rock County Airport (JVL) Runway Extension, Janesville, Wisconsin. http://www.edrgroup.com/pdf/benefit-cost-rock-county.pdf

Wisconsin DOT (2007). "Economic Evaluation of Highway Major Investment Program" www.dot.wisconsin.gov/business/econdev/highway-major.htm

Wisconsin DOT (2009). Slide show: "Evaluating and Ranking Highway Major Projects from an Economic Development Perspective." www.tredis.com/images/stories/pdf-docs/panel_workshop/transportation%20planning%20workshop%20-%20widot.pdf

8 UK & International Perspective

8.1 Introduction to Overseas Implementation Issues

This section described the practice of including considerations of economic productivity in transportation assessments outside of North America. Much of the discussion focuses on the practice in the UK, which has adopted a formal process for incorporating "wider economic impacts". The UK approach consists of adding what economists refer to as "welfare benefits" (additional benefits to society) that are due to (1) agglomeration economies, (2) increased output in imperfectly competitive markets, and (3) increased labor supply to a standard benefit-cost analysis. In addition, the UK estimates changes in Gross Domestic Product and employment using business and household surveys or transportation and land-use interaction models.

The rest of this chapter provides an overview of the general assessment approach in the UK, a clarification of terms used in the UK, a description of how "wider economy impacts" and "additional welfare benefits" are estimated, and a discussion of recent developments and challenges. It then briefly describes practices for incorporating economic productivity into transportation assessments in Europe, Asia, and Oceana.

8.2 The United Kingdom Perspective

The responsibility for the assessment of transportation projects has been devolved from the central government in London to the Scottish and Welsh Governments as well as to local authorities. This has resulted in the use of conflicting and overlapping terms. Despite this devolution, the UK approach is fairly standardized with a formal process for incorporating the wider economic impacts of transportation projects into their assessment.

The UK includes wider economic impacts in transportation assessments in two ways. First, the impacts on the economy are described as part of the business case for investment in transportation. These impacts are typically measured in terms of changes in GDP or employment using surveys or transportation and land-use interaction models. Second, these impacts are added to benefit-cost analyses as sources of additional welfare benefit, if market distortions such as agglomeration economies are relevant. As a result, the wider economic benefits are measured in terms of multiple economic and welfare outcomes.

Changes in economic productivity are not measured or reported as an economic output variable per se. However, changes in economic productivity are indirectly relevant to assessments as they influence economic outcomes that are reported (e.g., changes in GDP, employment, and welfare benefit). Additional welfare benefits related to agglomeration economies, and the movement to more productive jobs, are components of the UK approach and may be considered aspects of economic productivity increases.

The United Kingdom now routinely calculates the wider economic impacts of transportation projects as part of the assessment process. The inclusion of wider economic impacts has ranged from small or insignificant to a reported increase of 62.5 percent in project benefits. The size of the impact is determined by the market served, which is strongly correlated with location. Research and development on the productivity implications of gains in trade and foreign direct investment spurred by transportation investment have stalled due to a lack of conclusive evidence. However, the inclusion of economic outcomes when making the case for a transport investment is gathering pace. Modeling the economic outcomes of transportation projects remains a challenge.

General Approach to Assessments

The United Kingdom (UK) uses a standardized approach to assessing transportation projects, which is set forth by the national government, which has a direct responsibility for investment in national roads and railways. Local transportation is the responsibility of local governments, but investment in major projects has generally required funding support from the UK Government. In practice, the national government has established a formal framework for assessing transportation projects. An important feature is that projects requiring land acquisition are subject to planning approval and require hearings at local planning commission meetings. The national framework for project assessments is used by planning staff to review projects and make recommendations.

As a result of these circumstances, the UK Government has established a strongly codified approach to assessment guidance, within which individual project sponsors work. This is partly because the national government has an interest in establishing a "value for money" across the entire transportation program and partly because individual sponsors have an interest in demonstrating that their project assessments conform to the official guidance. The national guidance covers many aspects of engineering design, traffic modeling, forecasting and assessment.

Building on methods developed roughly 75 years ago by US Army Corp of Engineers, the pioneers of transportation assessment in UK, such as Foster and Beesley, established a benefit-cost analysis approach in the 1960s that is now codified through the guidance manuals. Broadly speaking, the assessment process has developed through several phases:

- During the 1960s and 70s, values were established for travel time, operating cost and accident savings. In addition, formal benefit-cost models were created in England and in Scotland.
- From the late 1970s to the 1990s, a model assessment framework was established that includes environmental impacts as part of the assessment process. In addition, a round of value of time and safety studies were conducted.

- In the 1990s, the method was developed to include the treatment of induced traffic. The Secretary of State for Transport's Standing Advisory Committee on Trunk Road Assessment (SACTRA) issued its report on transportation and the economy. In addition, the Department for Transport (DfT) developed its New Approach to Appraisal (NATA) (Price, 1999).

In 1998, the UK government devolved a number of matters including transportation to the newly created parliaments in Scotland, Wales and Northern Ireland. An equivalent English parliament was not created, so all government powers with respect to England remain under the control of the DfT. The DfT also retains centralized authority for cross-border (within UK and across international borders) and UK-wide issues (e.g. safety standards on railways).

In England, the Transport Business Case provides guidance on how to conduct transportation assessments (UK DfT, 2011a) through its Transport Appraisal Guidance (TAG). The guidance is provided through notes are available online in a collection known "WebTAG." In Scotland, the relevant guidance is provided in the Scottish Transport Appraisal Guidance or "STAG" (Scottish Government, 2008). In Wales, the corresponding guidance is called the Welsh Transport Planning and Appraisal Guidance or "WelTAG" (WAG, 2008). The UK Treasury proves guidance on BCA in the Green Book, which covers all three countries (HM Treasury, 2003). Transportation assessments in the three countries remain very similar in the three countries as a result of the Green Book and their common heritage. For example, BCA remains an integral part of each country's national assessment process. Other similarities include:

- The assessment process (Transport Business Case, STAG or WelTAG) is mandatory for projects that cost more than £5 million and are funded by the central government (UK DfT, Scottish Government, or Welsh Assembly Government). The processes are prescriptive with a defined set of impacts and an established method (including shadow prices) for each of the impacts.
- The impacts of a proposed transportation project are summarized in an Appraisal Summary Table (AST) which from an American perspective may be seen as a form of Multi-Criteria Analysis (MCA) ratings that incorporates Cost-Benefit Analysis (CBA) and Environmental Impact Assessment (EIA) techniques. The AST includes ratings for impacts on the environment, economy, safety, accessibility and integration (in Scotland and Wales) or economy, environment, and social and public Accounts (in England). The AST contains qualitative, quantitative, monetized and non-monetized impacts.
- All impacts, including items monetized as part of the BCA, are scored on a 7 point scale - ranging from strongly negative to strongly positive. However, a summed total score or weighted total score for the proposed project is not estimated. The AST is intended to be a framework that presents key decision criteria to decision-makers in an accessible format.

Productivity elements are represented in these transport project appraisal guidance documents in four main ways (see WebTAG Unit 3.5.14C):

- effects of increased competition, which are recommended to be estimated as an multiplier factor applied to the calculated value of business cost savings;
- agglomeration economies, calculated on the basis of an elasticity of productivity with respect to change in effective labor market density;
- increases in production due to better transport drawing more people into work;
- increases in productivity due to jobs being relocated to more productive locations.

Looking to the future, there is now a recognition of the need for area-wide assessment (often in a multi-modal context), and a greater attention to environmental impacts (especially greenhouse gas emissions) as well as reliability and resilience (or redundancy), which are difficult to model. Much more attention has been placed on the impacts on the real economy, especially since the 2006 Eddington Transportation Study and the global recession.

Consideration of Wider Economy Benefits

The assessment processes in all three countries (England, Scotland and Wales), capture the wider economic benefits (or those that are related to economic productivity) through two different mechanisms. First, the assessment processes result in estimates of changes in Gross Domestic Product (GDP), Gross Value Added (GVA), and employment. These measures can be considered ways of summarizing the effects on the wider economy. Second, the assessment processes add aspects of the wider economic benefits to the BCA calculations as addition benefits (or welfare impacts).

However, the terminology used varies across the three countries and the terms are often used loosely with a large degree of overlap. In Scotland and Wales, the impacts on the wider economy are called EALIs (Economic Activity and Location Impacts). In contrast, a mixture of terms is used in England to describe wider economy impacts. These can include: Regeneration Benefits, Wider Economic Benefits, and GVA or employment benefits. The welfare economic benefits added to the BCA are called "Wider Economic Benefits" in Scotland and Wales. This is also sometimes the case in England. However, the DfT refers to the additional welfare benefits (added to BCA) as "Wider Impacts." In all three countries, the term "Productivity Benefits" is loosely used in non-government circles to describe all wider economy and additional welfare economic impacts, including allocation efficiency benefits. Clearly, with such a large degree of overlap in terms and, in some instances, the same term being used to mean different things in different countries, there is plenty of room for confusion in what is already a complex technical area. To avoid any further confusion of terms, the remainder of this discussion of UK practice uses the term "wider economy impacts" to identify productivity impacts occurring outside the transportation market (e.g. in the labor market, product market, or land market as distinct from additional welfare benefits (added to BCA).

Estimation of Wider Economy Impacts

Estimating the anticipated economic outcomes of transportation projects in terms of GDP and employment now forms an essential component in the transportation assessment guidelines of England, Scotland, and Wales. There is a slightly longer history of economic outcomes being relevant to the objectives of a transportation project in Scotland or Wales than in England. Both countries use a two-stage assessment process that includes economic impacts. These expected economic outcomes play a more formal role in the Scottish and Welsh systems, since EALIs (Economic Activity and Location Impacts) must be reported for all projects. England has recently introduced a requirement for a Transport Business Case. This combined with a national policy focus on the economy has provided the impetus for including economic outcomes on GDP and employment in the case for transportation investment in England.

In England, there is a relatively new requirement to develop a Transport Business Case. In contrast to the prescriptive guidance for conducting a BCA and assessing the non-monetized impacts that appear in an Appraisal Summary Table (AST), there is no template for completing the business case. As a result, project stakeholders have tended to interpret the available guidance by describing expected economic outcomes on the wider economy (i.e., employment, GVA, labor market size, labor market composition, etc.) in two of the business cases that are required – the "strategic case" and the "economic case." The strategic case has to demonstrate how the project contributes to national objectives, such as those related to the economy and the climate. The economic case contains the BCA, the appraisal summary tables, impacts on public accounts, and ancillary economic evidence.

In the case of transportation projects occurring in redevelopment areas (called "Regeneration Areas" in England), the assessment is more prescriptive. The AST must summarize wider economy impacts in the redevelopment area in terms of employment and GDP. However, these measures relate exclusively to the impacts in the redevelopment area – impacts outside this area (including displacement effects) are omitted. The rationale is that changes in economic conditions (in terms of GDP and employment) have no additional welfare economic value unless there is a market distortion. Including them where there are no market distortions would double count user benefits. In a redevelopment area, such impacts will have some equity welfare value as they occur in an area of deprivation – and this equity value will not double count user benefits, such as time savings.

Scotland and Wales have adopted a two-stage assessment process. The project is assessed against economic objectives, if these were established as part of the Stage 1 assessment. Since these objectives are typically couched in terms of economic outcomes (e.g., employment and GDP), wider economy impacts can be described in the Stage 1 assessment. The Stage 2 assessment is required to include an evaluation of wider economy impacts, called EALIs (Economic Activity and Location Impacts). The EALI analysis is intended to show the spatial distribution of the total economic impact of a project. The analysis facilitates an understanding of the impact at the local level, while providing a distributional context

(Scottish Government 2012a, pp. 27-47). The EALI analysis is presented at the national level with intra-and inter-area impacts identified. Effects include positive, negative, and displacement impacts. Typically, EALIs capture changes in GDP (or GVA) and employment by industrial sector or skill level at some zonal level. The appraisal guidance recognizes that the EALIs wholly or partly double count other items of benefit that appear in the Appraisal Summary Table, such as time savings.

Wider economy impacts are typically estimated using a set of business and household surveys or using models, such as Land Use Transport Interaction (LUTI) models. For example, the webTAG provides guidance on using such methods (e.g. UK DfT, 2011b). The Scottish Government has developed a national LUTI model that can be used to assess the spatial economic impacts of major transport projects (Scottish Government 2012b).

In the absence of surveys or models, GDP impacts are estimated using "pre-specified" parameters in conjunction with elements of a BCA through the following approach (UK DfT 2005 pp31-32):

- Business and freight user benefits are taken as an estimate of the core GDP impact of a project.
- Increased supply of labor (at the national level) due to lower commuting costs is estimated from changes in commuting costs.
- Increased output in imperfectly competitive markets is estimated from business and freight user benefits.

As discussed further in the next section, the estimation of agglomeration benefits is complicated, so these are not estimated for all projects or proposals. When they are estimated, the increased labor productivity per worker (aggregated over all workers) represents an additional increase in GDP. If a modeling framework that predicts changes in employment is used (e.g. a LUTI model), a move to higher paying (i.e., more productive) jobs as a result of lower commuting costs can also be estimated. The increase in productivity from the move to more productive jobs also produces the GDP impact.

Calculation of Wider Economic Benefits

In the UK, the DfT has led efforts to incorporate welfare impacts beyond direct user benefits into the BCA. In general, Scotland has observed the developments at DfT and adopted final guidance wholly or in part. The guidance in Wales defers to the webTAG topic guidance notes issued by the DfT.

If markets are not distorted, measuring benefits in the primary transportation market gives a full measure of the welfare impacts of a transportation investment from a BCA perspective. This means the indirect effects on land, labor and output can be ignored for a benefit-cost analysis. Only if the secondary markets (e.g., labor market) are distorted is there a need to consider how indirect effects are treated in a BCA.

These fundamentals are the starting point for the treatment of additional welfare impacts in BCAs in the United Kingdom. The focus is on adding the impact of distortions in secondary markets to the user benefits. The Department for Transport's July 2005 discussion paper (UK DfT, 2005) provides a long list of potential market distortions in secondary markets. From this list, the DfT has produced guidance on four "wider impacts." Table 8-1 lists these impacts along with the associated market failures.

Table 8-1: Wider Impacts and Market Failures

Wider Impact	Market Failure	Labor Productivity Impact
The treatment of agglomeration economies	agglomeration externality	Yes
The treatment of increased output in imperfectly competitive markets	monopolistic competition	No
Increases in labor supply	labor tax	No
Moves to more/less productive jobs	Agglomeration externality / labor tax	Yes (indirectly)

Source: UK DfT (2012b)

As can be seen in the table, only two of the four wider impacts are related to changes in labor productivity as a result of transport investments. Agglomeration economies mean that transportation projects that effectively bring economic agents closer together raise average productivity beyond what would be expected from the time savings alone. This additional increase in productivity can be added to the BCA as an additional welfare impact (Venables, 2007).

The second wider impact related to productivity is the move to more or less productive jobs. There is spatial variation in worker and job productivity due to the presence of agglomeration economies among other factors. In response to changes in transport costs, businesses and households may re-locate or workers may change jobs. Either party would make such a move to take advantage of higher wages (for workers) or higher productivity per worker (for businesses). The impacts on businesses and users are already encapsulated within the user benefit calculation, but due to the presence of a distorting labor tax, an additional welfare impact equivalent to the change in tax revenues also occurs. Therefore, this wider impact is only indirectly related to productivity.

In England, the primary BCA estimated in the assessment includes the additional welfare impacts due to agglomeration economies, increased output in imperfectly competitive markets, and increased labor supply. Additional welfare impacts due to moves to more or less productive jobs do not appear in the initial analysis, but can be incorporated as part of a sensitivity test (UK DfT, 2012b). In Scotland, the additional welfare impacts due to effects in secondary markets do not appear in the primary BCA estimate and are included only as part of sensitivity testing (Scottish Government, 2012a). In addition, Scotland estimates impacts for only the first two "wider impacts" in Table 8-1. The Scottish Government does not provide guidance on any other sources of additional welfare impact.

Impact on Benefit-Cost Analysis

In the UK, the additional welfare impacts due to changes in the economy have been shown to have quite varied impacts on the BCAs of transportation projects. For some projects, their inclusion has only a marginal impact. The Crossrail project (to build new rail infrastructure in London) represents the other end of the spectrum with 62.5 percent additional benefits due to the additional welfare impacts (UK DfT, 2006). This additional benefit includes all the effects listed in Table 8-1, of which only one is a pure productivity effect.

While the sponsors of projects are free to estimate as many of the additional welfare impacts as they wish, the Department for Transport advises that agglomeration effects on productivity are typically significant only if the scheme affects a "functional urban area," which is defined as having a "core" with a working population of 60,000 and a job density of 7 jobs per hectare. If a proposed project lies outside a functional urban area, the implication is that agglomeration-related impacts on the BCA will be small to insignificant.

The size of the additional welfare impacts is dependent more on the location and market served than the type of the project. Crossrail serves the densest (most agglomerated) part of the UK – the City of London. The location, rather than the transportation mode, is the reason that it generates such a large effect. Of course, it would be inordinately expensive to construct a highway and ancillary infrastructure with the capacity of Crossrail in the center of London.

For the Eddington Study, the DfT added economic welfare impacts to prior assessments of some 170 proposed projects. This analysis showed that additional welfare impacts are typically more important in urban networks than inter-urban corridors (see Figure 8.1), but that a quite large variation can exist within individual urban areas (see Figure 8.2). The market that a proposed transport infrastructure serves is critical. Typically, those that serve city centers or business traffic have larger economy-related additional welfare benefits than those that do not. In addition, as Figure 8.2 demonstrates, both highway and mass transportation projects can generate large additional welfare impacts.

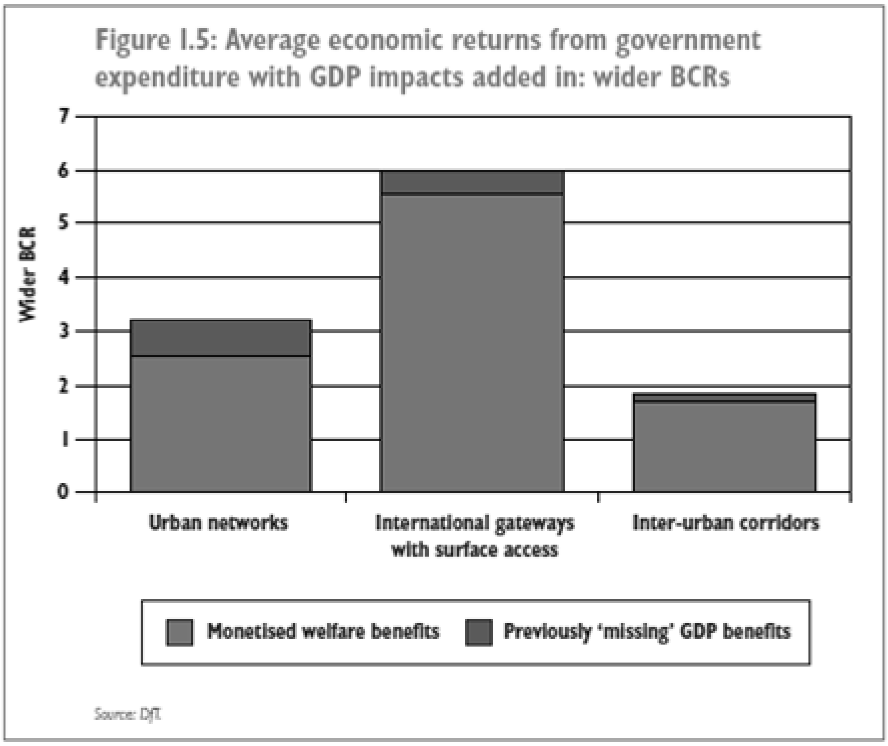

Figure 8.1: Contribution of economy additional welfare impacts to the BCA, by location of schemes

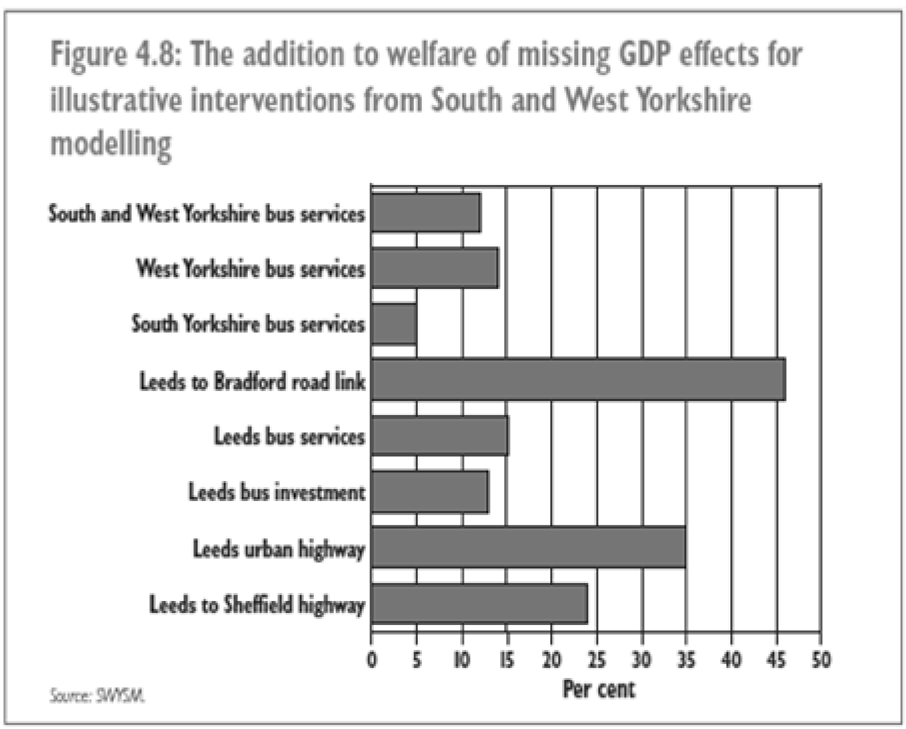

Figure 8.2: Contribution of economy additional welfare impacts to the BCA, for specific schemes

Recent Developments and Challenges

UK policymakers have long been interested in the wider economic impacts of transportation projects. The global financial downturn has only increased that interest and the UK method for incorporating wider economy impacts in assessments is evolving as a result. There remains ongoing interest in whether all additional welfare economic impacts have been captured in the current BCA approach. In addition, there is very active interest in how best to incorporate impacts on GVA and employment in the decision-making process. Related to both of these concerns is the modeling of impacts and benefits.

The incorporation of further additional welfare impacts into BCAs has been hampered by a lack of data and evidence. Eddington (2006 Figure 2.8 p36) identified gains from trade and globally mobile activity as two potential channels through which transportation could have an important influence on the UK's productivity and competitiveness. Increases in international trade and Foreign Direct Investment (FDI) are expected not only to increase GDP, but also to result in productivity increases. If investment in transportation can influence the rate of FDI and result in increased trade then the additional productivity gain is an externality that is currently missing from the assessment process. For these reasons, Eddington emphasized access to international gateways (i.e. ports and airports) as part of his study. NERA (2010) reviewed the international evidence regarding the productivity impacts of FDI and gains from trade as well as the role that transportation can play in influencing the location choices of FDI. While developing case studies of airport expansion, NERA found the evidence contradictory and quite difficult to apply to the transportation case. Developments in this area have since stalled.

At the local level, there has not been the same history of BCA as at the national level. Local politicians, and local government staff, are more focused on local outcomes of transport interventions - whether that is social inclusion, the economy, the environment or safety – rather than the national picture. Typically, they are not concerned about spillover effects between regions or displacement effects. The current "localism" political agenda in England has brought the difference between local and national government much further to the fore than it has been historically. "Localism" in this context refers to proposals by the England central government to decentralize funding for major transportation projects to local government or regional groupings of local governments (e.g., Greater Manchester)6. With the current focus on the economy, local governments have been developing indicators to prioritize transportation infrastructure investment and to prioritize investment among transport, housing and redevelopment based on GVA impact. The work undertaken by Greater Manchester has led in this area:

[6] In Scotland a decentralization of local government funding has also occurred but not to the extent that it is happening in England – as there are no plans to devolve major transport scheme funding to local authorities in Scotland.

> "The impact of the [Central Government's] Spending Review on transport results in major challenges in prioritising limited funds to address the outcomes that matter most in the short term. Our approach is to priorities in a manner that complements the Government's priorities for the Spending Review, which clearly point towards activities that provide 'substantial economic value', targeted at 'those most in need' and delivered increasingly at the local, rather than national, level." GMPTE (2011 p. 16)

In essence, the Greater Manchester work has used cost-effectiveness indicators on the local economy as a way to prioritize major projects. The indicators typically used are local GVA and local employment. This approach has been adopted by other regions in England (e.g., West Yorkshire and South Yorkshire), and other regions are actively considering adoption. This satisfies the needs of local government, but if adopted nationwide, it does raise a series of questions about the direction that transportation planning and assessment is moving in England (Laird and Mackie 2010, pp. 20-24). The primary issue is that cost-effectiveness indicators based on a narrow, local economic agenda are not holistic. They exclude impacts on carbon, safety, and access to services for example. Additionally, in a densely populated country, like England, the actions of one local or regional authority have an impact on neighbors. In a holistic appraisal there is the need to account for positive and negative spillover effects between regions, in which the national government has a vested interest, but local government does not. To date these issues remain unaddressed.

There remain a number of ongoing technical challenges with incorporating impacts in the wider economy into the assessment process. Modeling is a key issue. Forecasting impacts on the economy and employment are central to the inclusion of wider economy impacts in a transportation assessment. However, this modeling is at the cutting edge of regional science and often is more appropriate when applied at national levels rather than the tactical level of a highway improvement or an urban public transit project. The modeling tools are not necessarily available for all applications.

A related issue is the debate whether the UK approach to the BCA is appropriate. The UK approach adopts a separate market analysis for each market failure in the wider economy (a partial equilibrium approach). In contrast, a more comprehensive approach of using a multiple market framework (e.g. Spatial Computable General Equilibrium models) is possible. The key reason why a separate market analysis is undertaken in the UK is that the modeling effort for a multiple market framework is regarded as too high. The criticism of a separate market analysis approach is that it overstates the additional welfare impact of changes in the wider economy.

There is also an ongoing debate regarding double counting within the UK framework. By including both a BCA (with additional wider economy impacts) and an appraisal method that brings economic outcomes to the fore (e.g. EALIs in Scotland and the Transport Business Case in England), there remains a risk of double counting benefits.

8.3 Other Countries

While the United Kingdom has adopted a formal process for including wider economic and economic productivity impacts in project assessments, other countries have adopted much less formal approaches. This is partially in recognition of the difficulty in quantifying impacts. The most common approach is to incorporate productivity impacts in the assessment process through the use of multi-criteria analysis. Under this approach, each factor is given a defined weight to determine a maximum or best decision. In addition, some countries have relied on macroeconomic techniques, such as computable general equilibrium and macroeconomic growth models, to estimate economic impacts.

Europe

A variety of practices have been developed and used in Europe. Grant-Muller et al. (2001) provides a summary of European practices as of 2000. At that time, only Germany had incorporated economic development aspects into a formal, monetized benefit-cost analysis. However, a number of other countries made quantitative or qualitative assessments and, in many cases, included the assessments in an MCDA (multi criteria decision analysis) framework. France is an example of a country that made a broad assessment of likely employment effects arising from a project as a measure of the socio-economic impact. As Quinet (2011) outlined, France has made an attempt to revise its assessment process to formally include a range of social economic impacts. However, this attempt has not yet resulted in significant changes in practice.

Some of the most advanced use of modeling in evaluation has been in the Netherlands. The Netherlands has been using social benefit cost analysis since 2000, and they also utilize MCDA techniques to address broader issues in their transport decision-making. They have more recently added consideration of wider economic effects (Oosterhaven et al., 2004). These efforts have been augmented by the use of a various ad hoc modeling methods (Annema et al. 2007), including the addition of reliability factors (de Jong et al., 2009) and development of a multi-regional economic impact simulation model called RAEM (Ivanova et al., 2007; Tavassy et al. 2011). The RAEM economic model has been used to examine the spatial pattern of labor mismatch and the potential relocation of employment at the national level. And this refinement has been used in a major corridor study -- the evaluation of alternatives to improve transportation links between the Randstad (the Amsterdam/ Rotterdam region) and the Northern Netherlands. (See Knaap and Oosterhaven, 2011).

Recent developments in Germany have also concentrated on the development of enhanced macroeconomic modeling, though that work has been used primarily for large scale transport planning rather than for project decision making. The model analysis has focused on evaluating employment effects (mainly of construction and operation) and economic impacts on less developed regions. It has also examined potential impacts on international trade. In that work, there has been particular focus on evaluating changes in accessibility as a function of the relative attractiveness of different locations, the distance among locations, and other barriers. This accessibility measure is an input to regional productivity functions that are estimated sector by sector (see IWW et al, 2009 for an example). In addition, the Germans are interested in the building large-scale models that use a system dynamics approach to capture the more active effects.

France is showing a renewed interest in estimating the wider impacts of projects. The motivation is the Grand Paris concept of new urban rail and metro links that is intended to provide a focus for research-based and high-tech industries in the Paris region. In addition to estimating the employment effects of construction and operation and a forecast of likely impacts on primary economic activities, French researchers are developing extended land-use transport interaction models to determine impacts on the location of firms, employment, productivity, and land values. In addition, there are efforts to use macroeconomic models to estimate potential growth (De Palma 2011).

Spain has recently seen the fast growth of high-speed rail of any European county. Despite the clear development impact, the Spanish assessment process does not include wider economic or productivity impacts. In effect, the Spanish make an assumption that any improvement to the existing underdeveloped rail network would have positive benefits, so no further evaluation is necessary. Another factor is that a considerable part of the financing comes from external (European Union Structural and Cohesion) funds, so the use of these funds is considered to be a net gain. Since the completion of the Spanish high-speed rail network, it is clear that the high-speed rail has had considerable impact on the spatial functioning of labor markets, often in unforeseen ways (Garmendia et al. 2012; Urena 2012). Research to date has measured these impacts largely in terms of changed commuter flows rather than in productivity or agglomeration effects.

Asia and Oceana

In Japan, there has been no formal inclusion of wider economic impacts in the project assessment process. The official guidance on the assessment of road projects (Study Group on Road Investment Evaluation 2000) provides a classic benefit-cost framework with a focus on direct user benefits. However, Japanese researchers have shown considerable interest in the use of CGE models to estimate the likely impact of transport investments on the economy and to provide very detailed estimates of implied social rates of return (see Miyagi 1998 for a good example).

Both New Zealand and Australia have used traditional benefit-cost frameworks for estimating project impacts. In both countries, there have studies that have re-estimated benefits using an approach akin to the Graham-inspired UK practice of wider economic impacts (Mare and Graham 2009; Hensher et al. 2012a, Hensher et al. 2012b). Transport for New South Wales, the state public transport planning agency, recently commissioned a study utilizing conjoined spatial and economic models (TRESIS-TREDIS) to evaluate the effect of incorporating broader labor market access effects into benefit/cost analysis for proposed new commuter rail lines.

8.4 References Cited: International Practices

Annema, J.A., C. Koopmans and B. Van Wee (2007). Evaluating Transport Infrastructure Investments: The Dutch Experience with a Standardized Approach. Transport Reviews, 27(2), pp. 125–150.

De Jong, G., et al. (2009). Preliminary Monetary Values for the Reliability of Travel Times in Freight Transport, European Journal of Transport and Infrastructure Research, 9(2), 1567-7141.

De Palma, A. 2011. The “Grand Paris” Project: Tools and Challenges, Discussion Paper No. 2011-28, OECD-ITF Joint Research Centre, Paris: OECD.

Department for Transport (UK DfT). 2005. Transport, Wider Economic Benefits, and Impacts on GDP. Discussion Paper.

Department for Transport (UK DfT). 2008. The Additionality of Wider Economic Benefits in Transport Appraisal. Department for Transport, London. http://www.dft.gov.uk/publications/the-additionality-of-wider-economic-benefits-in-transport-appraisal.

Department for Transport (UK DfT). 2011a. The transport business case. Department for Transport, London. www.dft.gov.uk/publications/transport-business-case .

Department for Transport (UK DfT). 2011b. Regeneration Impacts, TAG Unit 3.5.8. www.dft.gov.uk/webtag .

Department for Transport (UK DfT). 2012a. Wider Impacts and Regeneration, TAG Unit 2.8. www.dft.gov.uk/webtag .

Department for Transport (UK DfT). 2012b. The Wider Impacts Sub-Objective, TAG Unit 3.5.14. www.dft.gov.uk/webtag .

Eddington, R. 2006. The Eddington Transport Study. Main report: transport’s role in sustaining the UK’s productivity and competitiveness, The Stationery Office, London.

Garmendia, M., V. Romero, J. M.de Ureña, J. M. Coronado and R.W. Vickerman. 2012. “High-Speed Rail Opportunities around Metropolitan Regions: The Cases of Madrid and London.” Journal of Infrastructure Systems, in press.

GMPTE. 2011. Third Greater Manchester Local Transport Plan 2011/12 – 2013/14. www.tfgm.com/journey_planning/LTP3/Pages/default.aspx .

Grant-Muller, S.M., P. Mackie, J. Nellthorp and A. Pearman. 2001. Economic Appraisal of European Transport Projects: The State-of-the-Art Revisited. Transport Reviews, 21,(2), pp. 237-261.

Hensher, D.A., P. Truong, C. Mulley, R. Ellison. 2012a. Assessing the Wider Economy Impacts of Transport Infrastructure Investment with an Illustrative Application to the North-West Rail Link Project in Sydney, Australia. Journal of Transportation Geography.

Hensher, D.A., R. Ellison, C. Mulley. 2012b. Assessing the Wider Economy and Social Impacts of Highspeed Rail in Australia, Report for the Australasian Railway Association, Institute of Transport and Logistics Studies, University of Sydney Business School.

HM Treasury. 2003. The Green Book. Appraisal and Evaluation in Central Government, The Stationery Office, London.

Ivanova, O. et al. (2007). RAEM Version 3.0. Transport Mobility Leuven, Netherlands. http://www.tmleuven.be/project/raem/RAEMFinalreport.pdf

IWW, SRF, VWI. 2009. Volkswirtschaftsliche Bewertung des Projektes Baden-Württemberg 21.

Knaap, T. and J. Oosterhaven. 2011. "Measuring the Welfare Effects of Infrastructure: A Simple Spatial Equilibrium Evaluation of Dutch Railway Proposals." Research in Transportation Economics, 31, pp. 19-28.

Laird, J.J. and P.J. Mackie. 2010. Review of methodologies to assess transport's impacts on the size of the economy. Report to the Northern Way. www.northernwaytransportcompact.com/downloads/Evidence%20Base/Transport%20&%20the%20Economy/Review_of_Methodologies_to_Assess_Transports_Impacts_on_the_Size_of_the_Economy.pdf

Mare, D. and D. Graham. 2009. Agglomeration Elasticities in New Zealand, Motu Economic and Public Policy Research Working Paper 09-06, Auckland, New Zealand.

Miyagi, T. 1998. "A Spatial Computable General Equilibrium Approach for Measuring Multiregional Impacts of Large Scale Transportation Projects." Network Infrastructure and the Urban Environment, Heidelberg: Springer.

NERA Consulting. 2010. Representing International Business Impacts in Transport Appraisal. Report for the Department for Transport. www.dft.gov.ukpublications/representing-international-business-impacts-in-transport-appraisal .

Oosterhaven, Jan et al. (2004). Indirecte Effecten Infrastructuur: Aanvulling Leidraad OEI (Indirect Effects of Infrastructure: Supplement OEI Guide), Netherlands Ministry of Transport, Public Works and Water Management, The Hague. (in Dutch)

Price, A. 1999. A New Approach to the Appraisal of Road Projects in England. Journal of Transport Economics and Policy, 33(2), pp. 221-226.

Quinet, E. 2011. The Practice of Cost-Benefit Analysis in Transport: The Case of France, in Improving the Practice of Transport Project Appraisal, ITF Round Tables, No. 149, OECD.

Scottish Government. 2008. Scottish Transport Appraisal Guidance (STAG). Edinburgh.

Scottish Government. 2012a. Economy Objective. STAG Technical Database. www.transportscotland.gov.uk/stag/td/Part2/Economy .

Scottish Government. 2012b. LATIS (Land Use and Transport Integration in Scotland). www.transportscotland.gov.uk/analysis/latis

Tavassy, L.A., M.J.P.M. Thissen, J. Oosterhaven. 2011. Challenges in the Application of Spatial Computable General Equilibrium Models for Transport Appraisal. Research in Transportation Economics, 31, pp. 12-18.

Urena, J.M. de, ed. 2012. Territorial Implications of High Speed Rail: a Spanish Perspective, Ashgate, Farnham.

Venables. 2007. "Evaluating Urban Transport Improvements. Cost–Benefit Analysis in the Presence of Agglomeration and Income Taxation." Journal of Transport Economics and Policy, 41(2), pp.173–188.

Welsh Assembly Government (WAG). 2008. Welsh Transport Planning and Appraisal Guidance. http://wales.gov.uk/topics/transport/publications/weltag/?lang=en .

9 CONCLUSIONS

9.1 Key Findings

From the review of research and practice (prior chapters), we can identify key findings from which to draw conclusions regarding how to define and measure economic productivity impacts. This provides a foundation from which we can design approaches for evaluating productivity impacts and incorporating them into transportation project assessment. The findings and associated conclusions are as follows.

1. There is strong interest in, and demand for, recognition of broader economic impacts in the assessment of economic benefits for transportation projects. This is exhibited by the broad base of research, covering a wide range of impacts on business organization and operation. It includes effects of changes in labor markets, product/service delivery markets, and processes for production, stocking and fleet deployment. It is multi-faceted, transcending both academic research (covering theory and empirical analysis) and implementation analysis (covering business management and public policy discussions).

   è *This finding indicates that the analytic framework for transportation project assessment should be multi-modal and cover the movement of both freight and people.*

2. The measurement of productivity impacts is equally relevant to the prominent forms of decision support tools, including economic impact analysis (EIA), benefit-cost analysis (BCA) and multi-criteria analysis (MCA). Enhancing productivity (maximizing output /cost) and increasing cost competitiveness (minimizing input cost/output) are two facets of the same basic effect – which leads to income creation and investment in business growth. BCA seek to identify the *net* value of both money and non-money benefits which should include productivity impacts. EIA seeks to identify *gross* effects of job and income growth on an area, based on changes in economic competitiveness. Thus, the two perspectives can be considered complementary, consistent, and both useful in answering different questions. And productivity impacts are relevant to both. MCA is fundamentally a variant of BCA (that allows but does not require effects to be measured in money terms), so productivity impacts are also relevant for this form of evaluation (and could be viewed as preferable to other economic benefit proxy measures now commonly in use).

   è *This finding indicates that the analytic framework for measuring productivity effects of transportation projects should be designed for EIA, BCA or MCA application.*

3. Effects on productivity may occur from investments in any mode of transportation, and in any setting. The literature on productivity effects spans aviation, marine, rail and roadway modes. It also spans both freight and passenger transportation and can be applicable for both urban settings and rural regions. And in the US, much of the consideration of productivity impacts has come as part of an effort to broaden the range of economic considerations incorporated into multi-modal prioritization and alternatives analysis.

è *This finding indicates that an analytic framework relevant for measuring productivity effects in the US should to be applicable for all modes and settings, and set up in a way that is not seen as unduly biasing decisions towards investment in certain modes or certain types of settings.*[7]

4. There are four fundamentally different ways of viewing the processes by which transportation improvements lead to productivity changes in the broader economy.

(A) *Transportation impact effects* – This includes a distinction between *effects on transportation system users* (including time, cost and safety changes for current travelers and projected future travel patterns) and *wider effects on the economy* (creating opportunities for both new activities and reorganization of existing activities, affecting non-users as well as system users).

(B) *Impact processes* - There are distinctive pathways whereby transportation changes lead to wider effects on business productivity. The effects may occur through changes in: *(1) access to labor and customer markets, (2) freight delivery processes,* and/or *(3) business organization and operations*. Each of these effects represents a different facet of wider impact but they all share a common denominator – they relate to processes that enable greater production to occur with the same cost, or the same production to occur with a lesser cost.

(C) *Measurement metrics* – To make productivity impact estimation practical, data required to drive the analysis must be measureable, and the calculation of resulting impacts must be tractable. The most widely available metrics for capturing transportation factors that drive productivity change are: *(1) market accessibility, (2) intermodal connectivity* and *(3) reliability* indices. (These indices are in addition to the more traditionally covered measurement of changes in travel times, expenses and safety). In each case, there has been past funded research that has defined these measures and provided tools for calculating them.

(D) *Intermediate behavioral factors* – Theoretically, the preceding impact processes occur because of changes in factors such as network access and use, intermodal interchange and effects on economies of scale, matching of specialized worker skills,

[7] The interest in prioritizing multi-modal freight and passenger proposals in the US context is in contrast to the UK context, where most of the application of productivity impact has focused on passenger travel and research regarding how agglomeration benefits should be incorporated into the benefit calculation for passenger transport schemes.

spatial competition and relative costs. These intermediate factors interact and overlap and many of them are hard to quantify, though the ultimate productivity outcomes are not hard to quantify.

è *This finding indicates that future analysis of productivity impacts needs to be sufficiently transparent to connect from (a) changes in transportation system characteristics to (b) impacts on business productivity outcomes. The relationships should also be understandable to all stakeholders, enabling robust decisions to be made.*