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Performance Measures for Sustainable Freight Movement

Final Report

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16. Abstract

Freight movement by road and rail is a cornerstone of the economy of the United States. However, the movement of freight in the U.S. is increasingly impacted by congestion, overburdened infrastructure, and economic issues. Thus, there is a need to emphasize and improve sustainability of the freight system, by both enhancing the benefits of a robust freight system and minimizing the negative impacts freight movement can have on transportation corridors. In general, sustainability refers to providing for environmental stewardship, economic efficiency and social equity in the present as well as into the future. This project developed a framework and methodology to address the issues of freight sustainability at the transportation corridor level, i.e., for highways and rail facilities. Steps included defining the goals and objectives of sustainability pertaining to freight movement and developing appropriate performance measures that reflect progress toward these goals. A set of performance measures were developed to accommodate the specific needs of both urban and rural corridors. This research also developed a methodology for evaluating individual performance measures for a specific transportation corridor and combined them into an aggregate sustainability indicator. This process enables users to compare results for different corridors or for alternate development scenarios for a specific corridor. This project included a case study for a major freight corridor. The resulting tools provide an analysis methodology for departments of transportation, metropolitan planning organizations, and other private- and public-sector officials to use in planning, project development, operations, and other aspects of their businesses.

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for
Sustainable Freight Movement

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EXECUTIVE SUMMARY

Freight movement by road and rail is a cornerstone of the economy of the United States. However, the movement of freight is increasingly impacted by congestion, overburdened infrastructure, and economic issues. Freight movement also has an impact on transportation safety, environmental concerns, and the overall viability of our economy. Thus, there is a need to emphasize and improve sustainability of the freight system, both in terms of enhancing the benefits of a robust freight system and minimizing the negative impacts freight movement can have on transportation corridors.

The environmental impacts of freight movement and other socioeconomic issues need to be taken into consideration from a sustainability perspective. Many federal, state, and local agencies are undertaking a variety of initiatives to ensure that the performance of the nation's freight system does not considerably deteriorate in the coming years. Metropolitan planning organizations (MPOs) and state departments of transportation (DOTs) are also working to incorporate freight into the transportation planning and programming processes. As freight becomes an integrated part of transportation planning, there is greater need to include a holistic consideration of the impacts of freight movement at all the stages of planning and project development. The use of performance measurement is ideal in this context.

Project Objectives

This project developed a framework and methodology to address the issues of freight sustainability at the transportation corridor level. The specific project objectives were:

- Develop a framework for assessing freight sustainability and identifying the relevant performance measures.
- Identify the data requirements for using the performance measures.
- Propose a methodology for quantifying relevant performance measures.
- Develop an aggregate measure of sustainability for a freight corridor, based on the evaluated performance measures.
- Apply the developed methodology to a test case corridor.

Research Approach

This project used a combination of past research and applications, a targeted performance measure framework, and the developed methodology to establish specific measures and data to evaluate performance; researchers then applied the proposed methodology to a specific test case in the Houston area.

Findings—State of the Practice

While there is extensive research discussing sustainable transportation, sustainability of freight transportation and measures for sustainable freight transportation have been largely missing in sustainability evaluations. In this context, a performance measurement framework for freight transportation sustainability must be developed for a target agency's planning goals. An approach based on the multi-attribute utility theory has been identified as the most suitable to

identify and aggregate freight transportation sustainability performance measures. The following are conclusions drawn from past research and current practice:

- There are many variations of the definition of sustainability. However, sustainability is typically considered to be a combination of economic, social, and environmental progress, usually termed "sustainability dimensions." The issue of equity (among populations and/or over time) is also relevant.
- Sustainability is not something that is fully achievable; it represents a direction, not an end state. Hence, sustainability should be considered in terms of outcomes, not outputs.
- Transportation system sustainability is traditionally thought of in three ways: environmental, economic, and social/socio-cultural. The goal of sustainable transportation is to ensure that economic, environmental, and social considerations are factored into decisions affecting transportation activity.
- The success of an economy depends to an extent upon the amount of trade it can generate and support. Movement of goods depends on robust sustainable freight transportation.
- Large increases in freight movement are occurring (fastest growing economic sector) due to growing international trade. Continued internal economic growth depends on smooth, uninterrupted domestic movement. Sustainable freight transportation systems are those that can maintain that smooth, uninterrupted flow over time, causing the least damage to the environment and culture.
- Performance measures are used to evaluate status or progress toward achieving goals.
- Robust performance measurement systems conform to a set of attributes that are:
    - Relevant to the organization/strategy.
    - Clearly defined/easy to understand/transparent.
    - Based on available data/measurable.
    - Controllable/attributable.
    - Limited in number.
    - Timely.
    - Devoid of perverse incentives/are non-corrupting/are not corruptible.
    - Statistically/scientifically valid.
    - Comparable/consistent over time.
    - Responsive.
    - Capable of innovation.
    - Capable of aggregation.
- In general, DOTs often measure the following strategic areas to evaluate how well transportation systems perform:
    - Mobility and congestion.
    - Accessibility.
    - Safety.
    - Quality of life.
    - Environment.
    - Economic development.
    - System preservation.
    - Project delivery.
    - Traffic operations.
    - Maintenance.
    - Human resources.

- Performance measurement is used to drive freight-related decision-making in both the private and public sectors. Primary considerations include:
    - Private:
        - Market and shipper demand.
        - Financial performance metrics.
        - Volume, schedule, and cost management.
        - Regulatory issues.
    - Public:
        - Investment and financing: taxes, fees.
        - Economic regulation.
        - Infrastructure provision and maintenance: highways, tracks, ports, air.
        - Land use: facility location and access.
        - Environmental issues.
        - Safety.
        - Operations.
        - Jobs and employment.

These findings all lead to one conclusion: the decisions that will have to be made in both private and public sectors to produce and maintain sustainable effective freight transportation will need to consider multiple, sometimes diverse outcomes, and a performance measurement framework is needed to project the overall outcome in terms of individual considerations.

Framework and Quantification

In general, sustainability in the freight sector can be addressed by targeting the following:

1. Policy and regulation.
2. Technology.
3. Infrastructure.
4. Operation and maintenance.
5. Non-transportation factors.

There are significant benefits to aligning performance measurement with agency policy using a framework of goals, related objectives, and performance measures. This approach starts with the basic principles of sustainability. The basic components of this performance measurement framework include:

- Goals—usually the general statements relating to the intended users' desired outcomes.
- Objectives—more specific statements relating to the attainment of goals.
- Performance measures—measurable quantities linked to the objectives that can be applied for performance measurement.

The measures that form part of this framework are then developed into performance measures, which are quantified and benchmarked to develop a "freight sustainability index."

The framework was developed in this project for use in evaluating highway transportation. Table ES-1 shows the goals, objectives, and performance measures suggested for use in evaluating sustainability of freight transportation. Not all objectives will be applicable for all situations. Likewise, it may be appropriate to add additional objectives and measures to address conditions or considerations in some instances. Given the constraints of restricting the evaluation of freight sustainability to highway segments, the suggested performance measures adequately represent the overall concept of freight sustainability along a corridor, without being impractical to evaluate.

Another interesting aspect of sustainability is the consideration of changes over time. Future and present conditions should be evaluated on a common ground, rather than making allowances or accepting that future conditions would be worse.

Table ES-1. Proposed Objectives and Measures.

Goal No.	Sustainability Dimension	Goal	Objectives	Measure No.	Performance Measure
1	Social	Improve safety of freight movement and of the general public	Reduce freight-related crash rates and crash risk	1a	Annual fatal accidents per truck-mile
			Reduce freight-related hazardous material (HAZMAT) accidents	1b	Annual HAZMAT accidents per mile
2	Economic	Support freight activity level while ensuring functionality and efficiency of freight operation	Improve road-based freight movement	2a	Truck throughput efficiency (TTE); TTE = daily truck volumes per lane × truck operational speed
			Improve freight movement efficiency	2b	Average cargo weight per truck
			Improve freight movement mobility	2c	Travel rate index
			Improve freight movement reliability	2d	Buffer index
			Improve intermodal activity	2e	Number of intermodal facilities along the section
			Invest in improving freight fleet	2f	Average truck age
3	Environmental	Reduce negative impacts of freight movement on the environment and human health	Reduce criteria pollutant emissions from freight vehicles	3a	Grams per mile of PM, NO_x, VOC
			Improve freight fleet emissions characteristics	3b	Percentage of trucks complying with the second most recent emissions standards (e.g., model year 2004 for now)
			Reduce greenhouse gas (GHG) emissions from freight vehicles	3c	Grams of CO2eq per mile
			Reduce impact on sensitive population	3d	Number of sensitive areas (schools/hospitals) within 1 mile from the road
			Reduce buffer between road and residential development	3e	Population residing within 1 mile from the road
			Protect natural habitats	3f	The number of sensitive environmental areas within 1 mile from the road

This project established procedures for estimating performance for each of the measures. These procedures are recommended for use in evaluating sustainability of highway freight transportation.

Final Conclusions and Recommendations

The framework presented in this report can be used to comprehensively and objectively evaluate the sustainability of freight transportation. This can be done for a highway corridor or a portion of a highway network. Goals applicable to sustainability principles are suggested. These can be used as is or modified to fit specific local circumstances. The researchers recommend that each application be initiated with a careful look at goals and objectives (local, areawide, or beyond, as applicable for the evaluation). Additional objectives may be applicable; some listed in this summary may not be relevant or important in some cases.

CHAPTER 1: INTRODUCTION

Freight movement by road and rail is a cornerstone of the economy of the United States. However, the movement of freight is increasingly impacted by congestion, overburdened infrastructure, and economic issues. Freight movement also has an impact on transportation safety, environmental concerns, and the overall viability of our economy. Thus, there is a need to emphasize and improve sustainability of the freight system, both in terms of enhancing the benefits of a robust freight system and minimizing the negative impacts freight movement can have on transportation corridors. Issues such as congested highways, the economic downturn, and rising transportation costs all have an impact on the viability of the existing freight system. An unsustainable freight system can also lead to further congestion, slower freight movement, fragmentation, and economic slow-down. In addition to these outcomes, the environmental impacts of freight movement (whether by road or by rail) and other socioeconomic issues need to be taken into consideration from a sustainability perspective. Many federal, state, and local agencies are undertaking a variety of initiatives to ensure that the performance of the nation's freight system does not considerably deteriorate in the coming years. Metropolitan planning organizations (MPOs) and state departments of transportation (DOTs) are also working to incorporate freight into the transportation planning and programming processes. As freight becomes an integrated part of transportation planning, there is a greater need to include a holistic consideration of the impacts of freight movement at all the stages of planning and project development. The use of performance measurement is ideal in this context.

In general, sustainability refers to providing for environmental stewardship, economic efficiency, and social equity in the present, as well as into the future. This project developed a framework and methodology to address the issues of freight sustainability at the transportation corridor level, i.e., for highways and rail facilities. Steps included defining the goals and objectives of sustainability as it pertains to freight movement and developing appropriate performance measures that reflect progress toward these goals. Different sets of performance measures were developed to accommodate the specific needs of both urban and rural corridors. The data requirements for evaluating the performance measures were also taken into account during performance measure development.

Project Goals

The overall goal of this research was to develop and apply a methodology through which performance measures for sustainable freight movement along a corridor could be identified, quantified, and used in different levels of the planning and project development process. A major freight corridor in Texas was used as the test bed for this analysis. The specific project objectives were as follows:

- Develop a framework for assessing freight sustainability and identifying the relevant performance measures. Different performance measures were considered for rural and urban areas and to suit various other possible requirements.
- Identify the data requirements for evaluating the performance measures.
- Propose a methodology for quantifying the relevant performance measures.

- Develop an aggregate measure of sustainability for a freight corridor, based on the evaluated performance measures.
- Apply the developed methodology to a test case corridor in Texas.

Research Approach

This project used a combination of past research and applications, a targeted performance measure framework, and the developed methodology to establish specific measures and data to evaluate performance; the researchers then applied the proposed methodology to a specific test case in the Houston area. Specific tasks completed were:

- Task 1—Perform a comprehensive literature review on the subject.
- Task 2—Identify suitable performance measures that incorporate goals and objectives of sustainability in the context of freight movement.
- Task 3—Identify the data needs and requirements for candidate performance measures and identify possible sources for obtaining required data.
- Task 4—Develop a methodology to evaluate and aggregate the performance measures.
- Task 5—Apply the developed methodology to a selected freight corridor in Texas.
- Task 6—Prepare the results and findings containing the recommended performance measures, performance indices, and data collection procedures.

Report Outline

This report describes the work completed and the findings, conclusions, and recommendations developed in this project. This report is comprised of six chapters:

1. Introduction.
2. Background and Literature Review.
3. Development of a Sustainability Framework for Freight Corridors.
4. Quantification and Benchmarking of Performance Measures.
5. Case Study Application for IH-10 Corridor.
6. Summary, Conclusions, and Recommendations.

Two appendices contain background information details on freight data sources and truck model year (MY) distributions.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

Introduction

The success of an economy to an extent depends upon the amount of trade—internal and external—that it can support. The movement of goods within and outside borders relies on a robust freight transportation network. The value of goods transported by freight was $3 trillion in 1998, according to the Federal Highway Administration (FHWA), and is estimated to amount to $90 trillion by 2035. There are large monetary benefits associated with the efficient delivery of goods from the point of origin to their destination. Thus, freight movement has come to be recognized as the heartbeat of an expanding economy, one that needs to be supported with a strong and stable infrastructure in order to sustain its ever-growing needs.

A vast body of literature exists on the topics of sustainability, sustainable transportation, and performance measures. This background section references key literature and discusses the research team's approach and framing of the research problem in the context of the existing literature.

Sustainability and Sustainable Development

The issue of sustainability has been given increasing focus recently in almost every sector, ranging from private organizations/industries to a variety of government and public-sector entities. In general, sustainability can be thought of as relating to the holistic consideration of environmental, economic, and social concerns, with a long-term perspective.

There is a significant amount of literature (mostly developed since the late 1980s) devoted to discussing sustainability and what it means as a concept. Often, in such research, the terms "sustainability" and "sustainable development" are used in similar contexts, and they are used interchangeably in this report. The term "sustainable development" evolved to link two distinct yet related concerns—sustainability (fairness with respect to future generations' needs, i.e., preserving the earth's natural life-support systems into the future) and development (more immediate concerns over progress and improvement in living conditions for the present).[1] The emergence of the terms "sustainability" and "sustainable development" into common usage can be traced through various global events, conferences, legislation, and publications.[2,3] To this day, however, a majority of the work that discusses sustainability inevitably refers to the 1987 report for the United Nations World Commission on Environment and Development (commonly referred to as the Brundtland Commission report).[4] In this report, sustainable development is defined as "development that meets the needs of the present without compromising the ability of

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[1] Gudmundsson, H. *Sustainable Mobility and Incremental Change—Some Building Blocks for IMPACT*. WP2 IMPACT, TransportMistra, Sweden, 2007.
[2] Hall, R. P. *Understanding and Applying the Concept of Sustainable Development to Transportation Planning and Decision-Making in the U.S.* Ph.D. Dissertation, Massachusetts Institute of Technology, 2006.
[3] Kelly, C. *Origins of Sustainability*. Report for Task 1.1, Appraisal of Sustainability Project Report, Institute for Transport Studies, University of Leeds, Leeds, United Kingdom. Working Paper. http://www.its.leeds.ac.uk /projects/sustainability/project_outputs.htm
[4] United Nations World Commission on Environment and Development. *Our Common Future: Report of the World Commission on Environment and Development* (A/42/427). August 4, 1987.

future generations to meet their own needs." The report also defines strategic imperatives and preconditions for implementing sustainability and is considered a turning point in recognizing that sustainability needs to be addressed comprehensively through coordination among various sectors, and not with a piecemeal approach.[5] The popularity of the Brundtland definition of sustainability can be attributed to the fact that it presents a broad agenda that even entities with conflicting interests or goals can agree upon.[6] However, other variations emphasize specific characteristics, such as environment or infrastructure.

Sustainability Dimensions

The dimensions of sustainability (also termed the pillars of sustainability) are the environmental, economic, and social dimensions. The underlying understanding is that environmental, economic, and social systems are interconnected. If development is to be sustainable, it has to consider these dimensions comprehensively. This is termed a triple bottom-line approach to sustainability. Many definitions of sustainability address these three dimensions: for example, "striving for an optimal balance between economic, social, and ecological objectives"[7] or "[sustainability]… requirements reflect that social conditions, economic opportunity, and environmental quality are essential if we are to reconcile society's development goals with international environmental limitations."[8] The dimensions do not represent isolated areas of human life but are more like metaphors for a comprehensive approach to judge if development is sustainable overall.[9]

How the dimensions of sustainability are to be made operational and what their roles are in regard to one another are open to interpretation and may vary according to what sustainability is being applied. Often, the dimensions overlap, and the issue of trade-offs between the dimensions has to be addressed. Conceptually, one way to relate the dimensions to one another is as a set of nested circles with the economic dimension being contained within the social dimension, which in turn is encompassed by the environmental sphere. This represents the view that economic systems are contained within a social framework; similarly, society exists within the natural environment. There are many alternative conceptual representations in published literature used to illustrate the linkages between the three sustainability dimensions, including the three dimensions as intersecting circles or as sides of a triangle.

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[5] Clayton, A., and N. Radcliffe. *Sustainability: A Systems Approach.* Westview Press, Boulder, Colorado, 1996.
[6] Jones, C., M. Baker, J. Carter, S. Jay, M. Short, and C. Wood. *Strategic Environmental Assessment and Land Use Planning: An International Evaluation*. Earthscan, Sterling, Virginia, 2005.
[7] Litman, T., and D. Burwell. "Issues in Sustainable Transportation." *Int. J. Global Environmental Issues*, Vol. 6, No. 4, 2006, pp. 331–347.
[8] Mihelcic, J. R., J. C. Crittenden, M. J. Small, D. R. Shonnard, D. R. Hokanson, Q. Zhang, H. Chen, S. A. Sorby, V. U. James, J. W. Sutherland, and J. L. Schnoor. "Sustainability Science and Engineering: The Emergence of a New Meta-Discipline." *Environmental Science and Technology*, Vol. 37, No. 23, 2003, pp. 5314–5324.
[9] Gudmundsson, H. *Sustainable Mobility and Incremental Change—Some Building Blocks for IMPACT*. WP2 IMPACT, TransportMistra, Sweden, 2007.

Strong and Weak Sustainability

Also relevant in this discussion is the difference between what are termed strong and weak approaches to sustainability.[10] A weak approach to sustainability is one in which trade-offs among various facets of sustainable development (i.e., the dimensions) are considered acceptable. In other words, the weak approach views man-made capital and natural resources as interchangeable, without consideration of the finite qualities of the ecosystem. On the other hand, the strong approach views natural capital as the limiting factor. While a strong approach to sustainability is most desirable, often trade-offs are necessary. Gudmundsson also provides a comprehensive discussion of issues relating to weak and strong sustainability and recommends a nuanced approach to the issue of trade-offs, for example, by identifying certain critical environmental resources that cannot be depleted, as opposed to some that may be substituted or renewed.[9]

Summary of Key Sustainability Issues

Because of the wide scope of sustainability, there are many issues involved in defining and measuring it. The terminology cuts across a number of scientific disciplines rather than forming a universal language. This section summarizes the most relevant observations for this project.

The research team position is that sustainability denotes a state to try to achieve, even if it cannot necessarily be reached. Sustainable development, on the other hand, can be viewed as a process by which sustainability can be attained. The term "sustainable development" can sometimes be more limiting than "sustainability," in that it focuses more on human needs (i.e., the development aspect). In this research, the two terms are used interchangeably, with the understanding that while sustainability reflects a broader scope and is a convenient term to use, true sustainability is more of an idealized state that can potentially be reached through sustainable development.

The following points summarize the research team's understanding of sustainability, which forms the basis for applying sustainability in the transportation context:

- While there is a distinction between the terms "sustainability" and "sustainable development," the terms are used interchangeably with the understanding that true sustainability is not necessarily something fully achievable, and when sustainability is referred to, it can be taken to represent a direction and not an end state.
- The definition of sustainability/sustainable development will be contested, and it is not the purpose of this study to resolve that. A preferred approach is to note the key components of sustainability and develop related goals, objectives, and strategies to operationalize them in the relevant context.
- Sustainability is typically considered a combination of economic, social, and environmental progress, usually termed "sustainability dimensions." The issues of future needs (i.e., intergenerational equity) are also relevant.

[10] Turner, R. K. *Sustainable Environmental Economics and Management: Principles and Practice*. Bellhaven, London, 1993.

- Additionally, there is a need to recognize the difference between having a "strong" versus "weak" approach to sustainability, i.e., whether other aspects of sustainability can be traded-off for gains on the economic front (when a weak approach is adopted).

Hence, the core principles of sustainable development—which include meeting human needs and improving community health and vitality, living within the earth's ecological carrying capacity and maintaining/enhancing natural capital, and protecting future generations—have been used as a starting point in addressing sustainability and its relation to transportation in this research.

Sustainability in the Transportation Sector

Transportation, as a major human activity, is an important consideration for sustainability. When addressing sustainability in relation to transportation, there are two divergent approaches noted among literature and practices—one that is centered on transportation (i.e., a transportation-centric view) and another that looks at transportation in support of a broader agenda for sustainability (i.e., a holistic view).[11]

While the term "sustainable transportation" is often used in the context of transportation and sustainability, it can sometimes narrow the scope of the problem being addressed. To quote Greene, "Sustainability pertains to the responsibility of an entire generation of society to future generations; whether it can meaningfully be applied to a single area of human activity such as transportation has been a subject of debate. That is, sustainability must be satisfied by the integral activities of a society and so, in this sense, it is not possible to judge whether one sector of society is sustainable on its own."[12]

The core principles of sustainable development have been incorporated to varying degrees in several conceptualizations of sustainable transportation.[13,14,15] In general, sustainable transportation is articulated using the sustainability dimensions (also termed the three E's), which have been described as environment, economy, and equity/society/employment.[16,17,18,19]

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[11] Hall, R. P. *Understanding and Applying the Concept of Sustainable Development to Transportation Planning and Decision-Making in the U.S.* Ph.D. Dissertation, Massachusetts Institute of Technology, 2006.

[12] Greene, D. L. "Sustainable Transportation." *The International Encyclopaedia of the Social & Behavioural Sciences*, Baltes, Paul B., and Smelser, N. J. (eds.), Elsevier Science Ltd., Oxford, 2001, pp. 15335–15339.

[13] Kelly, C. *Origins of Sustainability*. Report for Task 1.1, Appraisal of Sustainability Project Report, Institute for Transport Studies, University of Leeds, Leeds, United Kingdom. Working Paper. http://www.its.leeds.ac.uk/projects/sustainability/project_outputs.htm

[14] Holdren, J. P., C. Daily, and P. R. Ehrlich. "The Meaning of Sustainability: Biogeophysical Aspects." *Defining and Measuring Sustainability: The Biogeophysical Foundations*, Munasinghe, M. (ed.), World Bank, distributed for the United Nations University, Washington, D.C., 1995.

[15] Rees, W. E. "Achieving Sustainability: Reform or Transformation?" *Journal of Planning Literature*, Vol. 9, No. 4, 1995, pp. 343–361.

[16] Button, K. *Transport, the Environment and Economic Policy*. Edward Elgar, Aldershot, 1993.

[17] Centre for Sustainable Transportation (CST). *Definition and Vision of Sustainable Transport.* CST, Ontario, October 2002.

[18] Organisation for Economic Co-operation and Development (OECD). *Environmentally Sustainable Transport: Futures, Strategies and Best Practice.* Synthesis Report of the OECD Project on Environmentally Sustainable Transport, OECD, Paris, 2000.

[19] Transportation Research Board. *Toward a Sustainable Future: Addressing the Long-Term Effects of Motor Vehicle Transportation on Climate and Ecology*. National Academy Press, Washington, D.C., 1997.

However, a different but similar way of looking at the dimensions is to consider environment, economy, and social/cultural to be the three principles of sustainability and to consider equity to be an overarching factor that plays a major role in all three dimensions (principles). Figure 1 characterizes this description of sustainability, as defined in a recently published National Cooperative Highway Research Program (NCHRP) report.[20]

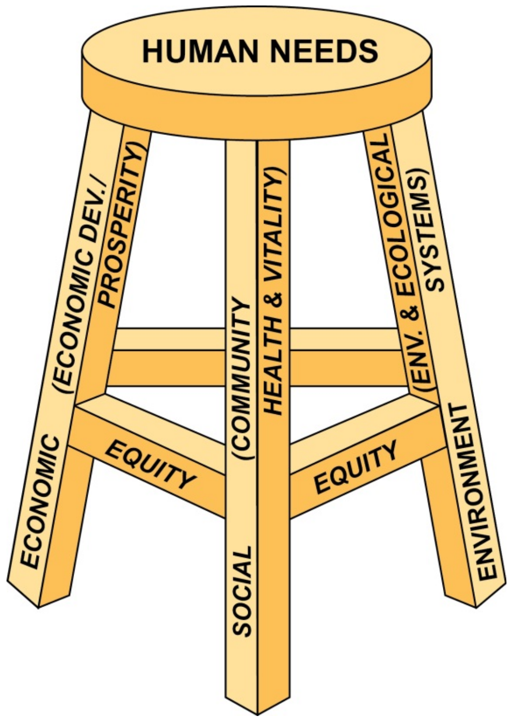

Figure 1. Principles of Sustainability and Significance of Equity[21] .

Sustainable transportation is treated as "an expression of sustainable development in the transportation sector."[22] A limitation of this conceptualization is that it has the potential to perpetuate the status quo by focusing only on change *within* the transportation sector to the exclusion of change *across* sectors. It can be argued that the sectoral focus implied by sustainable transportation may limit opportunities for radical technological and societal transformations across several systems/sectors at once. Thus, an important question is whether it is more beneficial to develop transportation policies from a *sustainable development* (i.e., holistic) rather than a *sustainable transportation* (i.e., transportation-centered) perspective.

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[20] Zietsman, J., and T. L. Ramani. *Sustainability Performance Measures for State DOTs and Other Transportation Agencies—Contractor's Final Report.* Prepared for the National Cooperative Highway Research Program, July 2011.
[21] Zietsman, J., and T. L. Ramani. *Sustainability Performance Measures for State DOTs and Other Transportation Agencies—Contractor's Final Report.* Prepared for the National Cooperative Highway Research Program, July 2011.
[22] Zietsman, J., and L. R. Rilett. *Sustainable Transportation: Conceptualization and Performance Measures*. Report SWUTC/02/167403-1, Southwest Region University Transportation Center, Texas A&M University, College Station, Texas, March 2002.

Table 1 summarizes the differences between a holistic and transportation-centric approach to sustainability. In practice, neither the transportation-centered nor the holistic approach will be easy to implement. However, the need for a strong and long-term public-sector commitment to sustainable development makes the holistic approach significantly more challenging. This observation is perhaps one reason why the transportation-centered approach has monopolized the attention of sustainable transportation researchers and practitioners.

The research team proposes that a transportation-centric viewpoint can be considered as a starting point to addressing sustainable freight movement. However, there should be an underlying recognition of the need for a more holistic approach in viewing freight transportation sustainability.

Table 1. Advantages and Disadvantages of Adopting a Transportation-Centered or Holistic View of Sustainable Development.[23]

	Sustainable Transportation (*Transportation-Centered View*)	**Viewing Transportation from the Perspective of Sustainable Development** (*Holistic View*)
Focus	• Single system/sector.	• Multiple systems/sectors.
Advantage	• Provides sector-specific objectives and principles that guide the development of transportation policies and programs. • Does not require a strong external commitment to sustainable development to enact sustainable transportation policies/programs at the regional/local level.	• Highlights the need to establish a national framework/policy to address sustainable development that can encourage sectors to coordinate/integrate their activities.
Disadvantage	• Does not explicitly connect impacts from the transportation sector with those from other sectors. Thus, transportation tends to be considered in a vacuum.	• Does not provide detailed sector-specific objectives and principles to guide the development of transportation policies and programs. • Requires a strong and long-term external commitment to sustainable development that may not be forthcoming in the current political climate.

Sustainability for Freight Movement

The movement of freight acts as the backbone of the economy and is often a direct indicator of growth pertaining to the economy. All industries that produce or sell goods that need to be transported rely on freight transportation. The freight transportation system in the United States

[23] Zietsman, J., and T. L. Ramani. *Sustainability Performance Measures for State DOTs and Other Transportation Agencies—Contractor's Final Report.* Prepared for the National Cooperative Highway Research Program, July 2011..

(U.S.) is a complex framework involving the participation of public and private entities. While the highways and waterways are public-owned, the railroads and trucking companies are private ventures. A healthy interaction between the public and private sector and a general alignment in the decision-making process is needed to ensure the optimal performance of the freight transportation system.

The freight and logistics sector in the U.S. is observing the fastest growth rate of all the sectors in the economy. Large increases in freight volumes have been projected due to growing international trade and increased consumption of goods following economic and population growth. The overall demand for freight is estimated to increase by 90 percent from 2004 to 2035.[24] Due to its implications on the economic progress of the nation, it is becoming increasingly critical to maintain a smooth and uninterrupted flow of freight within the country boundaries and outside.

While the concept of freight and sustainability has existed for a while now, if only in print, it is only recently that the concept has gained traction among the policy makers and operators. Long delays in border crossing points and congestions in port terminals negatively impact highway traffic hundreds of miles interior of these corridors. This situation not only hampers economic activity but also results in severe environmental and health consequences.

Sustainable freight systems, apart from the general sustainable transport system qualities discussed, are those that ensure a timely, continual flow of freight from the point of origin to delivery while at the same time causing the least damage to the environment. Of the surface freight transportation modes available, there is sufficient literature concluding that road transport via trucks is considered the least sustainable, followed next by rail.[25,26] A modal shift from truck to rail or barge would cause significant reduction in emissions of greenhouse gases (GHGs). Great environmental and economic benefit can be realized if a combination of modes is chosen to optimize freight shipping.

Studies of Freight Sustainability

Several countries, especially in Europe, have started to address issues concerning the sustainability of their freight systems. The government of Canada, under the Government of Canada Action Plan 2000 Climate Change, started five transportation initiatives, one being the Freight Sustainability Demonstration Program. Under this program, organizations that undertake freight projects that reduce GHG emissions and promote sustainability of freight are allocated funds to carry out their projects.[27] The Department for Transport (DfT), in the United Kingdom (UK), has made available freight grants through which freight traffic can be removed from the highways and distributed amongst rail and shipping systems instead. The Freight Best Practice Program is one such initiative that encourages efficiency of freight systems through the cooperation of freight operators.

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[24] NCFRP report 1, Public and Private Sector Interdependence in Freight Transportation Markets.
[25] Air Quality Impacts of Intercity Freight, Vol. 1, Report No. FHWA-PD-97-051, U.S. Department of Transportation, March 1997.
[26] Air Quality Impacts of Intercity Freight, Vol. 2, Report No. FHWA-PD-97-051, U.S. Department of Transportation, March 1997.
[27] http://www.arrc.ca/news.asp?nuid=90 (November 2009).

A modest amount of literature exists in the areas of freight sustainability, both from a technological as well as a policy viewpoint. Studies were done to analyze the effectiveness of existing freight policies on actual truck emission reduction in the port terminals where they were put in place. A good example of this would be the passage of the California Assembly Bill 2650 (AB2650). Southern California is home to the largest container ports in the U.S., and this is the reason for high levels of congestion in the ports of Southern California. With the intention of reducing truck emissions, the state passed AB2650. The regulation required marine port terminals to extend hours of operation for truck pick-ups and deliveries, establish an appointment system for trucks, or otherwise reduce truck queuing at terminal gate entries. It was the first state regulation on operating practices at port terminals primarily aimed at mitigating air emissions. A 2007 study reviewed the legislation to verify if it did indeed help mitigate the high levels of congestion and idling in the Los Angeles and Long Beach ports, and it was found to be minimally effective. The performance measures used to carry out this study were transaction duration, queue time, turn time, and per turn time saving for appointment scenarios as well as trucking company responses.[28]

The Department of Air Resources in New York carried out a study to evaluate the environmental impacts of goods movement within the city by truck mode. It was revealed that the trucks traveling within the city were the major environmental villains and that the rail and water networks were not being used to full capacity.[29]

The effects of truck idling on the contribution to GHGs have also been studied extensively. In a 2009 study, real-world field data were obtained from 20 auxiliary power unit (APU)-equipped and shore power (SP)-compatible trucks observed through a travel of 2.8 million miles across 42 states. It was found that compared to the base-engine idle time scenario with the scenario of installation of idle-reduction technologies like APUs, fuel use was reduced by 22 percent and carbon dioxide (CO_2) emissions by up to 5 percent. Shore power in trucks was found to be even more effective, as it reduced energy use as well as emissions by almost 48 percent with respect to the base-engine idle time scenario. The research suggested installing APUs in trucks and improving infrastructure for SPs, for reducing emissions from idling.[30]

Other studies evaluated the air quality impacts of freight from different modes, factors affecting freight efficiency, emission control strategies for freight, and adoption of intermodalism to reduce environmental impacts of freight.[31] One such effort aimed at evaluating the feasibility of intermodal transportation was done in Quebec, Canada. The potential for alternate freight modes of transport in a major freight corridor linking Windsor, Ontario, to Quebec City, Quebec, was analyzed by using survey data and considering the preference of shippers toward specific carriers. The feasibility study gave information for estimation of possible CO_2 reductions achievable due to a modal shift. A rail-yard catchment approach was used to arrive at estimates

[28] Genevieve Giuliano, Thomas O'Brien, Reducing port-related truck emissions: The terminal gate appointment system at the Ports of Los Angeles and Long Beach, Transportation Research Part D 12 (2007) 460–473.
[29] Arrow, M.M., Coyle J.J. and Ketcham, Brain, Impacts of Goods movement activity in New York City.
[30] H. Christopher Frey, Po-Yaokuo and Charles Villa, Effects of Idle Reduction Technologies on Real World Fuel Use and Exhaust Emissions of Idling Long-Haul Trucks, *Environ. Sci. Technol.* 2009, *43*, 6875–6881.
[31] Air Quality Impacts of Intercity Freight, Vol. 1, Report No. FHWA-PD-97-051, U.S. Department of Transportation, March 1997.

of contestable intercity truck traffic using a subset of the Ontario Ministry of Transportation's Commercial Vehicle Survey.[32]

The project "Advanced Technologies and Innovative Tools for Freight Distribution in the Sustainable City," jointly funded by the Italian Ministry of Transport and universities, aims to provide innovative organizational and technological solutions to optimize the freight distribution process. Some of the studies carried out by this project include use of smaller ecological vehicles for capillary transport in urban areas, development of software for service management, and development of advanced semi-automatic equipment for load handling.[33]

Performance Measurement for the Transportation Sector

Overview of Performance Measurement

Performance measures (or indicators) are measurable criteria that can be used to evaluate progress toward achieving goals and can be applied in many ways. The generally applicable performance measurement process can be described as having the following steps:[34]

1. Determine objectives.
2. Set targets.
3. Measure performance.
4. Monitor performance against targets.
5. Evaluate and review the process.

The outcome of this process can lead to decision-making or actions taken to improve performance.

While starting out as a tool to improve efficiencies and performance in the private sector, performance measurement has become increasingly common among public-sector agencies as well. Transportation agencies are public entities with a range of stakeholders and are facing increasing scrutiny from the general public. Thus, these agencies can benefit from the proper application of performance measurement and management.

Behn identified eight main purposes for using performance measurement in the public sector:

- Evaluate.
- Control.
- Budget.
- Motivate.
- Promote.
- Celebrate.

[32] Zachary Patterson, Gordon O. Ewing and Murtaza Haider, The potential for premium-intermodal services to reduce freight CO_2 emissions in the Quebec City–Windsor Corridor, Transportation Research Part D: Transport and Environment, Vol. 13, Issue 1, 2008, pp. 1–9.

[33] TADIRAM Project: Organizational and Technical proposals for Freight Distribution in a sustainable city, Association for European Transport and contributors, 2006.

[34] Marsden, G., C. Kelly, C. Snell, and J. Forrester. *Improved Indicators for Sustainable Transport and Planning.* http://www.distillate.ac.uk/outputs/Deliverable%20C1%20Indicators%20specification%20v9.pdf. Accessed July 2010.

- Learn.
- Improve.[35]

While evaluation was identified as the most common use of performance measurement, it was stressed that all these purposes overlap and tie into the final purpose of overall improvement. While data availability/use of the right data is a very important consideration, it needs to be combined with having a clear idea of appropriate data for a particular use.

Requirements for Robust Performance Measurement Systems

Research and guidance on implementing performance measurement emphasize the importance of creating tailored measures that fit the culture and constraints within individual agencies. Even if organizations have similar areas of focus, they may apply measures differently or use different data collection methods, benchmarks, etc. However, there are certain commonalities identified in research as to what constitutes good or robust performance measurement. Zietsman identified a set of 15 characteristics of good performance measures, including being measurable, relevant, sensitive to change, and indicative of trends.[36] Similarly, Marsden et al. assembled a set of attributes for good performance measures identified from a variety of sources.[37] Good performance measures:

- Are relevant to the organization/strategy.
- Are clearly defined/easy to understand/transparent.
- Are based on available data/measurable.
- Are controllable/attributable.
- Are limited in number.
- Are timely.
- Avoid perverse incentives/are non-corrupting/are not corruptible.
- Are statistically/scientifically valid.
- Are comparable/consistent over time.
- Are responsive.
- Allow for innovation.
- Are capable of aggregation.

A comprehensive analysis of criteria for selection of performance measures was developed in a report on environmental sustainability measures for transportation.[38] The report defined 10 criteria that fall into the following groups:

- Representation of reality (criteria such as validity and reliability).

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[35] Behn, R. D. "Why Measure Performance? Different Purposes Require Different Measures." *Public Administration Review*, Vol. 63, No. 5, 2003, pp. 588–606.
[36] Zietsman, J. *Incorporating Sustainability Performance Measures into the Transportation Planning Process*. Ph.D. Dissertation, Texas A&M University, December 2000.
[37] Marsden, G., C. Kelly, C. Snell, and J. Forrester. *Improved Indicators for Sustainable Transport and Planning.* http://www.distillate.ac.uk/outputs/Deliverable%20C1%20Indicators%20specification%20v9.pdf. Accessed July 2010.
[38] Joumard, R., and H. Gudmundsson (eds). *Indicators of Environmental Sustainability in Transport: An Interdisciplinary Approach to Methods* (pdf file 17 Mo). INRETS report, Recherches R282, Bron, France, 2010, p. 422. http://hal.archives-ouvertes.fr/hal-00492823/fr/.

- Monitoring and operation (criteria such as measurability, data availability, and ethical concerns).
- Management and policy (criteria such as transparency, target relevance, and action ability).

Use of Performance Measurement and Management by U.S. Transportation Agencies

Performance measures are increasingly used by state DOTs and other transportation agencies and are a key mechanism employed to monitor progress toward a set of goals. Guidelines for the development and tracking of transportation performance measures and the integration of these measures into transportation agency decision-making have become well established in recent years and include a number of projects conducted under NCHRP.[39,40,41,42,43] Legislative mandates sometimes drive the development of performance measures. In other instances, performance measurement/management is aimed at improving agency practices and accountability to external stakeholders. A 2003 NCHRP study identified key strategic areas of importance that many state DOTs already measure or seek to measure at a strategic level.[44] These include:

- Mobility and congestion.
- Accessibility.
- Safety.
- Quality of life.
- Environment.
- Economic development.
- System preservation.
- Project delivery.
- Traffic operations.
- Maintenance.
- Human resources.

When assessing the extent of use of performance measures in these areas, it is generally noted that performance measurement is more widely implemented in operations-focused areas (such as

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[39] Cambridge Systematics, Inc. *A Guidebook for Performance-Based Transportation Planning.* NCHRP 446, Transportation Research Board, Washington, D.C., 2000.

[40] Cambridge Systematics, Inc., PB Consul, Inc., and Texas Transportation Institute. *Performance Measures and Targets for Transportation Asset Management.* NCHRP Report 551, Transportation Research Board, Washington, D.C., 2006.

[41] Cambridge Systematics, Inc. *Task 47: Effective Organization of Performance Measurement.* NCHRP 08-36, Transportation Research Board, Washington, D.C., 2006.

[42] Cambridge Systematics, Inc., Texas Transportation Institute, University of Washington, and Dowling Associates. *Guide to Effective Freeway Performance Measurement.* NCHRP Project 3-68, Transportation Research Board, Washington, D.C., 2006.

[43] Cambridge Systematics, Inc., Dowling Associates, Inc., System Metrics Group, Inc., and Texas Transportation Institute. *Cost-Effective Methods and Planning Procedures for Travel Time, Delay, and Reliability.* NCHRP Report 618, Transportation Research Board, Washington, D.C., 2008.

[44] TransTech Management, Inc. *Strategic Performance Measures for State Departments of Transportation—A Handbook for CEOs and Executives.* NCHRP Project No. 20-24(20), Transportation Research Board, Washington, D.C., August 2003.

congestion/mobility) and for organizational performance (for example, project delivery/human resources).

Performance Measurement for Sustainable Transportation

Addressing the sustainability of transportation systems is an important activity, as evidenced by a growing number of initiatives around the world to define and measure sustainability in transportation planning and infrastructure provision. Existing literature discusses the selection of performance measures for comprehensive and sustainable transportation planning. There is frequent mention of the concept of sustainability and the role of measures in planning, description of factors to consider in selecting measures, identification of potential problems with conventional measures, examples of measures, and recommendations for selecting measures for use in a particular situation.[45]

Frameworks based on important causal relationships between infrastructure and the broader environment, infrastructure impacts on the economy, environment, and social well-being, and the relative influence of agencies over causal factors are largely being used to develop and determine indicator systems for measuring sustainability in transportation systems. Process-based approaches involve community representatives and other stakeholders in planning and present opportunities to educate the public and influence collective behaviors. These frameworks can be used collectively to help agencies refine their visions as well as develop policies, planning procedures, and measurement and monitoring systems for achieving sustainable transportation systems.[46] However, an important shift has been from outputs (e.g., mobility) to outcomes (e.g., accessibility). In assessing sustainability of freight movement, measurement should be of sustainability-related outcomes.

In a study by the Texas Transportation Institute (TTI),[47] sustainable transportation for the Texas Department of Transportation (TxDOT) was evaluated using a performance-measurement-based approach. A total of 13 performance measures were developed covering the five goals under TxDOT's strategic plan, which are:

- Reduce congestion.
- Enhance safety.
- Expand economic opportunity.
- Improve air quality.
- Increase value of transportation assets.

A set of performance measures were developed to encompass the sustainability aspect of these goals. The performance attributes were quantified using the multi-attribute utility theory (MAUT). The tool developed was also applied to various corridors in Texas including US 281 in

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[45] Todd Litman, Developing Indicators for Comprehensive and Sustainable Transport Planning, *Transportation Research Record: Journal of the Transportation Research Board, No. 2017,* 2007, pp. 10–15.
[46] Christy Mihyeon Jeon, and Adjo Amekudzi, Addressing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics, *Journal of Infrastructure*, March 2005, pp. 31–50.
[47] Developing Sustainable Transportation Performance Measures for TxDOT's Strategic Plan: Technical Report, Texas Transportation Institute, 2009.

San Antonio, US 290 in Houston, and IH-27 in Amarillo. Table 2 provides an overview of performance measures used in the above study.

Table 2. Performance Measures for Sustainability-Related Objectives to Address TxDOT's Strategic Plan.

Goal	Sustainability-Related Objective	Performance Measure
Reduce congestion	Improve mobility on highways	Travel time index
	Improve reliability of highway travel	Buffer index
Enhance safety	Reduce crash rates and crash risk	Annual severe crashes per mile
	Improve traffic incident detection and response	Percentage lane-miles under traffic monitoring/ surveillance
Improve economic opportunity	Optimize land-use mix for development potential	Land-use balance
	Improve road-based freight movement	Truck throughput efficiency
Increase value of transportation assets	Maintain existing highway system quality	Average pavement condition score
	Reduce cost and impact of highway capacity expansion	Capacity addition within available right-of-way
	Leverage non-traditional funding sources for highways	Cost recovery from alternative sources
	Increase use of alternatives to single-occupancy vehicle (SOV) automobile travel	Proportion of non-SOV travel
Improve air quality	Reduce adverse human health impacts	Daily nitrogen oxide (NO_x), carbon monoxide (CO), and volatile organic compound (VOC) emissions per mile of roadway
	Reduce greenhouse gas emissions	Daily CO_2 emissions per mile of roadway
	Conform to emissions exposure standards	Attainment of ambient air quality standards

Several state agencies and other organizations have established processes and performance measures for evaluating status and/or progress toward achieving sustainability in pursuing their business. NCHRP Report 708, *A Guidebook for Sustainability Performance Measurement for*

Transportation Agencies, describes best practices for a number of organizations.[48] See that guidebook for more information.

Applying Performance Measures for Freight and Freight Sustainability

The application of performance measurement in freight systems of transport is a relatively new topic. Freight performance measures (FPMs) are gaining importance with the rapid growth in the freight sector and the rising need to maintain a fully efficient and operational system of transportation for free movement of goods. An FPM is a qualitative and quantitative measurement that is heavily dependent on the quality of data used to describe the freight system and the technologies used to record the data. Freight sustainability is measured by parameters that influence the environmental, safety, economic, and social aspects of its movement.
The development of freight performance measures is emerging on the local, state, and national front with evidence of freight measures being implemented in local MPOs, state DOTs, and the United States Department of Transportation (USDOT). Previous studies have addressed the feasibility of performance measures in freight applications. Though FPMs are gaining popularity, transportation agencies of only a few states have incorporated them.[49] The Center for Transportation Research (CTR) at the University of Texas at Austin, in partnership with TTI, completed a study to observe the recent developments in FPMs nationwide and found that FPM strategies are mostly used in the planning process rather than in the operational stages. FPMs are yet to be used as a strategy to monitor real-time performance of freight transportation systems or to supply data for use by transportation researchers and road users.[50]

Federal Efforts

FHWA, as part of its national strategic plan, contracted out a project to identify possible performance measures to be applied for measuring highway performance pertaining to goods movement and the intermodal freight system.[51] A set of seven measures were chosen based on the cost and the difficulty involved in acquiring the data. Due importance was given to the value of the data toward contributing to a better analysis, rather than just the ease of acquiring it. For example, customer satisfaction was recommended, as it can provide important information to the FHWA, even though considerable efforts would go into designing suitable surveys and obtaining the cooperation of private agencies. The seven measures recommended for further development by FHWA are as follows:

- Cost of highway freight per ton-mile.
- Cargo insurance rates.
- Point-to-point travel times on selected freight-significant highways.
- Hours of delay per 1,000 vehicle miles on selected freight-significant highways.

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[48] Zietsman, Josias; Ramani, Tara; Porter, Joanna; Reeder, Virginia; and DeFlorio, Joshua; *A Guidebook for Sustainability Performance Measurement for Transportation Agencies*, NCHRP Report 708, Transportation Research Board, Washington, DC, 2011.
[49] Harrison R., M. Schofield, L. Loftus-Otway, D. Middleton, and J. West. *Developing Freight Highway Corridor Performance Measure Strategies in Texas.* Report No. 0-5410. University of Texas, Austin, TX, December 2006.
[50] Harrison R., M. Schofield, L. Loftus-Otway, D. Middleton, and J. West. *Developing Freight Highway Corridor Performance Measure Strategies in Texas.* Report No. 0-5410. University of Texas, Austin, TX, December 2006.
[51] Hagler Bailly Services, Inc. *Measuring Improvements in the Movement of Highway and Intermodal Freight.* Federal Highway Administration, U.S. Department of Transportation, March 2000.

- Crossing times at international borders.
- Condition of connectors between the National Highway System (NHS) and intermodal terminals.
- Customer satisfaction.

In a partnership between FHWA and the American Transportation Research Institute (ATRI) in 2002,[52] methods and approaches were explored in order to measure freight performance on national highways. Recognizing that the increased volume of freight in the future would call for a controlled growth of transportation corridors, a study was conducted to develop strategies and metrics that could be applied to the performance, maintenance, and reliability of freight-significant corridors. During the initial two phases of the performance measurement initiative, ATRI worked with technology vendors and commercial carriers to demonstrate that location data from communications technologies could be used to derive measures of travel time and reliability. The corridors included were I-5, I-10, I-45, I-65, and I-70.[53] The study concluded that positioning data from trucks could be processed in a confidential manner to provide average travel rates along major U.S. freight corridors. The research also suggests that the approach used for this study can be applied and expanded to establish a national system of freight performance measurement.

In an effort to review the available data collection technologies, an FHWA-funded study in 2003[54] looked into the various freight tracking devices to be used for developing FPMs, finally deciding on the global positioning system (GPS) technology widely adopted by U.S. motor carriers. The many applications of this GPS-obtained truck data were considered for both real-time analyses as well as long-term planning. In 2005, FHWA described freight mobility and reliability of five interstate corridors using the data from GPS-equipped vehicles.[55]

State Practices

State transportation departments like the Minnesota Department of Transportation (MnDOT) and the California Department of Transportation (CalTrans) have identified freight performance measures. The North Jersey Transportation Planning Authority (NJTPA) has also used FPMs to forecast future freight needs in 2025. Oregon does not have a comprehensive freight plan but has included FPMs in its general transportation plan.

Minnesota. The Minnesota Statewide Multimodal Freight Flows Study was commissioned in 2000 to determine how goods move in the state and to identify key corridors where improvements should occur. The study represents the state's initial efforts to identify key logistical patterns within the freight sector that result in varying demands of the transportation

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[52] Methods of Travel Time Measurement in Freight-Significant Corridors, *American Transportation Research Institute (ATRI)*, January 2005.
[53] Office of Freight Management and Operations, Federal Highway Administration, U.S. Department of Transportation. Freight Analysis, Freight Performance Measurement. http://www.ops.fhwa.dot.gov/freight/freight_analysis/perform_meas.htm. Accessed October 2009.
[54] Schofield M., and R. Harrison. *Developing Appropriate Freight Performance Measures for Emerging Users.* University of Texas at Austin, Austin, TX, September 2007.
[55] Harrison R., M. Schofield, L. Loftus-Otway, D. Middleton, and J. West. *Developing Freight Highway Corridor Performance Measure Strategies in Texas.* Report No. 0-5410. University of Texas, Austin, TX, December 2006.

services.[56] It aimed to provide data and recommendations regarding freight flows to MnDOT. While it was successful in recognizing the areas representative of freight efficiency, the study was limited by the lack of sufficient data to support the measurement.

MnDOT formulated a framework of freight performance measures that emanated from the policies within the 2003 Statewide Freight Plan.[57] These comprehensive multimodal performance measures were to provide a link to policies and to form a basis of comparison between relevant transportation modes, especially in the freight context. MnDOT realized the high value of information that can be gained by FPMs to aid in investment decision-making. A framework was developed for identifying possible linkages between the Minnesota Statewide Freight Plan and the adopted Minnesota Statewide Transportation Plan. Minnesota developed strategies to address how its state transportation plan (STP) policies and performance measures can be met by the freight plan, and also ways to improve the FPMs.

The performance measures developed by the STP describe movement on highways and bridges. However, due to the important role played by highways in freight transport, these are directly relevant to freight transportation as well.

Existing measures are listed below by mode:[58]

- Trucking:
    - Percent of miles of highway that meet “good” and “poor” ride quality targets.
    - Percent of townships, counties, and municipalities along interregional corridors (IRCs) whose adopted local plans and ordinances support IRC management plans and partnership studies.
    - Percent of IRC and bottleneck removal projects identified in the 10-year program for which right-of-way needs have been protected.
    - Clearance time for incidents, crashes, or hazardous materials (HAZMATs; metro).
    - Snow and ice removal clearance time.
    - Percent of miles of principal arterial corridors that are managed.
    - Percent of major generators with appropriate roadway access to IRCs and major highways.
    - Percent of IRC miles meeting speed targets (from STP measure 5.1H).
    - Peak-period travel time reliability on IRCs and other high-use truck roadways.
    - Ratio of peak to off-peak travel time—travel rate index (metro).
    - Peak-period travel time reliability on Texas City Management Association (TCMA) highways.
    - Miles of peak-period congestion per day.
    - Heavy-truck crash rate (three-year average).
    - Number of heavy-truck-related fatalities (three-year average).
- Rail:
    - Percent of major generators with appropriate rail access.
    - Total crashes at at-grade rail crossings (three-year average).

[56] Minnesota Department of Transportation. *Statewide Multimodal Freight Flows Study: Preserving Minnesota’s Economic Competitiveness.* Cambridge Systematics, Inc, Cambridge, MA, April 2000.
[57] Minnesota Department of Transportation, Minnesota Statewide Freight Plan, May 2005.
[58] Minnesota Department of Transportation, Minnesota Statewide Freight Plan, May 2005.

- Number of truck-related fatalities at at-grade rail crossings (three-year average).
- Waterways:
  - There are no existing measures for the waterways mode.
- Air Cargo:
  - Percent of airport runways that meet good and poor pavement condition targets.
  - Percent of air cargo facilities with appropriate roadway and rail access.
- Intermodal Facilities:
  - Percent of intermodal facilities (ports/terminals) with appropriate roadway and rail access.

The 2005 Minnesota Statewide Freight Plan[59] identifies additional performance measures and measures for all modes of freight transportation:

- Trucking:
  - Benefit of truck weight enforcement on pavement service life.
- Rail:
  - Percent of rail track-miles with track speeds >25 miles per hour.
  - Percent of rail track-miles with 286,000-pound railcar capacity rating.
- Waterways:
  - Average delay time at river locks.
- Air Cargo:
  - Availability of direct international air cargo freighter service.
- Intermodal Facilities:
  - Percent of intermodal facilities whose infrastructure condition is adequate.
  - Availability of container-handling capability and/or bulk transfer capability.

These FPMs help MnDOT's Office of Freight and Commercial Vehicle Operations (OFCVO) in responding to the various public and private stakeholders about the current performance of the state freight transportation system. They also assist in the long-term planning needs of the DOT, such as in revising the STP and the Statewide Freight Plan. In a study by MnDOT,[60] assessment of key performance measures and indicators and related measurement sources was carried out. Barriers, best available measurement sources, good existing practices, and recommended improvements pertaining to measurement sources for freight performance measures and indicators for Minnesota were identified.

In 2009, Minnesota started a new initiative called the Freight and Passenger Rail Plan,[61] in which several rail performance measures were proposed. The plan gave importance to five main components:

- System performance.
- System condition.
- Accessibility/connectivity.

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[59] Minnesota Department of Transportation, Minnesota Statewide Freight Plan, May 2005.
[60] Varma, A. *Measurement Sources for Freight Performance Measures and Indicators.* Report MN/RC 2008-12. Minnesota Department of Transportation, St. Paul, MN, July 2008.
[61] Cambridge Systematics, Inc, Kimley-Horn Associates, Inc, and TKDA, Inc. Minnesota Comprehensive Statewide Freight and Passenger Rail Plan. Presented to the Passenger Technical Advisory Committee, Minnesota Department of Transportation, August 2009.

- Safety/security.
- Financial/economic.

New Jersey. The NJTPA, through its investments in projects like Freight Planning Support System (FPSS),[62] has made efforts to plan a sustainable system of freight transport. In the FPSS, plans and strategies were developed considering the forecasted ballooning of freight movement in the ports, highways, and rail systems of New Jersey. Transportation indicators, data, and performance measurements relevant to freight were developed to assist the NJTPA with its performance-based planning process. A case study of the September 11, 2001, terrorist attacks was done to analyze the impacts of disaster events on freight volume and other parameters. A framework of responsive strategies was formulated to handle the variability of freight movement encountered during such events in the state and to identify the inefficiencies in the transport system.

In a system that relies on performance-based measurements to arrive at short-term and long-term decisions, it is critical to understand the exact implications of individual freight measures on the all-encompassing framework that is the economy. With this purpose in mind, the relationship between truck movements and the economic performance of New Jersey was investigated by testing whether truck movements on the I-95 Corridor (New Jersey Turnpike) are a leading measure of changes in the performance of the New Jersey economy.[63] The models developed for the study were instrumental in developing a methodology to predict the economic activity in the New Jersey region.

California. CalTrans is working toward implementing the various methodologies and concepts found for transportation system performance measurement. It has taken the initiative to fill the existing gap in monitoring data for the purpose of transportation operation and feedback.[64] CalTrans, in a specific research task,[65] found that it is feasible to involve state and regional participation to apply performance measures in a framework that includes freight movement. It found that the most applicable outcomes are safety/security, reliability, mobility/accessibility, equity, economic well-being, and environmental quality. Available measures for highway and other transit modes can be modified to measure freight performance. A detailed analysis of freight system performance could not be carried out due to lack of sufficient data for the indicators measured. The measures were specifically listed as safety rates, standard deviation of travel time, delay, accessibility to intermodal facilities, regional share of mobility benefits, and environmental measures.

In Southern California, the government is addressing its problems relating to freight efficiency by incorporating freight performance measures in the overall transportation plan of the Southern

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[62] Fallat, G., Keir O., Joshua C., Jakub R., and Lui, R. F. *Freight Planning Support System,* North Jersey Transportation Planning Authority. July 2003.
[63] Ozbay K., N. Mantel, P. Woods, and M. Robins. *Freight Movement as an Economic Indicator for New Jersey/New York/Connecticut Tri-State Area.* Rutgers University, Piscataway, NJ, March 2008.
[64] California Department of Transportation. *Transportation System Performance Measures: Status and Prototype Report*. October 2000.
[65] California Department of Transportation. *Transportation System Performance Measures Compendium of Phase II Results*. June 1999.

California Association of Governments (SCAG). The two major ports in the region, Los Angeles and Long Beach, handle close to 40 percent of the nation's containerized imports. Considering the rate of future growth in freight movement in the region, it is imperative to evaluate the sustainability of developmental projects and to carry out a thorough environmental assessment in the planning stages.
The freight-related performance measures in the regional transportation plan focus on mobility, reliability, safety, cost-effectiveness, productivity, and the environment. The mobility performance relates to average daily speed and delay. Reliability is defined by percentage variation in travel times. Accident rates measure the performance of the safety of the freight system. The benefit-to-cost ratio defines the cost-effectiveness performance measure. Production is represented by the percentage capacity in the peak period. The environmental measure focuses on the generation of emissions. Based on data limitations and the modeling process, SCAG is focusing on the mobility, cost-effectiveness, and environmental performance measures.

Examining capacity projects is based on the premise that infrastructure projects will reduce travel time for shippers and improve efficiency and reliability. Reliability has a real dollar value to shippers. The value of time savings will be significantly higher than the investment to achieve time savings. A 2005 study examined an as-is scenario in which fees were imposed but not used to provide new regional congestion relief and a congestion-relief scenario in which fees or tolls were paid by users of newly constructed highway and rail systems that provide regional congestion relief.[66] The private-sector investment in the congestion-relief scenario provided more positive results with less traffic congestion, and the port became more attractive to shippers, resulting in higher increases in the volume of shippers.

Oregon. The Oregon DOT (ODOT) is in the process of developing its first statewide freight plan that will further the efforts of the state in ensuring efficiency in goods movement, thereby enhancing the economy of the state as well as the businesses in Oregon. The purpose of the improvised freight plan[67] of 2008 is to improve freight connections to local, state, regional, national, and global markets to increase trade-related jobs and income for Oregon workers and businesses. Its objectives are to:

- Develop a framework to identify, prioritize, and facilitate Oregon's highway, rail, marine, air, and pipeline transport infrastructure in achieving an uninterrupted, safe, and efficient intermodal freight transportation system.
- Locate possible hurdles in the development of an efficient freight system and arrive at strategies to tackle the drawbacks.
- Relate the goals of the state transportation plan in relevance to freight movement.

Research is still underway[68] to incorporate performance measures other than those that are currently used and that are not adequately addressed by transportation policies, namely economic vitality, balance and adaptability, safety and security, environmental justice, land-use

[66] Performance Measures for Freight-related activity, Jim Gosnell, U.S. and International Approaches to Performance Measurement for Transportation Systems, Summary of a Conference.
[67] Oregon Department of Transportation. Oregon Freight Plan (under development), http://www.oregon.gov/ODOT/TD/FREIGHT/FREIGHT_PLAN.shtml. (As of October 2009).
[68] Reiff, B., and Brian G. *Transportation Planning Performance Measures*. Oregon Department of Transportation. October 2005.

compatibility, and quality of life. The focus is on employing model forecast data to evaluate future plan alternatives. So far, six performance measures have been analyzed separately in order to identify the feasibility of each measure, with consideration of the amount of data available. It was found that performance measures for urban mobility and freight delay costs could be implemented immediately in Oregon.

In another research effort,[69] the feasibility of using truck transponder data to produce freight corridor performance measures (travel time) and real-time traveler information was studied. Nearly 42,000 trucks from each of the 22 stations in Oregon were assembled, processed, and uploaded into a data archive. The analysis showed that corridor-level travel times for trucks for 2007 and 2008 could be generated from the archived data. To explore the feasibility using these same data for real-time traveler information, ground truth probe vehicle data were collected. The long distance between stations was concluded to be a primary challenge to directly adapting the archived data to real-time use. Recommendations were given on increased sensor spacing and filter improvement.

Washington. In 2005, the Washington DOT (WSDOT) designed and studied various methodologies[70] to measure the performance of freight mobility road improvement projects against benchmarks, or selected standards, that would be used both as part of the project selection process and to report on speed and volume improvements that resulted from completed freight mobility projects. Among the technologies tested was Commercial Vehicle Information System and Networks (CVISN) electronic truck transponders, which are mounted on the windshields of approximately 20,000 trucks in Washington. A second technology tested involved GPSs placed in volunteer trucks to collect specific truck movement data at five-second intervals. The study found that both data collection technologies could be useful; however, the key to both technologies is whether enough instrumented vehicles pass over the roadways for which data are required. While there is a substantial amount of freight-related data, the Office of Financial Management (OFM)[71] has not yet identified a specific high-level performance measure to best assess how well freight is moving on and through the state transportation system. State agencies, including the Freight Mobility Strategic Investment Board (FMSIB), the Transportation Improvement Board (TIB), the County Road Administration Board (CRAB), WSDOT, ports, shippers, private-sector rail, the trucking industry, and researchers are working with OFM to identify such a measure.

International Efforts. The London Freight Plan[72] is one among the many international efforts taken to improve intermodal efficiency in freight systems. Anticipating a 10 percent growth in demand for goods and services in the UK by 2016, the DfT formulated the Freight Best Practice

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[69] Monsere, C. M., M. Wolfe, H. Alawakiel, and M. Stephens, *Developing Corridor-Level Truck Travel Time Estimates and Other Freight Performance Measures from Archived ITS Data.* Oregon Department of Transportation, Salem, OR, August 2009.

[70] McCormack, E., and Hallenbeck M. E. *Options for Benchmarking Performance Improvements Achieved from Construction of Freight Mobility Projects*. Washington State Department of Transportation, Seattle, WA, July 2005.

[71] Washington State Department of Transportation, *Transportation Progress Report: The State of Washington's Transportation System.* January 2008.

[72] Steele S., and P. Dumble, Transport for London, UK. *The London Freight Plan,* Presented at the European Transport Conference 2006.

Programme (FBPP).[73] This program has made commendable advances in putting the theory of performance management into practice. A free information framework is available for workers in the haulage industry to conduct external benchmarking (against other sectors) as well as internal benchmarking (within the fleet). These publications are supported by software tools and can suggest methodologies and resources to accurately monitor performance within the fleet, or outside. Similarly, information on best-in-class performance can be obtained by transport managers to use to compare, contrast, and target set their own operations. Five key performance indicators (KPIs) found common for all operations are:

- Vehicle fill.
- Empty running.
- Time utilization.
- Deviations from schedule.
- Fuel consumption.

There is considerable variation in the operational efficiency for different operations. Once the factors that influence this variation can be understood, they can be used to help managers modify their operations to achieve benefits. The Fleet Performance Management Tool is a PC-based software tool (complete with manual) that allows operators to track fleet performance week by week for 22 KPIs. This tool can be used to measure performance for up to 25 vehicles for up to a two-year period. The FBPP has been hugely successful and has helped saved the industry £190m over the past two years in comparison to £65m in the 2003 impact assessment.

Other Studies. A study was conducted by FHWA in the U.S. to understand the performance measures used by China to manage its freight transportation.[74] It was found that the country's national, provincial, and metropolitan transportation and planning policies were woven into the fabric of the national economic and social consensus goals. Pulse Canada proposed the development of performance measures to understand the transportation processes for shipment of export containers and to enhance industry forecasting processes. Some of the measures proposed are shown in Table 3.

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[73] James, J. *The Road to Freight Operational Efficiency—Performance Management*, Faber Maunsell Ltd, Altrincham, UK. Presented at the European Transport Conference 2008.

[74] Cole, D. et al. *Freight Mobility and Intermodal Connectivity in China.* Report No. FHWA-PL-08-020. Federal Highway Administration, U.S. Department of Transportation, May 2008. Available online: http://international.fhwa.dot.gov/pubs/pl08020/index.cfm

Table 3. Proposed Measures for Pulse Canada.[75]

Area of Measurement	Measure	Measure Description
Forecast Performance	FP1	Measure of forecast container bookings versus actual container bookings
Booking Performance	BP1	Measure of containers departing on booked vessel versus rollover vessels
	BP2	Measure of containers shipped versus containers booked by shippers
Inland Transportation Equipment Supply	ITES1	Measure of railcars ordered versus allocated
	ITES2	Measure of railcars allocated versus supplied
Inland Transportation Equipment Condition	ITEC1	Measure of the railcars supplied versus railcars rejected
Inland Transportation Performance	ITP1	Measure of average transit time and transit variability by origin-destination pair
	ITP2	Measure of dwell time of rail cars and containers at key origin and destination terminals

A comparison was done to evaluate differences in the approach to performance measurement in New Zealand, Australia, and Japan, particularly for safety, congestion, and freight movement.[76] Of the areas that were found similar in all nations were the common framework that incorporates performance measurement, the importance of collaboration among different agencies for performance categories that transcend one policy area, the use of performance measures at different levels of planning and decision-making, and the vertical integration of information flow in agencies. All stressed the importance of data collection capability and the use of information technologies, the importance of performance measurement as a means of providing greater accountability and visibility to the public, and the need for top management leadership and commitment in the development and use of a performance measurement scheme. They also made distinctions between outcomes and outputs. Outcomes were viewed as the ultimate characteristic of transportation system performance, whereas outputs were the products and services of the organizations that led to those outcomes.

Queensland Transport used the following performance measures for freight systems:

- Average trains per week (number).
- Utilization of capacity (percent).
- Average below-rail delays (minutes).
- Total below-rail (infrastructure) delay events (number).
- Rail track availability (percent).

[75] Pulse Canada, Analysis of Supply Chain, Performance Measurement and Forecasting Processes**,** Phase 1 Report, March 2008.

[76] Meyer, M. D. *Use of Performance Measures for Surface Transportation in Different Institutional and Cultural Contexts: Cases of Australia, Japan, and New Zealand.* Transportation Research Record: Journal of the Transportation Research Board, No. 1924, Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 163–174. Available online: http://trb.metapress.com/content/v555120q267436wu/

- Temporary speed restriction variance against threshold (percent).
- Overall track condition index last recorded number (number).

Table 4 contains a comprehensive list of freight performance measures that are used by public agencies. The measures were compiled from sources gathered for this project. The measures were grouped by mode and goal categories. Table 5 lists some freight performance measures for use by public-sector transportation agencies. Also shown in this table are the scale of application, ease of data availability, and range of cost to acquire data.

Table 4. List of Freight Performance Measures (FPMs) Used in Transportation Agencies.

Organization	Mode	Goal	Measure
FHWA	Truck	Affordability	Cost of highway freight per ton-mile
		Reliability	Point-to-point travel times on selected freight-significant highways
			Hours of delay per 1,000 vehicle miles on selected freight-significant highways
	Neutral	Mobility	Crossing times at international borders
		Affordability	Cargo insurance rates
		Infrastructure improvement	Condition of connectors between NHS and intermodal terminals
		Reliability	Customer satisfaction
Minnesota	Truck	Mobility	% of miles of highway that meet good and poor ride quality targets
			% of townships, counties, and municipalities along IRCs whose adopted local plans and ordinances support IRC management plans and partnership studies
			% of IRC and bottleneck removal projects identified in the 10-year program for which right-of-way needs have been protected
		Reliability	Clearance time for incidents, crashes, or HAZMATs (metro)
			Snow and ice removal clearance time
			% of miles of principal arterial corridors in RTCs 0 and 1 that are managed
			% of major generators with appropriate roadway access to IRCs and major highways
			% of IRC miles meeting speed targets
			Peak-period travel time reliability on IRCs and other high-use truck roadways
			Peak-period travel time reliability on TCMA highways
		Congestion mitigation	Ratio of peak to off-peak travel time—travel rate index
			Miles of peak-period congestion per day
		Safety	Heavy-truck crash rate (three-year average)
			Number of heavy-truck-related fatalities (three-year average)
			Benefit of truck weight enforcement on pavement service life
	Rail	Accessibility	% of major generators with appropriate rail access
		Safety	Total crashes at at-grade rail crossings (three-year average)
			Number of truck-related fatalities at at-grade rail crossings (three-year average)
			Percent of rail track-miles with track speeds >25 miles per hour
			% of rail track-miles with 286,000-pound railcar capacity rating
	Waterways	Reliability	Average delay time at river locks
	Air Cargo	Infrastructure preservation	Percent of airport runways that meet good and poor pavement condition targets
		Safety	Percent of air cargo facilities with appropriate roadway and rail access
		Accessibility	Availability of direct international air cargo freighter service

Organization	Mode	Goal	Measure
	Other	Accessibility	Percent of intermodal facilities (ports/terminals) with appropriate roadway and rail access
		Infrastructure preservation	Percent of intermodal facilities whose infrastructure condition is adequate
	Neutral	Productivity	Availability of container-handling capability and/or bulk transfer capability
California	Neutral	Mobility	Average daily speed and delay
		Reliability	% variation in travel times
		Safety	Accident rates
		Cost-effectiveness	Benefit-to-cost ratio
		Productivity	% capacity in peak periods
		Environment	Generation of emissions
Oregon[77]	Truck	Safety	Large-truck at-fault crashes: number of large-truck at-fault crashes per million vehicle miles traveled (VMT)
		Mobility	Pavement condition: percent of pavement lane-miles rated “fair” or better out of total lane-miles in state highway system
	Rail	Safety	Derailment incidents: number of train derailments caused by human error, track, or equipment
			Rail crossing incidents: number of highway-railroad at-grade incidents
	Neutral	Customer service	% of customers rating their satisfaction with the agency’s customer service as “good” or “excellent”: overall customer service, timeliness, accuracy, helpfulness, expertise, and availability of information
Washington[78]	Truck	Preservation	% of state highway pavement in fair or better condition
			% of targets met for state highway maintenance levels
New Jersey Freight Plan[79]	Truck	Corridor congestion	Travel time index
			Lane-miles of congestion
			Truck vehicle hours of delay
			Average travel speed for trucks
		Peak and off-peak capacity	Report of available roadway capacity by time periods
	Rail	Current status and progress toward goal achievement	Percentage of track-miles in the state meeting basic weight and plate-size standards
		Justification for public-sector participation	Number and value (income) of jobs preserved or increased attributable to the added rail accessibility (or cost-effectiveness of service)
		Safety	Reduction of grade-crossing accidents

77 http://www.oregon.gov/DAS/BAM/docs/KPM/Budget_2009/SB5548ODOT.pdf
78 http://performance.wa.gov/TRANSPORTATION/TR011510/Pages/Default.aspx
79 http://www.state.nj.us/transportation/freight/plan/pdf/2007statewidefreightplan.pdf

Organization	Mode	Goal	Measure
		Congestion mitigation	Reduced wait times for road traffic
London Freight Plan, UK	Neutral	Energy efficiency	Vehicle fill
		Energy efficiency	Empty running
		Mobility	Time utilization
		Reliability	Deviations from schedule
		Energy efficiency	Fuel consumption
EU TERM	Neutral	Environment	Specific CO_2 emissions per tonne-km and per mode of transport in Europe
			Average age of vehicle fleet
			Specific air pollutant emissions per tonne-km and per freight transport mode
		Economy	Freight transport demand in volume and gross domestic product (GDP)

Table 5. Examples of Freight Performance Measures Proposed by Transportation Agencies.

Measure	Analysis Level	Data Availability	Data Cost
Cost per Ton-Mile	National	Easy	Low
Fuel Consumption of Heavy Trucks per Ton-Mile	National	Easy	Low
Cargo Insurance Rates	National	Easy	Low
On-Time Performance	National	Difficult	High
Point-to-Point Travel Times on Freight-Significant Highways	National/State/Corridor	Not Easy	Medium to High
Hours of Delay on Freight-Significant Highways	National/State	Not Easy	Medium to High
Incident Delay on Freight-Significant Highways	National/State	Not Easy	High
Ratio: Peak Travel Time to Off-Peak Travel Time	National/State	Not Easy	High
Ratio: Variance to Average for Peak Trip Times	National/State	Not Easy	High
Annual Miles per Truck	National	Easy	Low
Border Crossing Times	National/State/Corridor/Facility	Not Easy	Medium
Conditions on Intermodal Connectors	National/State/Corridor/Facility	Not Easy	High
Customer Satisfaction	National/State	Difficult	High
Total Freight Congestion Value	Corridor/Facility	Not Easy	Medium
Freight Transfer Time at Intermodal Terminal	Corridor/Facility	Difficult	High
Hours Waited at Toll Plazas and/or Weigh Station	Corridor/Facility	Not Easy	Medium
Daily/Annual Amount of Emissions from Freight per Section or per Mile of Roadway/Railway	Corridor/Facility	Not Easy	High
Number of Public Facilities Impacted (hospital, school, etc.)	Corridor/Facility	Difficult	Medium
Developable Areas Subjected to Unacceptable Noise Level	Corridor/Facility	Difficult	High
Total Crashes at At-Grade Rail Crossings	Corridor/Facility	Not Easy	Medium

Freight Data Sources

Data are the "raw materials" for establishing a performance measure. Data availability is a key component of a performance measurement system. Obtaining required data for a performance measurement system can be costly and difficult. Data availability must be examined for each potential performance measure as one of the main selection criteria. Another aspect of data availability is whether data are collectable even if the data are available. Addressing the data requirement aspect of performance measurement includes answering the following questions:

- Are data available in currently available databases?
- If data are available, are they easy to collect, or is obtaining the data difficult?
- Are there new ways to develop or collect the data?
- What is the cost of collecting the appropriate data?

Freight data are available from many public and private sources. They vary by collection method, timeframe, format, and quality. Data held by private companies may be very useful; however, they are usually very expensive to obtain or keep commercially confidential. U.S. Inland Trade Monitor (USITM) and Transearch by Global Insight[80] are examples of privately held data that are costly to obtain.

The North American Transborder Freight Database is the major publicly available information source of trade flow in North America. It contains freight flow data by commodity type and by mode of transportation (rail, truck, pipeline, air, vessel, and other) for U.S. trade flow to/from Canada and Mexico. The database provides freight movement based on either commodity type or geographical details. The database includes data from 1994 and is used for trade corridor studies, transportation infrastructure planning, marketing and logistics plans, and other purposes.
The information from the above data source is aggregate data. Although this level of aggregation might be appropriate for applications such as planning and corridor studies, it poses a challenge for more detailed analyses, such as a detailed air quality analysis. The Transborder Freight Data provides information on a state-to-state or state-to-province level.

In North America, the only publicly available information that provides geographically disaggregated freight flow information is the FHWA Freight Analysis Framework (FAF). The FAF is a commodity origin-destination (O-D) database and analytical framework that provides estimates of tonnage and values of goods shipped according to origin, destination, commodity, and mode.[81] Table 6 shows examples of publically available freight transportation data sources. A more detailed description of the data sources is provided in Appendix A.

[80] Global Insight, North American Commerce & Transport Data http://www.globalinsight.com/ProductsServices/ProductDetail1024.htm.
[81] Freight Analysis Framework (FAF). Office of Freight Management and Operations, Federal Highway Administration, Washington, D.C., 2009. http://ops.fhwa.dot.gov/freight/freight_analysis/faf/

Table 6. Examples of Publicly Available U.S. Freight Transportation Data Sources.

Data	Description
Freight Movements	
Freight Analysis Framework	Commodity movements among states and metropolitan areas by value, weight, and mode for 1997 and 2002, and forecasts for 2010 through 2035.
Transborder Surface Freight Data	North American merchandise trade data by commodity and mode. Geographic detail for U.S. exports to and imports from Canada and Mexico. Updated monthly and annually. Monthly data available by e-mail.
U.S.-Canada and U.S.-Mexico Border Crossings	Number of trucks, truck containers, train, and rail containers crossing into the U.S. through land ports on U.S.-Canadian and U.S.-Mexican borders. Updated monthly and annually.
Carload Rail Waybill Sample	Origin/destination of commodities shipped by rail, weight, number of cars involved, length of haul. Data based on the proprietary Carload Waybill Sample of Class I railroads.
Infrastructure	
Highway Performance and Monitoring System (HPMS)	Extent, condition, performance, use, and operating characteristics of U.S. highways.
Railroad-Highway Grade Crossings	Grade-crossing location and safety data. Other rail network characteristics in the National Transportation Atlas Database (NTAD).
U.S. Ports and Waterway Facilities Database	Physical characteristics of coastal, Great Lakes, and inland U.S. ports, terminals, and locks. Updated on an ongoing basis.
Freight Vehicles	
Vehicle Inventory and Use Survey (VIUS)	Physical and operational characteristics of private and commercial trucks registered/licensed in U.S., commodities hauled, truck configurations, trip mileage. Updated every five years.
FAF Highway Capacity Database	Truck flows at highway segment level for 1998 and forecasts for 2010 and 2020. Updates underway.
Vehicle Travel Information System (VTRIS-W)	Number of trucks weighed and vehicle weight information by type of vehicle and highway functional class. Updated annually.
Commercial Motor Vehicle Safety Data	Commercial motor vehicle crashes, fatalities, and injuries.
Comprehensive Tabulations	
Freight Facts and Figures	Volume and value of freight flows, network characteristics, economic, safety, and energy use data, and environmental effects. Available beginning in January 2005. Updated annually.
National Transportation Statistics	Overview of the extent, condition, and performance of U.S. transportation system. Updated annually.
North American Transportation Statistics	Information on transportation and related activities in Canada, the United States, and Mexico and between the three countries. Updated annually.

Freight Transportation Decision-Making

The freight transportation system in the U.S. is a culmination of the decisions made by the public and private sectors. Depending on the area of the freight transportation industry, the decision could be by one sector or both. The role of each sector in the many areas of decision-making is given in Table 7.

Table 7. Role of Each Sector in Decision-Making in Freight Sector.

Decision Type	Typical Lead Sector
1. Policy and Regulation	Public-sector led
2. Technology	Private-sector led
3. Infrastructure	Public-sector led
4. Operations/Maintenance	Public-sector/private-sector shared
5. Non-Transportation (behavioral)	Public-sector led

Public-Sector Decision-Making

The public sector gets involved in critical decisions regarding policy, planning, and regulations in the freight transport industry. The main drivers affecting public-sector decision-making are as follows:

- Investment and financing: taxes, fees.
- Economic regulation.
- Providing and maintaining infrastructure: highways, tracks, ports, air.
- Land use: facility location and access.
- Environmental issues.
- Safety.
- Operations.
- Jobs and employment.

Infrastructure-related decisions are all public led with the exception of the rail system, which is privately owned. Decisions on regulations that are of direct impact to the freight transportation system are also led by the public sector. In case of conflict with other jurisdictions, except with the private sector, it is the public sector that resolves conflicts. Table 8 shows the areas of government responsibility.

Table 8. Primary Government Level of Responsibility by Function and Mode.

	Pipeline	Rail	Truck	Inland Water	Deep Sea	Air
Safety	Federal	Federal	Federal	Federal	Federal	Federal
Economic	Federal	Federal	Federal/State/Local	Federal	Federal	Federal
Environmental	Federal	Federal/State	Federal/State	Federal	Federal	Federal
Land Use	Local	Local	Local	Local	Local	Local
Operations	Federal	Federal/Local	Federal/State/Local	Federal	Federal	Federal

Private-Sector Decision-Making

The private sector deals with decisions regarding investments, operations, marketing, and technology. Cost is an important consideration in private-sector-led decisions, and each operation is usually assigned a particular cost by the private companies. The general drivers of private-sector decision-making revolve around satisfying customers, getting returns on investments, and handling competition in the freight sector. They are specifically given below:

- Market and shipper demand.
- Financial performance metrics.
- Volume, schedule, and cost management.
- Regulatory issues.

In the private sector, decision-making in freight transportation businesses commonly extends from the board of directors and the chief executive officer (CEO) all the way down to the individual equipment operator (e.g., the truck driver).

Public and private decisions relating to freight transportation overlap in many areas. At times, the interests and responsibilities converge and facilitate cooperation. At other times, they diverge and create inefficiencies and conflicts. The fine differences and similarities between the functionalities of the two sectors are given in Table 9.

Table 9. Timeframe and Hierarchy of Decision-Making in Each Sector.

Timing	Responsibility	Mode	Decision Example	Public Interaction
Short Term: Hourly, Daily	Drivers, Local Terminal Staff	Primarily Truck	Congestion, Avoidance of Traffic, Construction, Events, Physical Access to Customer	Traffic Centers, Local Planning and Scheduling, Construction Permits and Scheduling
Mid-Term: Weekly, Monthly, Annual	Local, Regional, Some Corporate	All Modes	Repeat Routing and Scheduling, Fuel Routing, Technology Use, Customer Access Hours	Local, State, Federal, Planning, Operations, Regulatory
Longer Term: Annual 3–5 Years	Corporate	All Modes	Facility Location, Fleet Size, Schedules	Local, State, Federal, Planning, Policy, Regulatory
Very Long Term: Annual Beyond 3–5 Years	Corporate	All Modes	Equipment Purchases, Market Entry, Facility Ownership	Local, State, Federal, Planning, Policy, Regulatory

Overlapping of Roles and Responsibilities

Public- and private-sector decision processes intersect at many critical points in the nation's freight system. The intersection of decision-making reflects the joint ownership and provision of freight transportation services in the country as well as in areas such as safety regulations. The roles played by the public and private sectors vary by mode of transportation, though the public sector always sets the regulatory environment and the private sector always operates the freight equipment. The roles by each sector for each mode of transportation are given in Table 10, and the issues discussed by each sector are given in Table 11.

Table 10. Sector Responsibility or Ownership by Function and Mode.

	Pipeline	**Rail**	**Truck**	**Inland Water**	**Deep Sea**	**Air**
Infrastructure —Road/Rail "Line Haul" Network	Private	Private	Public	Public	None/ Public	None/ Public
Infrastructure —Terminals	Private	Private	Private	Public/ Private	Public/ Private	Public/ Private
Equipment/ Operations	Private	Private	Private	Private	Private	Private
Regulatory Environment	Public	Public	Public	Public	Public	Public

Table 11. Comparison of Freight Decision-Making Issues.

Freight Decision Issue	**Driver of Public Decisions**	**Driver of Private Decisions**
Planning/zoning of land use that accommodates ports, rail yards, and distribution centers	X	X
Investing in capacity to ensure profitability and efficiency		X
Investing in or addressing voter concerns	X	
Investing public funds in social, equity, and environmental justice issues	X	
Implementing cost-saving technology as soon as practical		X
Managing budgets and priorities that dramatically and rapidly shift	X	
Managing budgets with strict performance criteria accompanied by steady capital plans	X	X
Managing investments to return on investment (ROI) and hurdle rate standards		X
Pricing transportation to fully cover all costs and benefits		X
Managing executive turnover that coincides with national, state, local elections	X	

Differences between each sector are given in Table 12.

Table 12. Differences between Public and Private Sector in Freight Decision-Making.

Differences	Public Sector	Private Sector
Scale of investment	Entire system within its jurisdiction	One company at a time but international
Geography	U.S. political boundary	Global market
Process of reaching decisions	Collaborative	Hierarchical
Planning of horizon and timing	Longer-run, slower	Shorter-run, quicker
Objectives of decisions	Social and political as well as economic development	Increase shareholder value through higher profits/revenues
Attitudes	Attempt to address all stakeholder concerns	Satisfy owners, customers, and employees

Future Needs

Public and private stakeholders have realized the need for new investment strategies for freight transportation systems at the local, regional, state, and national levels. Public agencies have a good understanding of the freight transportation infrastructure and its needs, while the private entities have good knowledge of the freight transportation planning programs. This has led to the development of advisory groups, shared funding programs, and new partnerships. Bringing these public and private stakeholders together for a common purpose has led to increasing numbers and types of institutional arrangements designed to support freight mobility needs.[82]

Concluding Remarks

While there is a lot of research discussing sustainable transportation, sustainability of freight transportation and measures for sustainable freight transportation have been missing aspects in aligning the sustainability evaluations to the existing planning framework of a transportation agency. In this context, a performance measurement framework for freight transportation sustainability must be developed for a target agency's planning goals. An approach based on the multi-attribute utility theory has been identified as the most suitable to identify and aggregate freight transportation sustainability performance measure. The following is a list of conclusions from the literature review and scoping exercise that was used to define the final scope and direction of the project:

- There are many variations of the definition of sustainability. However, sustainability is typically considered to be a combination of economic, social, and environmental progress, usually termed "sustainability dimensions." The issues of future needs (i.e., intergenerational equity) are also relevant.
- Sustainability is not something that is fully achievable; it represents a direction, not an end state. Hence, sustainability should be considered in terms of outcomes, not outputs.
- The success of an economy depends to an extent upon the amount of trade it can generate and support. Movement of goods depends on a robust freight transportation.
- Transportation system sustainability is traditionally thought of in three ways: environmental, economic, and socio-cultural. The goal of sustainable transportation is to

[82] *Institutional Arrangements for Freight Transportation Systems,* NCFRP Report 2, Transportation Research Board, Washington, D.C., 2009, Chapter 1.

ensure that economic, environmental, and social considerations are factored into decisions affecting transportation activity.

- Large increases in freight movement are occurring (fastest growing economic sector) due to growing international trade. Continued internal economic growth depends on smooth, uninterrupted domestic movement. Sustainable freight transportation systems are those that can maintain that smooth, uninterrupted flow over time, causing the least damage to the environment and culture. Our diverse transportation needs require a combination of modes. Inefficient freight movement can cause adverse environmental impacts (e.g., more polluting emissions).
- Performance measures are used to evaluate status or progress toward achieving goals.
- Robust performance measurement systems conform to a set of attributes; they are:
    - Relevant to the organization/strategy.
    - Clearly defined/easy to understand/transparent.
    - Based on available data/measurable.
    - Controllable/attributable.
    - Limited in number.
    - Timely.
    - Devoid of perverse incentives/non-corrupting/not corruptible.
    - Statistically/scientifically valid.
    - Comparable/consistent over time.
    - Responsive.
    - Capable of innovation.
    - Capable of aggregation.
- DOTs often measure the following strategic areas to evaluate how well transportation systems perform:
    - Mobility and congestion.
    - Accessibility.
    - Safety.
    - Quality of life.
    - Environment.
    - Economic development.
    - System preservation.
    - Project delivery.
    - Traffic operations.
    - Maintenance.
    - Human resources.
- To evaluate and measure sustainability of freight transportation, the FHWA recommends several measures, including:
    - Cost of highway freight per ton-mile.
    - Cargo insurance rates.
    - Point-to-point travel times on selected freight-significant highways.
    - Hours of delay per 1,000 vehicle miles on selected freight-significant highways.
    - Crossing times at international borders.
    - Condition of connectors between NHS and intermodal terminals.
    - Customer satisfaction.
- Several states and international organizations use other performance measures. They are listed in Tables 4 and 5.

- Performance measurement is used to drive freight-related decision-making in both the private and public sectors. Primary considerations include:
    - Private:
        - Market and shipper demand.
        - Financial performance metrics.
        - Volume, schedule, and cost maintenance.
        - Regulatory issues.
    - Public:
        - Investment and financing: taxes, fees.
        - Economic regulation.
        - Infrastructure provision and maintenance: highways, tracks, ports, air.
        - Land use: facility location and access.
        - Environmental issues.
        - Safety.
        - Operations.
        - Jobs and employment.

These findings all lead to one conclusion: the decisions that will have to be made in both private and public sectors to produce and maintain sustainable effective freight transportation will need to consider multiple, sometimes diverse outcomes, and a performance measurement framework is needed to project the overall outcome in terms of individual considerations.

CHAPTER 3: DEVELOPMENT OF A SUSTAINABILITY FRAMEWORK FOR FREIGHT CORRIDORS

As seen from the introductory and background sections, there are a wide range of issues, stakeholders, areas of decision-making, and other factors related to the freight and transportation sector that can affect freight sustainability issues. In general, sustainability in the freight sector can be addressed by targeting the following:

1. Policy and regulation.
2. Technology.
3. Infrastructure.
4. Operation and maintenance.
5. Non-transportation factors.

The aim of this research was to develop a performance measurement framework for freight sustainability that could be used to evaluate and benchmark freight operations. The framework defined here relates specifically to road-based freight activities and operations and their related sustainability issues. This focus area selection reflects the central role of truck freight in the U.S., as demonstrated in Chapter 2. The scope of the analysis was at the highway corridor level, i.e., focusing on freight activity and its allied impacts for highway corridors. For purposes of this project, a freight corridor is a linear system of freight transport infrastructure and related services connecting centers of economic activity and bounded by transport gateways that provide access to sources and destinations outside the corridor.[83] A freight corridor can be classified based on many parameters, namely freight volume, length of corridor, mobility, and access. While these parameters for classification may provide useful insight, there is limited information regarding corridors differentiated on the basis of mobility, access, and length.

There are significant benefits to aligning performance measurement with agency policy using a framework of goals, related objectives, and performance measures.[84,85,86] This approach starts with the basic principles of sustainability. Figure 2 is a graphic representation of the framework and process.

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[83] http://www.mcli.co.za/18Nov04/NEELESH_NCPM_MCLI.pdf

[84] Falcocchio, J.C. Performance Measures For Evaluating Transportation Systems: A Stakeholder Perspective. 83rd TRB Annual Meeting. Transportation Research Board, Washington, D.C., 2004.

[85] Pickerell, S., and L. Neumann. Use of Performance Measures in Transportation Decision Making. Conference Proc. 26: Performance Measures to Improve Transportation Systems and Agency Operations. Transportation Research Board, National Research Council, Washington, D.C., 2001, pp. 17–32.

[86] Zietsman, J. and Ramani, T., *Sustainability Performance Measures for State DOTs and Other Transportation Agencies,* NCHRP Project 8–74, Texas Transportation Institute, College Station, Texas, July 2011.

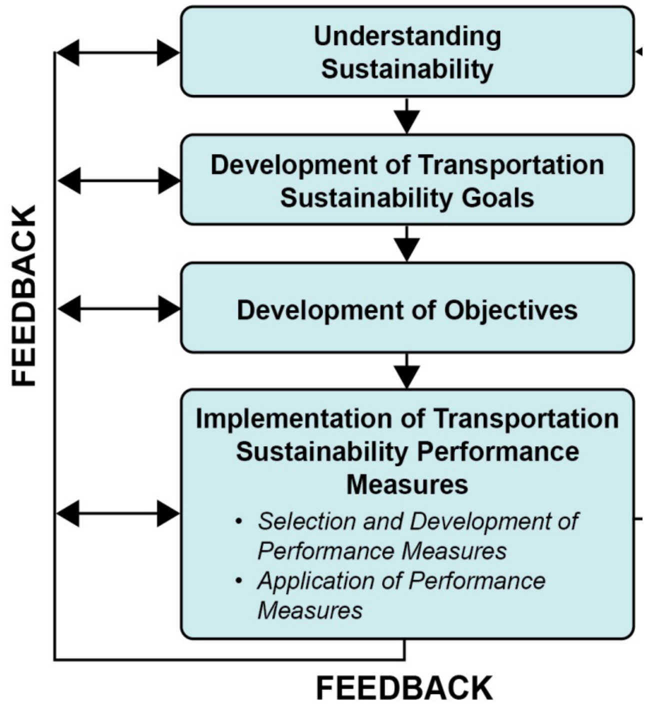

Figure 2. Simplified Framework Diagram.

The basic components of this performance measurement framework include:

- Goals—usually the general statements relating to the intended users' desired outcomes.
- Objectives—more specific statements relating to the attainment of goals.
- Performance measures—measurable quantities linked to the objectives that can be applied for performance measurement.

The measures that form part of this framework are then developed into performance measures, which are quantified and benchmarked to develop a "freight sustainability index," as is described in Chapter 4. The remainder of this chapter describes the goals, objectives, and measures developed for the framework in this project.

Developing Goals for Sustainability at the Corridor Level

Sustainability goals for freight can be considered in two separate but related categories—one that relates to sustainability in terms of freight activity and operation, and another that deals with sustainability in terms of the freight activity's larger impacts. The goals can then be further defined using objectives and performance measures to apply the goals for sustainable freight movement for highway corridors.

The goal developing stages of this project involved a scoping exercise including a literature review, as discussed in Chapter 2, that covered the basic concepts relating to sustainable transportation, performance measures, and freight transportation. It was during the initial stages of this process that the researchers recognized that the transportation agency level (MPO or state DOT) is the most appropriate analysis level for the project. Factors such as data availability and accessibility, overall compatibility with sustainability goals, and level of influence on the outcomes determined this decision. Furthermore, a review of practice with regard to sustainable transportation and freight performance measurement among state agencies, MPOs, and other entities were also conducted to help formulate an approach to this project.

Based on the results of the scoping exercise, a framework for this research (specifically applicable to highways) was developed consisting of performance measures defined to reflect sustainability with objectives linking the measures to higher-level sustainability goals compatible with transportation-agency-level strategic planning goals. It was agreed that the project scope be limited as follows:

- The framework should be applied at the planning level for a single freight-significant highway corridor, i.e., a section.
- The framework should be applied for the highway mode.

The framework is not intended be a decision-making tool but rather a sustainability enhancement tool and not linked to the budgeting process.

Linking Goals to Sustainability Principles

In order for a goal to be considered as a sustainability goal, it must have clear linkages to at least one of the sustainability dimensions, and perhaps linkages to more than one dimension as well. Table 13 shows the mapping of the six goals developed in this framework to the three sustainability dimensions. As seen from the table, the goal set provides comprehensive coverage of the three dimensions of sustainability across the goals.

Table 13. Mapping Goals to Sustainability Principles.

Goal	Sustainability Dimension		
	Environmental	Economic	Social
Improve safety of freight movement and of the general public	Yes		Yes
Increase freight activity levels while ensuring functionality and efficiency of freight operations		Yes	
Promote investment that supports freight operations, functionality, and efficiency over time		Yes	
Reduce freight-related pollutant emissions	Yes		Yes
Reduce freight-related greenhouse gas emissions	Yes		Yes
Reduce negative impact of freight movement on the environment and on human health	Yes	Yes	Yes

Developing Sustainability Objectives and Measures

The main challenge of this project was to develop a set of performance measures to reflect sustainability concerns within the scope of the freight movement. To facilitate this, an internal workshop was held with research team members with related experience. Workshop participants discussed how the dimensions of sustainability—economic development, environmental stewardship, and social equity—could be applicable to progress toward the identified goals. To facilitate ideas and discussion, the six goals were classified under the most appropriate sustainability principle (environmental, economic, and social). Equity is applicable across all goals since it considers how well a goal serves each population group or serves across multiple time periods. Following this, a set of potential objectives was defined under each of the strategic goals, and each objective was linked to a list of potential measurable indicators that could be used in the sustainability evaluation.

The set of potential objectives and their corresponding measures developed for this framework are shown in Table 14. To refine the list, each potential measure was assessed based on the data availability, desired level of detail, measurability, and relevance to the corresponding objective and goal. The final list of selected measures that resulted from this process is shown in Table 15. The next chapter discusses the definitions of these measures as well as the calculation procedures and data elements required to evaluate them as performance measures.

Table 14. Goals, Objectives, and Potential Measures.

Goal	Potential Objectives	Potential Measures
Improve safety of freight movement and of the general public	Reduce number of accidents involving heavy trucks	Truck crashes per truck VMT on corridor
		Number of truck crashes
		Number of fatalities
	Reduce risk of hazardous material transportation	Tons of hazardous material being shipped
		Hazardous material incidents
	Improve overall safety in freight-significant corridors (corridors with >x trucks per day)	Crash rates, fatalities, etc. on selected corridor
Support freight activity level while ensuring functionality and efficiency of freight operation	Improve truck throughput without adversely affecting speed	Truck throughput efficiency—function of truck volumes and speeds
	Improve freight movement efficiency	Ton-miles per truck-mile
	Improve overall corridor performance /reduce congestion in freight-significant corridors	Congestion indices, levels of service, number of bottlenecks, travel times, delay
	Improve intermodal activity	Number of intermodal facilities along corridor
	Invest in technologies that can improve freight efficiency	Presence of freight management or information systems, supply chains
	Invest in improving fleet	Average truck age
	Provide incentives for intermodal facilities	Presence of any incentives
	Assess long-term value of sector freight investments	Results of benefit-cost analysis or life-cycle cost analysis of all investments
Reduce negative impact of freight movement on the environment and human health	Reduce criteria pollutant emissions of freight vehicles	Total emissions of various pollutants in annual tons per mile of corridor, grams per truck-mile, or grams per ton-mile of freight
	Improve fleet emissions characteristics	Percentage of new vehicles (vehicles of specific model year or newer), percent of alternative fuel vehicles, average fleet age
	Reduce GHG emissions from freight vehicles	GHG emissions intensity (emissions per ton-mile or per truck-mile)
	Reduce fuel consumption	Average fuel economy, delay/idling, truck stops, or truck stop electrification (TSE) along corridor
	Promote alternative fuels for trucks	Compressed Natural Gas, other alternatives
	Reduce impact on sensitive populations	Sensitive areas (schools/hospitals/etc.) within specific distance of freight-significant corridors
	Provide buffer between freight and residential development	Number of residences (or population) within x miles of freight-significant corridor
	Protect natural habitats	Presence of natural or preserve areas in buffer zone along freight corridor

Table 15. Proposed Objectives and Measures.

Goal No.	Sustainability Dimension	Goal	Objectives	Measure No.	Performance Measure
1	Social	Improve safety of freight movement and of the general public	Reduce freight-related crash rates and crash risk	1a	Annual fatal accidents per truck-mile
			Reduce freight-related HAZMAT accidents	1b	Annual HAZMAT accidents per mile
2	Economic	Support freight activity level while ensuring functionality and efficiency of freight operation	Improve road-based freight movement	2a	Truck throughput efficiency, TTE = daily truck volumes per lane × truck operational speed
			Improve freight movement efficiency	2b	Average cargo weight per truck
			Improve freight movement mobility	2c	Travel rate index
			Improve freight movement reliability	2d	Buffer index
			Improve intermodal activity	2e	Number of intermodal facilities along the section
			Invest in improving freight fleet	2f	Average truck age
3	Environmental	Reduce negative impacts of freight movement on the environment and human health	Reduce criteria pollutant emissions from freight vehicles	3a	Grams per mile of PM, NO_x, VOC
			Improve freight fleet emissions characteristics	3b	Percentage of trucks complying with the second most recent emissions standards (e.g., MY 2004 for now)
			Reduce GHG emissions from freight vehicles	3c	Grams of CO2eq per mile
			Reduce impact on sensitive population	3d	Number of sensitive areas (schools/hospitals) within 1 mile from the road
			Reduce buffer between road and residential development	3e	Population residing within 1 mile from the road
			Protect natural habitats	3f	Number of sensitive environmental areas within 1 mile from the road

Concluding Remarks

The majority of the traditional sustainability-related measures are not practically implemented at the highway corridor level but can be more easily considered at the aggregate level (of a county/city). Given the constraints of restricting the evaluation of freight sustainability to highway segments, the selected performance measures adequately represent the overall concept of freight sustainability along a corridor, without being impractical to evaluate. Another interesting aspect of sustainability is the consideration of changes over time. Future and present conditions should be evaluated on a common ground rather than by making allowances or accepting that future conditions would be worse. This is a key sustainability consideration that the future conditions should be better than today. The following chapters deal with the quantification of these performance measures, their combination into an aggregate sustainability measure, and the application of this evaluation methodology as an analysis framework.

CHAPTER 4: QUANTIFICATION AND BENCHMARKING OF PERFORMANCE MEASURES

As discussed in the previous chapter, the framework for performance-based evaluation of freight movement sustainability developed as part of this project is intended to assess a single highway facility, termed as a “section.” The analysis does consider corridor-level information, such as adjacent transportation facilities or land use; however, the term “section” is used rather than “corridor” to describe the level of analysis because a corridor can usually include multiple parallel road facilities, whereas the approach used in this research covers a single facility and its impact.

Each section under consideration is divided into smaller subsections, and the calculation methodology can be applied to each individual subsection, as well as the aggregate highway section. Figure 3 shows a schematic setup. The main advantage of this approach is that the resolution of the analysis can be increased so that analysts can identify problem areas on a given section and can determine how each subsection measures up compared to the average. This assessment can also be used to compare different freight section or alternative projects for a single section.

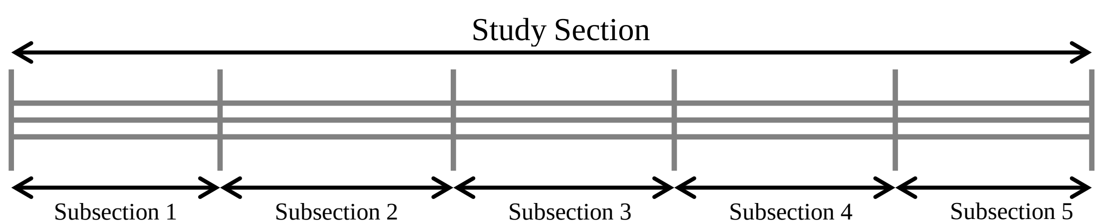

Figure 3. Setup of Links and Sections for Multi-Criteria Analysis.

The selected performance measures described in the previous chapter are to be quantified, scaled, and aggregated into a final index value representing the result of the sustainability evaluation according to the identified goals. As discussed in the literature review, the distinction between a sustainability measure and performance measure is the calculation/quantification step. When sustainability measures are quantified and benchmarked for a specific evaluation, they become performance measures. This chapter covers the selected freight sustainability performance measures proposed in the previous chapter and their calculation as performance measures.

Performance Measure Definition and Quantification

Selection of freight sustainability measures was discussed in previous chapter. Table 16 provides a summary of the corresponding performance measures, the data elements required to quantify them, and the units of expression for each performance measure. Each of these measures can be evaluated for the existing conditions as well as for a projected future scenario. As was discussed previously, the performance measures can be quantified for individual subsections and for the overall study section. This section explains the estimation processes for each of the measures.

Table 16. Data Elements for Quantification of Performance Measures.

Measure No.	Performance Measure	Data Elements for Quantification	Unit
1a	Annual fatal accidents per truck-mile	Number of annual fatal accidents Annual truck flow Length of section	Fatal accidents per truck-mile per year
1b	Annual HAZMAT accidents per mile	Number of HAZMAT accidents Length of section	HAZMAT accidents per mile per year
2a	Truck throughput efficiency, TTE = daily truck volumes per lane × truck operational speed	Daily truck volume Number of lanes	Truck-miles per hour per lane
2b	Average cargo weight per truck	Annual cargo weight Annual truck flow	Short ton per truck
2c	Travel rate index	Daily volumes (average daily traffic [ADT]) Number of lanes Speed limits	Dimensionless
2d	Buffer index	Travel time index	Percentage
2e	Number of intermodal facilities along the section	Number of intermodal facilities along the study section	Number of facilities
2f	Average truck age	Truck model year distribution	Average age
3a	Grams per mile of PM, NO_x	Emissions rates (emissions model) Peak and off-peak volumes Operating speeds	Grams per mile
3b	Percentage of trucks complying with the second most recent emissions standards (e.g., MY 2004 for now)	Dates of emission standard changes Truck model year distribution	Percentage
3c	Grams of CO2eq per mile	Emissions rates (emissions model) Peak and off-peak volumes Operating speeds	Grams per mile
3d	Number of sensitive areas (schools/hospitals) within 1 mile from the road	Number of sensitive areas within a mile from the road	Number of areas
3e	Population residing within 1 mile from the road	Number of people living within a mile from the road	Number of people
3f	The number of sensitive environmental areas within 1 mile from the road	Number of sensitive areas within a mile from the road	Number of areas

In many applications, a freight sustainability index, representing the overall sustainability state of the study section, is desired by the responsible agency. For this purpose, this study suggests utilizing a scaling approach to scale performance measures to comparable values based on their best and worst possible values and then combining them based on different weights for goals and/or objectives. The following explains the recommended scaling approach in a mathematical form. The word "iff" in the calculation is read as "if and only if," e.g., scaled measure is equal to 1 if and only if Measure Value ≤ Best.

$$Scaled\ Measure = \begin{cases} 1 & iff\ Measure\ Value \leq Best \\ 0 & iff\ Measure\ Value > Worst \\ \dfrac{Measure\ Value - Worst}{Best - Worst} & iff\ Best < x \leq Worst \end{cases}$$

Measure 1a—Annual Fatal Accidents per Million Truck-Mile

The annual fatal accident number can be primarily determined from the Fatal Analysis Reporting System (FARS)[87] database created by the National Highway Traffic Safety Administration (NHTSA). The fatal accidents were deemed to be a suitable measure for two main reasons: (1) the data are accurately and consistently collected and maintained by a national entity and are easily available through a website; and (2) according to FARS, trucks are disproportionally involved in fatal crashes. This performance measure is calculated as follows:

$$Total = \frac{Annual\ Fatal\ Accidents}{Length \times Annual\ Truck\ Flow}$$

Based on a quick study of the FARS data for 2008, the best and worst values for this measure were determined to be 0 and 1, respectively.

Measure 1b—Annual HAZMAT Accidents per Mile

Freight trucks carry a significant amount of hazardous material over the public highway system. HAZMATs include industrial and agricultural chemicals that are lethal or can cause serious damage to human health and the environment, and therefore their presence on public roads poses a risk to the public and the environment. This measure tries to capture this risk for the study corridor. The FARS database can be used to extract the incidents involving HAZMAT-carrying trucks. Based on the data from FARS, it was determined that the best and the worst values for this measure are 0 and 1, respectively.

$$Total = \frac{Annual\ HAZMAT\ Accidents}{Length\ (miles)}$$

Measure 2a—Truck Throughput Efficiency

The truck throughput efficiency is a measure reflecting the efficiency of the truck movement along a section of a highway. This measure is calculated as the product of daily truck volumes per lane and the truck operational speed.

TTE = Daily truck volumes per lane × Truck operational speed

This measure is calculated based on truck percentages, total daily traffic volumes per lane, and the operational speeds for trucks. Research indicates that trucks, on average, travel 6 percent slower than passenger cars in the traffic stream.[88] Thus, a reduced truck operational speed is considered. This performance measure is estimated for individual links, and the length-weighted average of these measures is calculated as the section's performance measure. The extreme

[87] NHSTA, Fatal Analysis Reporting System (FARS), http://www-fars.nhtsa.dot.gov

[88] Eisele, W.L., L.R. Rilett, K.B. Mhoon, and C. Spiegelman. Using Intelligent Transportation Systems Travel-Time Data for Multimodal Analyses and System Monitoring. In Transportation Research Record: Journal of the Transportation Research Board, No. 1768, Transportation Research Board, National Research Council, Washington, D.C., 2001, pp. 148-156.

values for this measure were identified as 170,700 and 5,600 daily truck-miles per hour per lane, respectively, in a previous TTI study.[89]

Measure 2b—Average Cargo Weight per Truck, Annual Amount of Cargo/Number of Trucks

Freight efficiency is directly related to the utilization of the truck's hauling capacity. The weight data required for this measure are expected to be mainly estimated based on data from weigh stations in the region. The calculation of this measure is as follows.

$$Total = \frac{Cargo\ Amount}{Annual\ Truck\ Flow}$$

Based on available truck weight data, the research team determined that the best and the worst values for this measure are 3 and 20 tons per truck, respectively.

Measure 2c—Travel Rate Index

The travel time index value is quantified as the following.

$$Travel\,Time\,Index = \frac{Peak\ Hour\ Travel\ Rate\,(Minutes\ per\ Mile)}{Travel\ Rate\ at\ Posted\ Speed\ Limit\,(Minutes\ per\ Mile)}$$

The estimation of the peak-period speeds is based on the procedure outlined in TTI's *Urban Mobility Report.*[90] In this procedure, peak-period vehicle operating speeds are a function of the ADT per lane. The following equations demonstrate this speed estimation.

$$Peak\ Period\ Travel\ Times = \frac{Length}{Peak\ Direction\ Speed\ from\ Speed\ Curves} \times 60$$

For ADT/Lane = 15,001–17,500,
Peak-Period Speed = 70 − (0.9×(ADT/1000)/Lane)

For ADT/Lane = 17,501–20,000,
Peak-Period Speed = 78 − (1.4×(ADT/1000)/Lane)

For ADT/Lane = 20,001–25,000,
Peak-Period Speed = 96 − (2.3×(ADT/1000)/Lane)

For ADT/Lane >25,000,
Speed = 76 − (1.46×ADT/Lane)

[89] Tara Ramani, Josias Zietsman, William Eisele, Duane Rosa, Debbie Spillane and Brian Bochner. Developing Sustainable Transportation Performance Measures for TxDOT's Strategic Plan, Report FHWA/TX-09/0-5541-1, 2008.
[90] *2007 Annual Urban Mobility Report.* Texas Transportation Institute, The Texas A&M University System, College Station, Texas, September 2007.

In the above equations, the speeds corresponding to an ADT per lane less than 15,000 are considered to be equal to the posted speed limit. The lower limit for speed calculations in this procedure is 35 miles per hour. Based on these estimated peak-period speeds, the peak-period travel times for each of the links can be calculated. The travel times corresponding to the posted speed limit are also calculated, and the travel time index value for each link is obtained.

A best-case scenario for this measure is represented by a value of 1.0, indicating peak-period travel that is not delayed by congestion. In this research, the worst-case scenario is defined as a travel time index value of 1.50, representing the worst-case scenario in the U.S. based on estimations for the city of Los Angeles.[91]

Measure 2d—Buffer Index

The buffer index indicates the extent to which the highest travel times exceed the average. The following equation shows the formula for the buffer index. A high buffer index indicates unreliable travel conditions and generally has some correlation with higher congestion levels and travel time index values. The Texas Transportation Institute developed an empirical relationship between the buffer index and the travel time index using available real-time data. This relationship (presented in the equation below) is used in this study to estimate the buffer index and is valid for travel time index values up to 1.5.

$$Buffer\ Index = \frac{95th\ Percentile\ Travel\ Time\ (Minutes) - Average\ Travel\ Time\ (Minutes)}{Average\ Travel\ Time\ (Minutes)}$$

$$Buffer\ Index = 2.189 \times (Travel\ Time\ Index - 1) - 1.799 \times (Travel\ Time\ Index - 1)^2$$

The best- and worst-case values for the buffer index are the values corresponding to the extreme values of the travel time index. Therefore, the best- and worst-case values are 0.65 and 0, respectively.

Measure 2e—Number of Intermodal Facilities along the Section

This measure intends to capture the availability of intermodal freight facilities in the vicinity of the study section. The measure is simply the number of such facilities that exist along the study section. The best- and worst-case values were determined to be 1 and 0, respectively.

Measure 2f—Average Truck Age

This measure captures the average age of the trucks on the study corridor. The measure is scaled based on the following assumptions and equation:

Assumptions: Best value 10.00 or lower, and worst value of 20.00 or higher

[91] *National Congestion Tables, Key Mobility Measures.* http://mobility.tamu.edu/ums/congestion_data/tables/los_angeles.pdf. Accessed May 2008.

$$Scaled\ Measure = \begin{cases} 1 & iff Measure\ Value \leq Best \\ 0 & iff\ Measure\ Value > Worst \\ \dfrac{Worst - Measure\ Value}{Worst - Best} & iff\ Best < x \leq Worst \end{cases}$$

Measures 3a and 3c—Daily Grams per Mile (PM, NO_x, CO_2)

Freight trucks are a significant source of PM, NO_x, and VOCs. They also consume a large amount of diesel fuel, which makes them a notable source of CO_2, the most prevalent greenhouse gas. Depending on the data availability, measures that represent the air quality impact of trucks can be calculated in terms of mass per distance (i.e., gram per mile) or mass per ton-mile; the latter is usually preferred since it reflects intended impact in a more accurate manner.

The emissions rate per equivalent ADT for NO_x, CO_2, and PM are obtained from the MOBILE6 model. The MOBILE6 model provides emissions rates that vary by speed. The total daily emissions of each pollutant are estimated based on peak and off-peak speeds and the proportion of the ADT occurring under peak and off-peak conditions. Figure 4 shows this process in a flowchart.

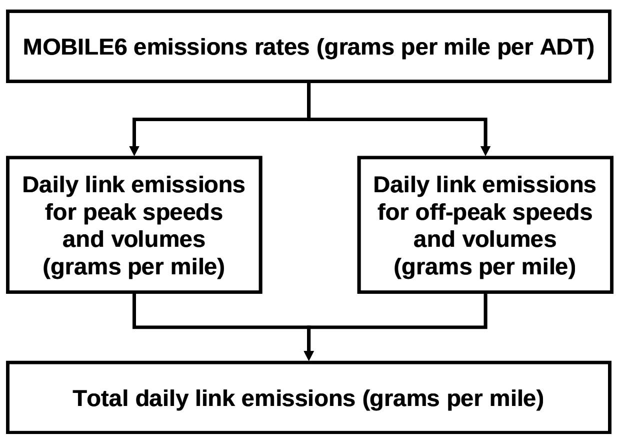

Figure 4. Estimation of Daily Combined VOC, NO_x, and CO Emissions.

$$Daily\ grams\ per\ mile = \frac{Daily\ grams\ for\ the\ entire\ section}{length\ of\ section}$$

The equation below shows the scaling calculations for the air quality impact measures. The extreme values for this measure are based on emissions for a range of extreme ADT values obtained from FAF[2] and different distributions of peak and off-peak conditions.

NO_x—scaling values: best value 232 or lower, worst value 215,878 or higher.

PM—scaling values: best value 5 or lower, worst value 9,227 or higher.

CO_2—scaling values: best value 2,798,629 or lower, worst value 46,733,896 or higher.

$$Scaled\ Measure = \begin{cases} 1 & iff\ Measure\ Value < Best \\ 0 & iff\ Measure\ Value > Worst \\ \dfrac{Measure\ Value - Worst}{Best - Worst} & iff\ Best \leq x \leq Worst \end{cases}$$

Measure 3a and 3c—Daily Grams per Ton-Mile of Cargo

If the average cargo tonnage of the trucks is available for a corridor, the air quality measures can be more precisely described in terms of mass per ton-mile (a measure of freight activity). The calculation of these measures includes using the above-mentioned methodology to obtain the average distance-based emissions rates and then combining them with tonnage data. Similar to mass-per-distance measures, the scaling extreme values are calculated based on a range of ADTs. To make the scaling meaningful, the minimum cargo weight is assumed to be 5 tons.

$$grams\ per\ ton - mile = \frac{grams\ per\ mile}{average\ cargo\ tonnage}$$

NO_x—scaling values: best value 11.61 or lower, worst value 43,147 or higher.

PM—scaling values: best value 0.3 or lower, worst value 1,845 or higher.

CO_2—scaling values: best value 25,670 or lower, worst value 9,346,779 or higher.

$$Scaled\ Measure = \begin{cases} 1 & iff\ Measure\ Value < Best \\ 0 & iff\ Measure\ Value > Worst \\ \dfrac{Measure\ Value - Worst}{Best - Worst} & iff\ Best \leq x \leq Worst \end{cases}$$

Measure 3b—Percent Trucks Complying with the Second Most Recent Emissions Standard (PM, NO_x)

The Environmental Protection Agency (EPA) is constantly tightening the emissions standards for diesel engines. Each new set of standards demands reduction of a pollutant for on-road heavy-duty engines manufactured after a set data. It is expected that the EPA will continue to update its on-road heavy-duty diesel emissions standards in the same fashion for the foreseeable future. This measure tries to capture how the freight trucking fleet is complying with the EPA standards. An examination of the current long-haul fleet shows that most of the trucks with high mileage are equipped with the second most recent emissions standards with regards to NO_x and PM. Therefore, it was decided that the percent trucks complying with the second most recent standards would sufficiently show the overall changes in fleet compliance with the standard. Scaling values are as follows.

NO_x and PM—scaling values: best value 0, worst value 1.

$$Scaled\ Measure = \begin{cases} 1 & iff\ Measure\ Value < Best \\ 0 & iff\ Measure\ Value > Worst \\ \dfrac{Measure\ Value - Worst}{Best - Worst} & iff\ Best \leq x \leq Worst \end{cases}$$

Measure 3d—Number of Sensitive Areas (Schools/Hospitals) within 1 Mile of Road

This measure intends to represent facilities with substantial vulnerable populations that are exposed to the pollution from freight trucking activity. The value of the measure is simply the number of schools, hospitals, and other sensitive facilities within 1 mile from the road. The best and worst values for scaling are 0 and 30 or higher (assuming the maximum has three sensitive areas per mile in the section), respectively.

$$Scaled\ Measure = \begin{cases} 1 & iff\ Measure\ Value \leq Best \\ 0 & iff\ Measure\ Value > Worst \\ \dfrac{Measure\ Value - Worst}{Best - Worst} & iff\ Best < x \leq Worst \end{cases}$$

Measure 3e—Average Population Residing within 1 Mile from Road

Similar to measure 3d, this measure tries to capture how many people per mile of road are directly impacted by the pollutions emitted from freight trucks. The value of the measure is the number of people living within 1 mile from the study corridor. The main data sources for this measure are the U.S. Census database and local government geographic information system (GIS) databases.

$$population\ per\ mile = \frac{Population}{Length}$$

Scaling: best value is 0 and worst value is 2,000 or higher.

$$Scaled\ Measure = \begin{cases} 1 & iff\ Measure\ Value < Best \\ 0 & iff\ Measure\ Value > Worst \\ \dfrac{Measure\ Value - Worst}{Best - Worst} & iff\ Best \leq x \leq Worst \end{cases}$$

Measure 3f—Number of Sensitive Environmental Areas within 1 Mile from Road

This measure was selected to represent the negative impact on the surrounding environment of the road. It is determined that sensitive environmental areas within 1 mile of a road are at high risk of being affected negatively by the freight activity. The best and worst values for scaling are 0 and 2 or higher.

$$Scaled\ Measure = \begin{cases} 1 & iff\ Measure\ Value \leq Best \\ 0 & iff\ Measure\ Value > Worst \\ \dfrac{Measure\ Value - Worst}{Best - Worst} & iff\ Best < x \leq Worst \end{cases}$$

Aggregation as an Index—Weights

In order to create an index that represents the overall sustainability of a freight corridor, the above discussed performance measures need to be aggregated in a meaningful manner. To achieve this objective, an approach based on the multi-attribute utility theory is applied to the measures. This aggregating approach consists of calculating an aggregate measure as the weighted sum of the individually scaled measures. This results in a composite measure that is also expressed on the same scale, in this case from 0 to 1.

The weights for individual measures are allocated such that they add up to 1, with the measures that are deemed more important by the decision makers being given a higher weight. Two sets of weights are used: goal-weights and measure-weights. Because the framework has three goals, each addressed by a set of performance measures, the performance measures corresponding to each goal are first assigned individual weights (measure-weights). This enables calculation of goal-wise performance to evaluate which goals are being sufficiently addressed from a sustainability perspective and which require further improvement. The set of goal-weights then define the relative importance assigned to the framework's three goals, and the aggregate measures for each goal can be combined into a final sustainability evaluation index. Figure 5 illustrates this process.

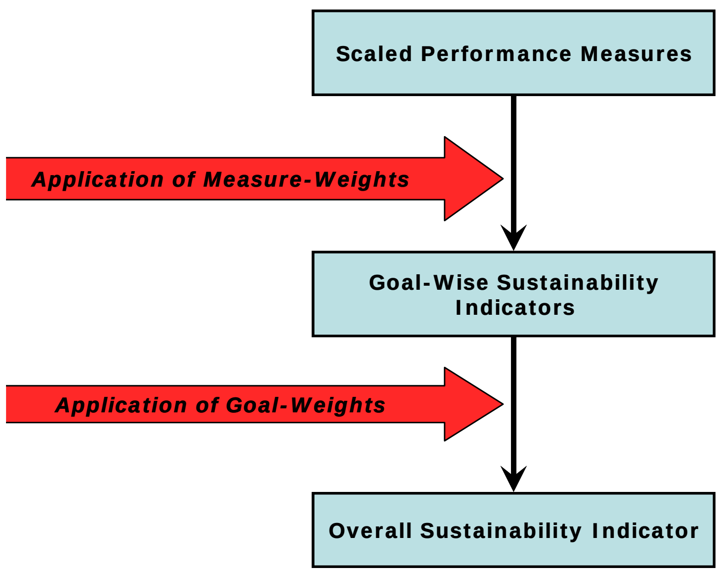

Figure 5. Application of Weights to Aggregate-Scaled Performance Measures.

The weights are usually obtained through a group decision-making process in a workshop format held by the organization that is using the framework. Tables 17 and 18 show examples of these weights that are partially based on a previous TTI study for Texas Department of Transportation.

Table 17. Example Goal-Weights for Aggregating Measures.

Goal No.	Goal	Goal-Weight (%)	
		Urban Default	Rural Default
1	Social—Improve Safety	40	40

2	Economic—Improve Freight Activity	25	40
3	Environmental—Improve Air Quality	35	10

Table 18. Example Measure-Weights for Aggregating Measures.

Goal No.	Performance Measure	Measure-Weight (%) Urban Default	Measure-Weight (%) Rural Default
1	Annual fatal accidents per truck-mile	70	80
	Annual HAZMAT accidents per mile	30	20
2	Truck throughput efficiency	30	15
	Average cargo weight per truck	30	10
	Travel rate index	15	25
	Buffer index	10	20
	Number of intermodal facilities along the section	10	20
	Average truck age	5	10
3	Grams per mile of PM, NO_x	5 (PM), 20 (NO_x)	5 (PM), 20 (NO_x)
	Percentage of trucks complying with the second most recent emissions standards (e.g., MY 2004 for now)	5 (PM), 10 (NO_x)	5 (PM), 10 (NO_x)
	Grams of CO_2 per mile	5	5
	Number of sensitive areas (schools/hospitals) within 1 mile of road	30	30
	Population residing within 1 mile from the road	15	15
	The number of sensitive environmental areas within 1 mile from the road	10	10

Concluding Remarks

This chapter covered the techniques that can be used to apply the proposed framework for sustainability evaluation of a given freight corridor section, including the process of quantification, scaling, and aggregation of the performance measures.

CHAPTER 5: EXAMPLE APPLICATION OF THE PROPOSED FRAMEWORK

This chapter presents a case study to show how the proposed framework can be used for sustainability assessment of a freight corridor. The main purpose of this example analysis is to illustrate how data are to be assembled and how the analysis framework can be used. This example illustrates how the data requirements can be approached and how reasonable assumptions may be made in cases where complete data are not available.

The data for the selected corridor were used in the case study as initial pilot applications for the analysis framework. Conducting the pilot test allowed examination of the outputs, in terms of both specific performance measures and the overall index values.

The selected pilot corridor was a 4.8-mile section of IH-10 in Houston, Texas, which is in a highly urbanized setting. The pilot corridor was selected based on availability of data from previous TTI research work.

This chapter discusses the setup and results from this case study. The individual inputs and results are presented.

Description of Study Section

A 4.8-mile section of IH-10 in Houston, Texas, was chosen as the study corridor. A sustainability evaluation was conducted for this interstate segment using the spreadsheet analysis tool. Figure 6 shows the location of the study segment.

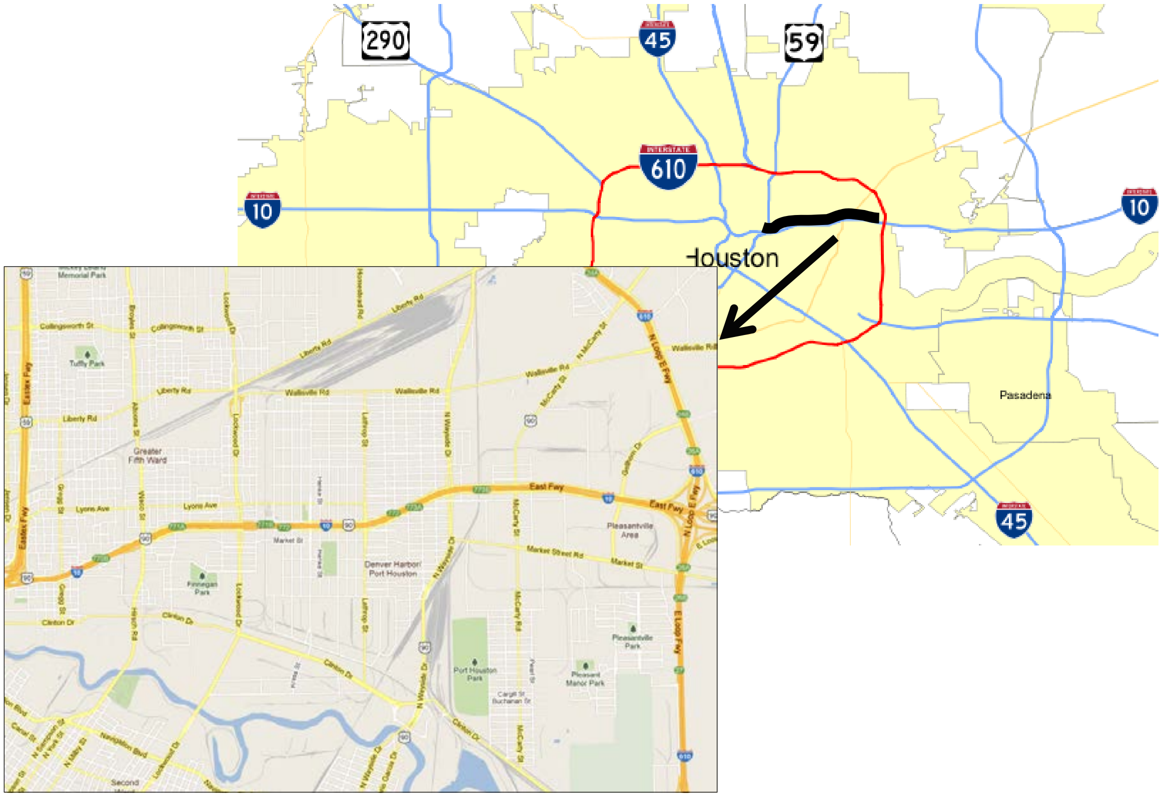

Figure 6. Case Study Location.

The study section is located on IH-10 in Harris County, Texas. The segment connects the IH-610 East Loop, which surrounds the city of Houston, to US 59. This section of IH-10 bisects the city of Houston and is a major thoroughfare for east-west travel through and within the city. IH-10 is fully access controlled with grade-separated interchanges, comprised of four lanes per direction (total eight lanes) with concrete median barriers. Due to the operating speed of the facility, there are no pedestrian or bicycle facilities on the roadway, although pedestrian fatalities have occurred, most probably because of the dense population surrounding the study section. Table 19 shows some of the properties of this interstate segment.

Table 19. Information of the Case Study Section.

Start	End	Length (miles)	Number of Lanes	AADT* (2007)	FAF AADT** (2007)
US 59	IH-610	4.8	8	138,379	7,170

* Total annual average daily traffic (AADT)
** Freight annual average daily traffic

Table 19 also shows the total AADT and freight annual average for the facility for the year 2007. These data were obtained from the FAF prepared by the FHWA and can be accessed for all freight routes throughout the country. The FAF AADT data listed in Table 19 include the number of freight carrying trucks, which is less than the total number of "trucks" that use this facility on a daily basis. These totals show that more than 5 percent of all the vehicular traffic on this segment of IH-10 is comprised of freight trucks.

As was shown in the previous chapter, quantification of the proposed performance measures requires information from different data sources. Table 20 shows the list of the required input data along with their value for the study section.

Table 20. Case Study Input Data.

Parameter	Value
Roadway Section	IH-10 between US 59 to IH-610
Average Daily Traffic Volume (vehicles/day)	140,000
Analysis Year	2007
Annual Truck Flow (trucks/year)	2,600,000
Average Speed (miles per hour)	56
Second Most Recent Emission Standard Year NO_x	2007
Second Most Recent Emission Standard Year PM	2006
HAZMAT Highway Section Length (mile)	4.8
Highway Section Length (mile)	4.8
Model Year Distribution	Appendix B
Number of Annual Fatal Accidents	2
Number of Annual HAZMAT-Related Accidents	0
Number of Intermodal Facilities along the Section	1
Number of Lanes	8
Number of Natural Habitats with 1-Mile Buffer	0
Number of Schools/Hospital with 1-Mile Buffer	19
Population with 1-Mile Buffer	34,000
Posted Speed Limit (miles per hour)	60
Proportion of Traffic Occurring under Peak Conditions	40%
Total Cargo Weight (tons)	39,000,000
8-Hour Ozone Attainment Status	E—Serious or Severe Nonattainment
CO Attainment Status	A—In Attainment
PM Attainment Status	B—Early Action Compact

As described above, the AADT and freight data were retrieved from the FAF^3 database. The average speed was calculated by TranStar, the Houston area's traffic management center, for the year 2007. Appendix B includes the accompanying table referred to in Table 20 for truck age distribution. The values shown in Appendix B are default values used in the MOVES emission model as provided on the EPA website.

The number of fatal accidents for the study section was obtained from the FARS. For the year 2007, this number was found to be seven. This value was not used in the analysis due to the outlying value of seven fatalities for the year 2007. An analysis of the FARS data showed that in the years 2004–2009, a total of 11 fatal accidents occurred on this roadway segment, thus confirming that seven fatalities in 2007 is an outlier. The average value for the 2004–2009 period is 1.8 fatal accidents per year. A value of two annual fatal accidents was used in the case study to portray a more representative description of the sustainability of the study section. The FARS database also showed no crashes involving hazardous material in the year 2007 or for the period of 2004–2009.

The number of schools and hospitals were found using aerial images provided by Google Maps and GIS software. The 1-mile buffer an each side of the interstate segment showed 19 schools and no hospitals. The area's population from 2010 U.S. Census data was selected to provide an estimate close to the 2007 analysis year. The census data revealed that 34,000 people lived within the 1-mile buffer of the study section. This is equal to a population density of 3,400 people per square mile, which is representative of an urban area. The research team could not obtain local data regarding cargo weight on the study section and therefore assumed an average representative value based on national average values. The total cargo weight of the freight trucks was assumed to be 15 tons per truck, which equated to 39 million tons of freight cargo that traveled on the study section in 2007.

With the data available to be analyzed, a spreadsheet-based analysis was established for the study section. As was described previously in the report, this analysis created scaled performance measures to be used for comparative analysis. Table 21 shows the results of this analysis effort in details. The table contains the final sustainability index as well as the goal index and raw and scaled performance measure values.

The intention of this case study was to demonstrate how the proposed framework works, and thus only one set of performance measures were created. Comparative analyses can be performed between different analysis years (e.g., 2007 versus 2010), build and no-build scenarios, or different link types (rural, urban) in an area.

Table 21. Sustainability Performance Measures—Analysis Output.

Measure Number	Measure Weight	Performance Measure	Measured Value	Scaled Value	Aggregated Value	Goal Weight	Sustainability Index
1a	0.7	Annual fatal accidents per truck-mile	0.16	0.84	**0.89**	0.40	**0.62**
1b	0.3	Annual HAZMAT accidents per mile	0.00	1.00			
2a	0.3	Truck throughput efficiency	44,779	0.24	**0.72**	0.25	
2b	0.3	Average cargo weight per truck, annual	15	1.00			
2c	0.15	Travel time index	1.12	0.88			
2d	0.1	Buffer index	0.24	0.63			
2e	0.1	Number of intermodal facilities along the section	1	1.00			
2f	0.05	Average truck age	7	1.00			
3a	0.05	Daily grams per mile (PM)	50,950	0.00	**0.24**	0.35	
	0.2	Daily grams per mile (ozone precursor)	1,329,129	0.00			
3b	0.05	Percentage of trucks complying with the second most recent emissions standards (PM)	15%	0.85			
	0.1	Percentage of trucks complying with the second most recent emissions standards (ozone precursor)	7%	0.93			
3c	0.05	Daily grams of CO2eq per mile	285×10^6	0.00			
3d	0.3	Number of sensitive areas (schools/hospitals) within 1 mile from the road	19	0.00			
3e	0.15	Population residing within 1 mile from the road	7083	0.00			
3f	0.1	Number of sensitive environmental areas within 1 mile from the road	0.00	1.00			

Concluding Remarks

This chapter demonstrated the proposed framework through a case study. An urban section of IH-10 in Houston, Texas, was selected for this purpose. Real-world data were obtained for the study section from different data sources including the FAF^3 database, the FARS database, and U.S. Census data. The research team implemented the quantification process in an Excel spreadsheet and calculated the raw and scaled performance measures as well as aggregated values for each goal and the overall freight sustainability index.

This output can be used to assess how well a highway segment performs against sustainability objective targets, whether the sustainability status is improving, or how it compares with other highway segments.

CHAPTER 6: SUMMARY AND CONCLUSIONS

This project developed a framework and methodology to address the issues of freight sustainability at the transportation corridor level, i.e., for highways and rail facilities. The specific project objectives were to:

- Develop a framework for assessing freight sustainability and identifying the relevant performance measures.
- Identify the data requirements for using the performance measures.
- Propose methodologies for quantifying relevant performance measures.
- Develop an aggregate measure of sustainability for a freight corridor, based on the evaluated performance measures.
- Apply the developed methodology to a test case corridor.

As a first step, an extensive literature review and a state-of-the-practice assessment were conducted. While there is extensive research discussing sustainable transportation, sustainability of freight transportation and measures for sustainable freight transportation have been largely missing in sustainability evaluations. In this context, a performance measurement framework for freight transportation sustainability must be developed for a target agency's planning goals. Researchers identified an approach based on the multi-attribute utility theory as the most suitable to identify and aggregate freight transportation sustainability performance measures by using a framework of goals, objectives, and performance measures.
The basic components of this performance measurement framework include:

- Goals—usually the general statements relating to the intended users' desired outcomes.
- Objectives—more specific statements relating to the attainment of goals.
- Performance measures—measurable quantities linked to the objectives that can be applied for performance measurement.

The measures that formed part of this framework were then developed into performance measures, which were quantified and benchmarked to develop a freight sustainability index. The goals, objectives, and performance measures developed were summarized in Chapter 3.

Given the constraints of restricting the evaluation of freight sustainability to highway segments, the suggested performance measures adequately represent the overall concept of freight sustainability along a corridor, without being impractical to evaluate. Another interesting aspect of sustainability is the consideration of changes over time. Future and present conditions should be evaluated on a common ground, rather than by making allowances or accepting that future conditions will be worse.

A case study application for a section of I-10 in Houston was performed to demonstrate the proposed framework. Real-world data were obtained for the study section from different data sources, and raw and scaled performance measures as well as aggregated values for each goal and the overall freight sustainability index were calculated. This case study output can be used to assess how well the highway segment performs against sustainability objective targets, whether the sustainability status is improving, or how it compares with other highway segments.

In conclusion, the framework presented in this report can be used to comprehensively and objectively evaluate the sustainability of freight transportation using appropriate performance measures, for a highway corridor or a portion of a highway network. The additional data sources and literature summarized in this report provide additional reference for agencies and groups interested in evaluating sustainability for freight movement using appropriate performance measures.

APPENDIX A: FREIGHT DATA SOURCES

I. EXISTING ELECTRONIC DATABASE AND MAP SOURCES

1. *Hazards U.S. Multi-Hazard (HAZUS-MH) Software*. Federal Emergency Management Administration (FEMA), U.S. Department of Homeland Security (DHS).

Website: www.fema.gov/plan/prevent/hazus/index.shtm

The HAZUS-MH "is a nationally applicable standardized methodology that estimates potential losses from earthquakes, hurricane winds, and floods. HAZUS-MH was developed by the Federal Emergency Management Agency (FEMA) under contract with the National Institute of Building Sciences (NIBS). HAZUS-MH uses state-of-the-art Geographic Information Systems (GIS) software to map and display hazard data and the results of damage and economic loss estimates for buildings and infrastructure." The primary application of the software is that it allows users to estimate the impacts of earthquakes, hurricane winds, and floods on populations. Its primary value for hazardous material commodity flow is the spatial data that comes with the software. HAZUS-MH provides readily available, geo-referenced, national data to enable identification of inventory assets (step 3) in a community, classified in seven categories:

1. General Building Stock: General building types (residential, commercial, industrial, public service) and occupancy classes (single-family, retail, industrial, church).
2. Essential Facilities: Facilities essential to the health and welfare of the community (hospitals, police, fire, emergency centers, schools).
3. Hazardous Material Facilities: Storage facilities for industrial hazardous materials (corrosives, flammables, explosives, radioactive, and toxins).
4. High Potential Loss Facilities: Facilities that, if affected by disaster, would have a high loss or impact on the community (nuclear power plants, dams, levees, military installations).
5. Transportation Lifeline Systems: Transportation systems for:
    - Air (airports, runways, heliports).
    - Road (bridges, tunnels, road segments).
    - Rail (tracks, light rail, tunnels, bridges, facilities [rail yards and depots]).
    - Water (ports, harbors, locks, ferries).
6. Utility Lifeline Systems: Potable water, wastewater, oil, natural gas, electric power, and communication systems.
7. Demographics: Population statistics (total population, age, gender, race, income, workforce location).

HAZUS-MH requires ESRI's ArcGIS 8.3 or 9.0 software and Spatial Analyst 8.3 in addition to standard personal computer hardware and software. Federal, state, and local government agencies and the private sector can order HAZUS-MH free of charge from the FEMA Publication Warehouse.

2. ***Freight Analysis Framework (FAF 2.2).*** **Freight Management and Operations, Federal Highway Administration (FHWA), U.S. Department of Transportation (USDOT).**

Website: ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm

The FAF "is basically a commodity origin-destination database whose latest version 2.2 covers the period 2002-2035. FAF estimates commodity flows and related freight transportation activity among states, sub-state regions, and major international gateways. It also forecasts future flows among regions and relates those flows to the transportation network. FAF includes an origin-destination database of commodity flows among regions, and a road network database in which flows are converted to truck payloads and related to specific routes."

The FAF includes "tons and value of commodity movements among regions by mode of transportation (truck, rail, water, air, truck-rail, and pipeline) and type of commodity. The FHWA bases provisional estimates for goods movement in the most recent calendar year (2006) on the 2002 base year database. It is built entirely from public data sources including the 2002 Commodity Flow Survey (CFS), developed by the Census Bureau, U.S. Department of Commerce, and the Bureau of Transportation Statistics (BTS), U.S. Department of Transportation; Foreign Waterborne Cargo data, developed by the U.S. Army Corps of Engineers; and a host of other sources. FAF statistics do not match those in mode-specific publications primarily due to different definitions that were used to avoid double counting. Methods in developing the 2002 base year data are transparent, and FAF has been expanded to cover all modes and significant sources of shipments. Future projected data covering years from 2010 to 2035 with a five-year interval are based on *Global Insight*'s proprietary economic and freight modeling packages." The FAF itself or subsequent reports, summaries, and maps can be downloaded from the website in MS Access format and in Microsoft Excel comma delimited (comma-separated value [CSV]) format for use with programming software. Associated geographical files are also available but require use with GIS desktop products, either by ESRI or TransCad. As in the CFS, SCTG numbers are used with hazardous materials included in select SCTG classes.

The FAF estimates commodity movements by truck and the volume of long-distance trucks over specific highways. Models are used to disaggregate interregional flows from the commodity origin-destination database into flows among individual counties and assign the detailed flows (truck traffic) to individual highways. These models are based on geographic distributions of economic activity rather than a detailed understanding of local conditions. While providing reasonable estimates for national and multi-state corridor analyses, FAF estimates are not a substitute for local data to support local planning and project development.

3. ***National Transportation Atlas Database (NTAD).*** **Bureau of Transportation Statistics (BTS), Research and Innovative Technology Administration (RITA), U.S. Department of Transportation (USDOT).**

Website: www.bts.gov/publications/national_transportation_atlas_database/2007/

NTAD "is a set of nationwide geographic databases of transportation facilities, transportation networks, and associated infrastructure. These datasets include spatial information for

transportation modal networks and intermodal terminals, as well as the related attribute information for these features, e.g. rail and road networks. A desktop Geographic Information System is required for using NTAD. The data can be ordered in the form of two CD-ROMs or directly downloaded from the website to support research, analysis, and decision-making across all modes of transportation. They are most useful at the national level, but have major applications at regional, state, and local scales throughout the transportation community."
HAZMAT routes and road segments from the HPMS are two of the layers in NTAD. Individual road segments can be selected graphically by county code and highway number, for example. However, only selected attributes of road segments are present in the NTAD GIS tables. Truck route designation (or not) of a segment is present, but the percent of trucks is not. The HPMS data file (or FAF network file) will have to be consulted directly on the latter for each segment selected graphically. Traffic data on rail routes or waterways are even poorer.
An advantage of NTAD is that it includes intermodal terminal locations, e.g., an airport would be an air and truck intermodal terminal. The majority of spill and release incidents occur in transfer, and it may be of help in a community trying to locate those. NTAD allows professional maps of the study area and corridors to be produced in order to visually aid the conduct of a local/regional CFS. An alternative to NTAD would be Google maps or state-provided maps.

4. ***Incident Reports Database.*** **Office of Hazardous Materials Safety (OHMS), Pipeline and Hazardous Materials Administration (PHMSA), U.S. Department of Transportation (USDOT).**

Website: www.phmsa.dot.gov/hazmat/library/data-stats/incidents

Website: https://hazmatonline.phmsa.dot.gov/IncidentReportsSearch/

The PHMSA Office of Hazardous Materials Safety maintains the Hazardous Materials Incident Reporting System (HMIRS). It is the most detailed, comprehensive source for reported hazardous materials incidents on all modes excluding pipeline. Transportation carriers are required to report HAZMAT-related accidents to the National Response Center. Deep sea vessel incidents are included, but not inland waterway incidents. Incidents are defined as spills or releases of a material classified as hazardous, whether a vehicular accident occurred or not. The OHMS compiles and updates the incident data from incident reports as they are received and makes them publicly available via an online user search.

Among reports and summaries, summary statistics are prepared by the OHMS and available for download in pdf format from the website. At the national level, 10-year and annual summaries of incidents are available. The 10-year summaries are of a more aggregate nature, providing number of incidents, injuries, fatalities, and property damage dollar values by HAZMAT type (radioactive materials or waste), incident type (total or serious), year, and mode. The annual summaries are more refined to include number of incidents, injuries, fatalities, and property damage values by mode, state, cause, hazard class, incident type (total or serious), incident result, and transportation phase. At the state level, incident summaries are refined only by mode to provide number of incidents, injuries, fatalities, and property damage values.

Users can use the search tool on PHMSA's HAZMAT incident reports database website and state their individual constraints (after selecting a year) by filling in any fields on the incident reports database search form. These constraints offer the ability for a more customized incident search than the ready-made summaries. Although the search tool user interface does not include county as a constraint, complete datasets for an entire state, for example, can be downloaded to a CSV file and then converted to a spreadsheet or database file such as Microsoft Excel or Access. If a user were to download the entire file for his or her state over the date range desired, he or she could then sort the dataset by county, city, or zip code to identify those incidents that occurred within specific jurisdictional boundaries. Therefore, a more accurate, disaggregate analysis of hazardous material incidents down to the regional or local level necessitates a modest exercise to search and retrieve the desired data directly from the database.

5. ***The National Hazardous Materials Route Registry and Route Maps.* Federal Motor Carrier Safety Administration (FMCSA), U.S. Department of Transportation (USDOT).**

Website: hazmat.fmcsa.dot.gov/nhmrr/index.asp?page=route

Website: hazmat.fmcsa.dot.gov/nhmrr/index.asp?page=maps

Based on the Federal Register route listing, the FMCSA website provides more useful and interactive ways to search and display the latest information on one or more hazardous material route designations. A mapping application also displays the hazardous material route(s) that should be traveled after the origin and destination addresses are entered.

6. ***Highway Performance Monitoring System (HPMS).* Office of Highway Policy Information, Federal Highway Administration (FHWA), U.S. Department of Transportation (USDOT).**

Website: www.fhwa.dot.gov/policy/ohpi/hpms/index.cfm

The HPMS is "a national level highway information system that includes a wide array of data on the extent, condition, performance, use, and operating characteristics of the nation's highways. The major purpose of the HPMS is to support a data-driven decision process within FHWA, the DOT, and the Congress for legislative and funding purposes. HPMS is a nationally unique source of highway system information that is made available to the transportation community for highway and transportation planning and other purposes through the annual *Highway Statistics* and other data dissemination media."

The latest annual edition of HPMS at the time of this writing is 2006. The file can usually be obtained by regions and localities by contacting the local office of the state DOT. Segment attributes of interest include truck route designation, and the percent of daily or peak-hour traffic that are combination trucks. An in-house exercise of considerable expertise and resources will have to be conducted by the region or locality to extract the segment data of need from the larger database, if a custom-made dataset is not readily provided by the local state DOT office. A more user-friendly alternative is the HPMS Map Viewer in the above link that enables selection of truck routes to the traffic-network level showing truck routes and overall traffic volumes (not truck specific). The viewer also displays population demographic information.

7. ***Carload Waybill Sample*. Surface Transportation Board (STB), U.S. Department of Transportation (USDOT).**

Website: http://www.stb.dot.gov/stb/industry/econ_waybill.html

The STB's Carload Waybill Sample "is a stratified sample of carload waybills for terminated shipments by railroad carriers. These waybill data are used to create a movement specific Confidential Waybill File and a less detailed Public Use Waybill File. The elements and the file structure for both the Confidential File and the Public Use File are described in the user guide, which is available for download from the website, as is the Public Use File."

The sample "includes waybill information from Class I, Class II, and some of the Class III railroads. The STB requires that these railroads submit waybill samples if, in any of the three preceding years, they terminated on their lines at least 4,500 revenue carloads. The Waybill Sample currently encompasses over 99 percent of all U.S. rail traffic. It is a continuous sample that is released in yearly segments. For the past several years, it has contained information on approximately 600,000 movements."

Data from the Master Waybill Sample File "are used as input to many STB projects, analyses, and studies. Federal agencies (Department of Transportation, Department of Agriculture, etc) use the Waybill Sample as part of their information base. The Waybill Sample is also used by States as a major source of information for developing state transportation plans. In addition, non-government groups seek access to waybill sample data for such uses as market surveys, development of verified statements in STB and State formal proceedings, forecast of rail equipment requirements, economic analysis and forecasts, academic research, etc."
The Master Waybill File "contains sensitive shipping and revenue information, so access is restricted to: railroads; Federal agencies; the States; transportation practitioners, consultants and law firms with formal proceedings before the STB or State Boards; and certain other users. Anyone can access the non-confidential data in the Public Use File by downloading it from the website or sending a written request to STB."

The Public Use File only provides an indication of the presence of a hazardous commodity in the car is hazardous via an "H" designation in the "Hazardous/Bulk Material in Boxcar" field, and the five-digit STCC of the commodity, that would only indicate the hazard class and division (at best). STCC codes at the seven-digit level that would identify the chemical name of the hazardous material are not provided in the Public Use File. The Confidential Waybill File, however, does provide the STCC HAZMAT code at the seven-digit level as well as the 49xxxxx series railroad code specifically for hazardous commodities in the "Hazardous/Bulk Material in Boxcar" field. In addition, the public file indicates only the origin and termination business economic area (BEA), whereas the confidential file disaggregates origins and terminations to the metropolitan statistical area (MSA) or county level, which is more appropriate for local use. Depending on the resources available for conducting a CFS and the level of detail a community desires in it, the community may decide to go into the legal and technical trouble of obtaining and analyzing the Confidential Waybill File. However, it would probably be more resource efficient to simply request commodity flow information on the top ten hazardous materials transported through the area from the operating railroad(s).

8. ***Rail Safety Data.*** **Office of Safety Analysis, Federal Railroad Administration (FRA).**

Website: safetydata.fra.dot.gov/officeofsafety/Default.asp

The FRA Office of Safety Analysis website "makes railroad safety information readily available to a broad constituency, including FRA personnel, railroad companies, research and planning organizations and the general public. Visitors have access to railroad safety information including accidents and incidents, inspections and highway-rail crossing data. From this site users can run dynamic queries, download a variety of safety database files, publications and forms, and view current statistical information on railroad safety. Dynamic queries dating back to 1978 can be run for accident/incident data for individual railroads, by railroad group, by region, state, or county, and for any multiannual, annual, multi-monthly, or monthly time frame." An online report that contains the number of cars that released hazardous materials and the number of cars that released hazardous materials as a result of damage or derailment is created and displayed. Additional queries offer further constraints, such as accident cause, type, damage, or the "HazMat option." Constraints under the "HazMat option" include cars carrying hazardous materials, cars carrying hazardous materials that were damaged, cars that released hazardous materials, or if evacuation occurred.

The geographic detail lends itself to use in a regional/local CFS since it goes down to the county and railroad line levels. However, the FRA accident/incident data do not contain any information on the quantities, classes, or chemical names of the hazardous materials released. The PHMSA HMIRS database remains a more detailed source for hazardous material incident data.

9. ***United States Census 2000.*** **U.S. Census Bureau, U.S. Department of Commerce (DOC).**

Website: www.census.gov/

The U.S. Census Bureau collects, compiles, analyzes, and makes publicly available national data through the Population & Housing Census (every 10 years); the Economic Census (every five years), the American Community Survey (annually), several other surveys (both demographic and economic), and economic measures (each released on a specific schedule). The topics range from data on people and households (housing, income, poverty, etc.) to data on business and industry (trade, employment, economic measures). The output format ranges from on-screen data and map output to geographic data, i.e., GIS maps (shapefiles) that are already prepared or custom made. The data can be queried at the state, county, or census tract level via a simple zip code entry. The most recent U.S. Census was in 2000; the 2010 Census is underway. The GIS-based maps would require a desktop GIS but are an invaluable tool for hotspot analyses. Overall, the Census Bureau website is a valuable source of data, especially in creating a community's profile for inclusion in the CFS document and overall support of local CFS efforts.

II. ELECTRONIC REPORT SOURCES

1. ***United States: 2002 Economic Census, Transportation, 2002 Commodity Flow Survey*. Report EC02TCF-US. Bureau of Transportation Statistics (BTS), U.S. Department of Transportation (USDOT), and Economics and Statistics Administration, U.S. Census Bureau, U.S. Department of Commerce, December 2004.**

Website: www.census.gov/svsd/www/cfsdat/2002cfs.html

The latest (2002) CFS is a primary data source in the world of freight transportation. Conducted every five years, the industry sectors surveyed include manufacturing, mining, wholesale, and select retail. Individual state CFS sections report on all commodities originating or terminating in each state, major metropolitan areas, and census regions. Shipment value, tons, and ton-miles originating are reported by mode, distance, and weight of shipment; by two-digit commodity code (SCTG) and by mode; and by state of destination.

2. ***National Freight Transportation Statistics and Maps.* Freight Management and Operations, Federal Highway Administration (FHWA), U.S. Department of Transportation (USDOT).**

Website: www.ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/nat_stat.htm

This webpage contains several freight-transportation-related links, including a link to the FAF, several FAF by-products, and external sites such as BTS.

Freight Facts and Figures is an annual publication that culminates from the FAF data and projections, as they are updated annually. Individual sections can be viewed online (html), or the file can be downloaded in its entirety in Adobe Acrobat format. It consists of tables and figures in the form of charts or maps. This publication is a "snapshot of the volume and value of freight flows in the United States, the physical network over which freight moves, the economic conditions that generate freight movements, the industry that carries freight, and the safety, energy, and environmental implications of freight transportation. This snapshot helps decision makers, planners, and the public understand the magnitude and importance of freight transportation in the economy. Chapter 1 summarizes basic demographic and economic characteristics of the United States that contribute to the demand for raw materials, intermediate goods, and finished products. Chapter 2 identifies the freight that is moved and the trading partners who move it. Chapter 3 describes the freight transportation system; volumes of freight moving over the system; the amount of truck, train, and other activities required to move the freight; and the performance of the system. Chapter 4 highlights the transportation industry that operates the system. Chapter 5 covers the safety aspects, energy consumption, and environmental implications of freight transportation. Many of the tables and figures are based on the Economic Census, which is conducted once every five years. The most recently published data from the Economic Census are for 2002. Several of the tables and maps in this report are based on the Freight Analysis Framework (FAF), version 2.2, which builds on the Economic Census, to estimate all freight flows to, from, and within the United States except shipments between foreign countries that are transported through the United States."

The National Freight Transportation Maps in *Freight Facts and Figures* are also made available independently on the main webpage for download in html, jpg, or pdf format. *Freight Facts and Figures* is primarily applicable to the national and sometimes regional levels. However, the main webpage provides links to freight profiles (statistics and maps) of individual states. FAF-based statistics are output directly in html or pdf format, whereas external information links the user to other FHWA offices such as the Bureau of Transportation Statistics, Bureau of the Census, or state-specific websites, such as DOTs. Additional links also provide access to other internal or external freight-transportation-related publications and resources, including links to the source of the freight statistics and maps, for example the FAF (FHWA), CFS (BTS), and Carload Waybill Sample (STB).

3. ***Freight Data and Statistics.* Bureau of Transportation Statistics (BTS), Research and Innovative Technology Administration (RITA), U.S. Department of Transportation (USDOT).**

Website: www.bts.gov/programs/freight_transportation/

The BTS website provides several publicly available reports for download. They are developed based on individual data sources or databases already discussed and are primarily based on the latest Commodity Flow Survey (2002). However, users may find access to the same freight data through the BTS portal to be more concise, concentrated, structured, and user friendly.

4. ***Crash Statistics.* Analysis & Information Online (A&I), Federal Motor Carrier Safety Administration (FMCSA), U.S. Department of Transportation (USDOT).**

Website: ai.fmcsa.dot.gov/CrashProfile/CrashProfileMainNew.asp

Crash Statistics data "are summarized crash statistics for large trucks and buses involved in fatal and non-fatal crashes that occurred in the United States. They are derived from two databases: the Fatality Analysis Reporting System (FARS) and the Motor Carrier Management Information System (MCMIS). They are compiled through SAFETYNET, a database management system that allows entry, access, analysis, and reporting of data from driver/vehicle inspections, crashes, compliance reviews, assignments, and complaints that have been entered online by state agencies."

Access to the actual data "is restricted to authorized users e.g. state and federal government agencies. However, compilations of *Crash Statistics* data are made publicly available online. They contain information that can be used to identify safety problems in specific geographical areas or to compare state statistics to the national crash figures. The statistics are represented in state profile summaries in the following focus areas: Summary, Vehicle, Driver, Environment, Crash, Carrier, and Maps. Historical state profiles are provided for the most recent five years and feature dynamic colorful state maps highlighting the large truck crash location data. National Crash Profile Reports (and maps) are also available online."

The "Vehicle" area of the state profiles includes a hazardous materials report that summarizes crashes by presence or absence of a hazardous material placard on the truck, by whether a release occurred or not, and by hazardous material class (if released). The state profile summaries include total number of large trucks involved in crashes in the last five years, by county. Generally, though, the lowest level of geographic detail is the state level, and the lowest level of commodity release detail is the class of hazardous material as opposed to chemical name, both of which may limit support for route/local/regional analyses and emergency response plans. The PHMSA HMIRS database remains the most detailed source for hazardous material incident data.

5. ***National Transportation Statistics.*** **Bureau of Transportation Statistics (BTS), Research and Innovative Technology Administration (RITA), U.S. Department of Transportation (USDOT).**

Website: http://www.bts.gov/publications/national_transportation_statistics/index.html

Most rail methodologies rely on fuel consumption data to determine emissions. Detailed fuel consumption data are typically considered sensitive information by railroads. However, nationwide aggregate fuel consumption data, which are based on 100 percent reporting for Class I railroads, are available from industry or government agencies (i.e., U.S. Department of Transportation, Association of American Railroads, Energy Information Administration, state agencies, private companies via surveys). When fuel consumption data are not available for the region of interest, they must be estimated either by apportioning fuel consumption from a larger geographic area ("top-down") or by aggregating fuel consumption from individual rail movements ("bottom-up"). Both methods require measurements of rail activity. National Transportation Statistics can provide national-level data on both rail fuel use and revenue ton-miles.

APPENDIX B: FREIGHT TRUCK AGE DISTRIBUTION

Table B-1. Heavy-Duty Truck Fleet Age Distribution (Source: EPA—MOVES Default Values).

Model Year	Age	Percentage
2007	0	7.34%
2006	1	7.81%
2005	2	7.73%
2004	3	6.84%
2003	4	5.17%
2002	5	4.86%
2001	6	5.17%
2000	7	7.59%
1999	8	9.10%
1998	9	7.04%
1997	10	5.79%
1996	11	5.56%
1995	12	5.55%
1994	13	3.65%
1993	14	2.83%
1992	15	1.72%
1991	16	1.25%
1990	17	1.25%
1989	18	1.23%
1988	19	1.07%
1987	20	0.28%
1986	21	0.30%
1985	22	0.38%
1984	23	0.20%
1983	24	0.04%
1982	25	0.03%
1981	26	0.10%
1980	27	0.03%
1979	28	0.03%
1978	29	0.02%
1977	30	0.03%
Total		**100.00%**

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