



DEMAND

**Freight Transportation Demand:
Energy-Efficient Scenarios for a
Low-Carbon Future**

TRANSPORTATION ENERGY FUTURES SERIES:
Freight Transportation Demand:
Energy-Efficient Scenarios for a Low-Carbon Future

A Study Sponsored by
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Prepared by
CAMBRIDGE SYSTEMATICS
Cambridge, MA 02140
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Technical monitoring performed by
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Golden, Colorado 80401-3305
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ABOUT THE TRANSPORTATION ENERGY FUTURES PROJECT

This is one of a series of reports produced as a result of the Transportation Energy Futures (TEF) project, a U.S. Department of Energy (DOE)-sponsored multi-agency project initiated to identify underexplored strategies for abating greenhouse gases (GHG) and reducing petroleum dependence related to transportation. The project was designed to consolidate existing transportation energy knowledge, advance analytic capacity-building, and uncover opportunities for sound strategic action.

Transportation currently accounts for 71% of total U.S. petroleum use and 33% of the nation's total carbon emissions. The TEF project explores how combining multiple strategies could reduce GHG emissions and petroleum use by 80%. Researchers examined four key areas – light-duty vehicles, non-light-duty vehicles, fuels, and transportation demand – in the context of the marketplace, consumer behavior, industry capabilities, technology and the energy and transportation infrastructure. The TEF reports support DOE long-term planning. The reports provide analysis to inform decisions about transportation energy research investments, as well as the role of advanced transportation energy technologies and systems in the development of new physical, strategic, and policy alternatives.

In addition to the DOE and its Office of Energy Efficiency and Renewable Energy, TEF benefitted from the collaboration of experts from the National Renewable Energy Laboratory and Argonne National Laboratory, along with steering committee members from the Environmental Protection Agency, the Department of Transportation, academic institutions and industry associations. More detail on the project, as well as the full series of reports, can be found at <http://www.eere.energy.gov/analysis/transportationenergyfutures>.

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REPORT CONTRIBUTORS AND ROLES

National Renewable Energy Laboratory

Austin Brown Co-lead

Laura Vimmerstedt Co-lead

Argonne National Laboratory

Anant D. Vyas Co-lead and contributing author

Cambridge Systematics

Lance R. Grenzeback Primary author

Michael J. Fischer Contributing author

Nathan Hutson Contributing author

Yi Lin Pei Contributing author

Christopher R. Lamm Contributing author

Energy & Environmental Research Associates

Dr. James J. Winebrake Contributing author

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Dr. Gerard McCullough, Associate Professor, Department of Applied Economics, University of Minnesota

Dr. Thomas O'Brien, Director of Research, Center for International Trade and Transportation, California State University, Long Beach

Art Rypinski, Economist, Office of the Secretary, U.S. Department of Transportation

Dr. Frank Southworth, Principal Research Scientist, Civil and Environmental Engineering, Georgia Institute of Technology

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ACRONYMS

BEA	Bureau of Economic Analysis
BMI	Business Market Insights
BTM	Business Transaction Matrix
CFS	Commodity Flow Survey
CO ₂	carbon dioxide
EPA	U.S. Environmental Protection Agency
FAF	Freight Analysis Framework
FHWA	Federal Highway Administration
GDP	gross domestic product
GHG	greenhouse gas
GVW	gross vehicle weight
IO	Input-Output
IP	intellectual property
LCFS	low-carbon fuel standards
NAICS	North American Industry Classification System
NREL	National Renewable Energy Laboratory
RFID	radio-frequency identification
RUBMZIO	Random-Utility-Based Multi-Zonal Input-Output Model
SCTG	Standard Classification of Transported Goods
TEF	Transportation Energy Futures
TRB	Transportation Research Board
U.S. DOT	U.S. Department of Transportation
VDOT	Virginia Department of Transportation
VMT	vehicle miles traveled

EXECUTIVE SUMMARY

30 Billion Tons of Freight by 2050

Freight transportation demand is projected to grow to 27.5 billion tons in 2040, and by extrapolation, to nearly 30.2 billion tons in 2050, requiring ever-greater amounts of energy. This report describes the current and future demand for freight transportation in terms of tons and ton-miles of commodities moved by truck, rail, water, pipeline, and air freight carriers. It outlines the economic, logistics, transportation, and policy and regulatory factors that shape freight demand; the possible trends and 2050 outlook for these factors, and their anticipated effect on freight demand and related energy use. The report draws upon a variety of sources, including published literature and unpublished perspectives based on authors' expertise. After describing federal policy actions that could influence freight demand, the report then summarizes the available analytical models for forecasting freight demand, and identifies possible areas for future action. This is not intended to propose or promote particular policy actions.

The U.S. Department of Transportation (U.S. DOT) Federal Highway Administration (FHWA) Freight Analysis Framework (FAF) estimates that 18.3 billion tons of goods were moved in the United States in 2007, generating 5.4 trillion ton-miles of travel (U.S. DOT FHWA Undated). Trucks moved about 72% of all freight tonnage, accounting for 42% of all ton-miles. Rail accounted for 11% of tons moved, but 28% of ton-miles. Domestic waterborne and air freight transportation shares were considerably smaller.¹

While all modes of domestic freight transportation are expected to experience significant growth in the coming decades, trucking's share – when measured in tons and ton-miles – is projected to continue to grow at the expense of rail and waterborne freight. This reflects changes in the U.S. economy that are anticipated to favor the production and shipment of higher-value-added and time-sensitive goods, as well as an established preference among many freight shippers for using trucks to move such goods. Even as freight needs grow, more accurate demand forecasting, paired with effective policymaking, can help minimize this sector's energy consumption and emissions. As shown in Table ES.1, increasing heavy-duty engine efficiency and emission standards and imposing low-carbon fuel standards were identified as the policy options with the greatest probability of implementation and the highest potential for energy use and GHG emissions reduction. The assessments are based on available data, historic trends, and the authors' professional insights on this industry.

Table ES.1. Key Findings: Opportunity Matrix for Freight Transportation Energy Use and Greenhouse Gas Emissions Initiatives

		Potential Reduction in Freight Transportation Energy Use and GHG Emissions		
		Low	Moderate	High
Probability of Implementation	High			Increase heavy-duty engine efficiency and emission standards.
	Moderate		Increase investment in freight infrastructure. Increase federal motor fuel tax. Implement road pricing (vehicle-miles-traveled user fees).	Impose low-carbon fuel standards.
	Low	Provide tax incentives for co-location of freight generators and terminals. Deregulate U.S. coastal shipping.	Restructure U.S. trade policies to promote in- and near-sourcing.	

¹ The FAF demand projections are described further in Section 2.

Influential Factors and Policies

The factors expected to have the most influence on freight demand between now and 2050 are:

Economic Factors

- Population and income
- Economic growth rate (Gross Domestic Product)
- Trade volume and partners
- Urbanization and mega-region concentration.

Logistics Factors

- Supply chain restructuring.

Transportation Factors

- Petroleum fuel availability and cost.

Policy and Regulatory Factors

- Truck engine efficiency and greenhouse gas (GHG) emissions standards
- Federal funding for freight infrastructure.

A range of federal policy actions could influence freight transportation demand. They include:

- Increasing heavy-duty engine efficiency and emission standards
- Imposing low-carbon fuel standards
- Increasing investment in freight infrastructure
- Increasing federal motor fuel tax
- Implementing road pricing (vehicle miles traveled user fees)
- Restructuring U.S. trade policies to promote in- and near-sourcing
- Providing tax incentives for the co-location of freight generators and terminals
- Deregulating U.S. coastal shipping.

The first half of this report takes a closer look at how these demand factors, trends and policies have been assessed using the existing knowledge base.

Selecting the Most Effective Models

A half-dozen types of analytical models can be used to project and assess the potential impact of these policy actions on freight transportation demand. They include:

- *Macroeconomic/Commodity Models*, which estimate current and future freight traffic by linking economic activity to freight flows
- *Time Series Models*, which extrapolate future demand based on historical freight volumes
- *Behavioral Models*, which include both choice- and survey-based demand models, and capture how shippers select modes
- *Demand/Supply Equilibrium Models*, which estimate freight demand based on balancing demand against supply of transportation services that have acceptable characteristics
- *Microsimulation and Agent-Based Models*, which simulate large numbers of individual freight shipments and sum them to produce total freight flow estimates
- *Supply Chain and Logistics Models*, which are intended to capture the relationship between suppliers and customers, as well as the decisions made by participants in the supply chain that affect freight demand.

The second half of this report explores how these models might be applied to expand understanding of future freight transportation demand. None of the available demand models addresses all the factors that shape freight transportation demand. Macroeconomic input/output models and behavioral (price elasticity of demand models)—coupled with national-level freight flow assignment network models—can provide direct estimates of the impacts of key factors—such as population, economic activity, and trade patterns, on tons and ton-miles of freight demand—which can then be translated into fuel use and GHG emissions estimates. While most of the other models also address population, economic activity, and trade patterns, extensive data collection and calibration requirements make them less suited to a first approximation of impacts of national-level changes in freight demand on fuel use and GHG emissions.

Using appropriate models to project freight demand, based on a deep understanding of the diverse set of factors that influence it, can help assess the effects of possible actions to reduce petroleum-based fuels and emissions.

1.0 INTRODUCTION

Freight accounts for about 26% of all petroleum-based fuels consumed in the U.S. transportation sector. This report is designed to help decision makers better understand the factors that shape freight transportation demand and gauge how federal actions might influence demand in ways that change petroleum-based fuel use.

Freight demand is typically estimated using historical trend data and macroeconomic forecasts of industry production and household consumption. These traditional models are limited in their ability to consider the potential impact of shifts in fuel prices and transportation modes. At the same time, energy demand projections often neglect to factor in changes in freight demand, relying primarily on distance and fuel consumption data. This report provides a bridge between the existing methodologies and possible new approaches with an analysis of the current knowledge base, examination of potential policy actions, and recommendations for future analysis.

Existing literature on freight demand tends to view rapid growth in demand as a result of a burgeoning consumer base, the expansion of global trade, and changing logistics patterns. Research reviewed for this report—from agencies including the Transportation Research Board (TRB), U.S. Department of Transportation (U.S. DOT), the American Association of State Highway and Transportation Officials, and the U.S. Army Corps of Engineers—addresses the impact of demographic trends, off-shoring and near-shoring production, supply chain customization, transportation network capacity, and government regulations. Drawing from this literature, the report presents trends with the potential to affect energy use and greenhouse gas (GHG) emissions. These are not intended as predictions, but as explorations of important interactions within the freight sector. The report draws on a range of evidence, including empirically verifiable statements of fact and quantitative findings from published studies, as well as interpretations and judgments. The authors used expert judgment based on the literature to select and describe possible trends.

The report is structured as follows:

- **Freight Transportation Demand.** Section 2 describes how freight transportation demand is measured and summarizes the current and projected demand for freight transportation. The section then discusses four broad groups of key factors that affect freight transportation demand: economic factors, logistics factors, transportation industry factors, and public policy and regulatory factors.
- **Policy Actions.** Section 3 outlines potential federal government policy actions that could influence the demand for freight transportation.
- **Freight Transportation Demand Projection Methods.** Section 4 describes the methods that can be used to estimate the impact of policy actions on freight transportation demand.²
- **Additional Analysis.** Section 5 suggests areas of research and development where additional work could significantly improve understanding and anticipate the effects of trends and policies on freight transportation demand and energy use.
- **A Literature Review** is provided in Appendix A.

This report also provides background for the development of the National Renewable Energy Laboratory (NREL) Freight Energy Analysis Tool. The tool makes it possible to evaluate the transportation energy and GHG impacts of tonnage, location, and mode scenarios at a national level through 2050. Information from the literature reviewed for this report informed the choice of datasets, variables, and analytical

² The section mentions but does not describe in detail the methods available to project changes in mode shares (e.g., the potential to shift freight from truck to rail or water). Those methods are covered elsewhere in the Transportation Energy Futures project.

methods to develop this tool. This tool can be accessed through the NREL Transportation Energy Futures website: http://www.nrel.gov/analysis/transportation_futures.

This report focuses on the structure and dynamics of freight transportation demand. Companion Transportation Energy Futures reports describe other transportation demand issues, including freight modal choice; strategies for trip reduction and efficient driving in personal transportation; and effects of the built environment on transportation demand (Porter, Brown, Dunphy et al. 2013; Porter, Brown, DeFlorio et al. 2013; Brogan et al. 2013).

2.0 FREIGHT TRANSPORTATION DEMAND

This section presents current and historical freight demand, drawing from public data, especially the Federal Highway Administration's (FHWA's) Freight Analysis Framework (FAF). It also summarizes important factors that influence freight demand, drawing from the literature and selected by the authors based on expert judgment. Possible future trends are identified and discussed to illustrate interactions of various factors within the freight sector and how those could influence its development. Trends and projections are not precise predictions; a range of possible future outcomes is possible. The authors also use expert judgment based on the literature to select and describe possible trends.

2.1. Current/Historical Freight Demand

Freight transportation demand is typically measured in tons, ton-miles, and value (dollars) of goods moved by the freight sector.³ The FAF estimates that 18.5 billion tons of goods were moved in the United States in 2007, generating 5.4 trillion ton-miles of travel, and with a value approaching \$16.7 trillion (U.S. DOT FHWA Undated).⁴

The ton, ton-mile, and value data can be broken down by mode, as shown in Figure 2.1 (Cambridge Systematics, Inc. analysis of 2007 FAF3.2 data using the NREL Freight Energy Analysis Tool). In 2007, trucks moved about 72% of all freight tonnage, accounting for 42% of all ton-miles and 70% of freight commodity value.⁵ Rail accounted for only 11% of tons moved, but 28% of ton-miles and 3.5% of total value, reflecting rail's cost effectiveness in hauling heavier, but generally lower-value, commodities, such as coal and grain, over long distances. Excluding international maritime shipments, waterborne transportation accounted for a smaller percentage of tons and ton-miles. Air freight transportation constituted an even smaller share, except when measured by value.

³ A ton of goods moved one mile is counted as one ton-mile. There is some double-counting in the reporting of aggregate national freight transportation statistics because data are compiled by mode, not specific shipment. A ton of goods transported two miles by truck is counted as one ton of freight and two ton-miles of freight movement; however, a ton of goods transported the one mile by truck, then transferred to rail and transported one more mile by rail is counted as two tons of freight (one by truck, one by rail) and two ton-miles of freight movement.

⁴ Unless otherwise noted, the freight demand statistics are based on FAF versions 3.1 and 3.2.

⁵ The FAF captures most Interstate and intercity freight traffic and some but not all local freight traffic. As an example, the FAF will capture and report the shipment of food products by truck from Iowa to the Washington, D.C. metropolitan area, but may not capture all the local truck movements involved in the final delivery of those food products to local supermarkets, restaurants, and neighborhood stores. Overall, the FAF accounts for almost all ton-miles of travel by air, water, and rail, but only about half of all ton-miles of travel by truck because the FAF does not survey or report local truck freight trips. This qualification is important when attempting to estimate freight transportation energy consumption and greenhouse gas emissions by mode based on the FAF data.

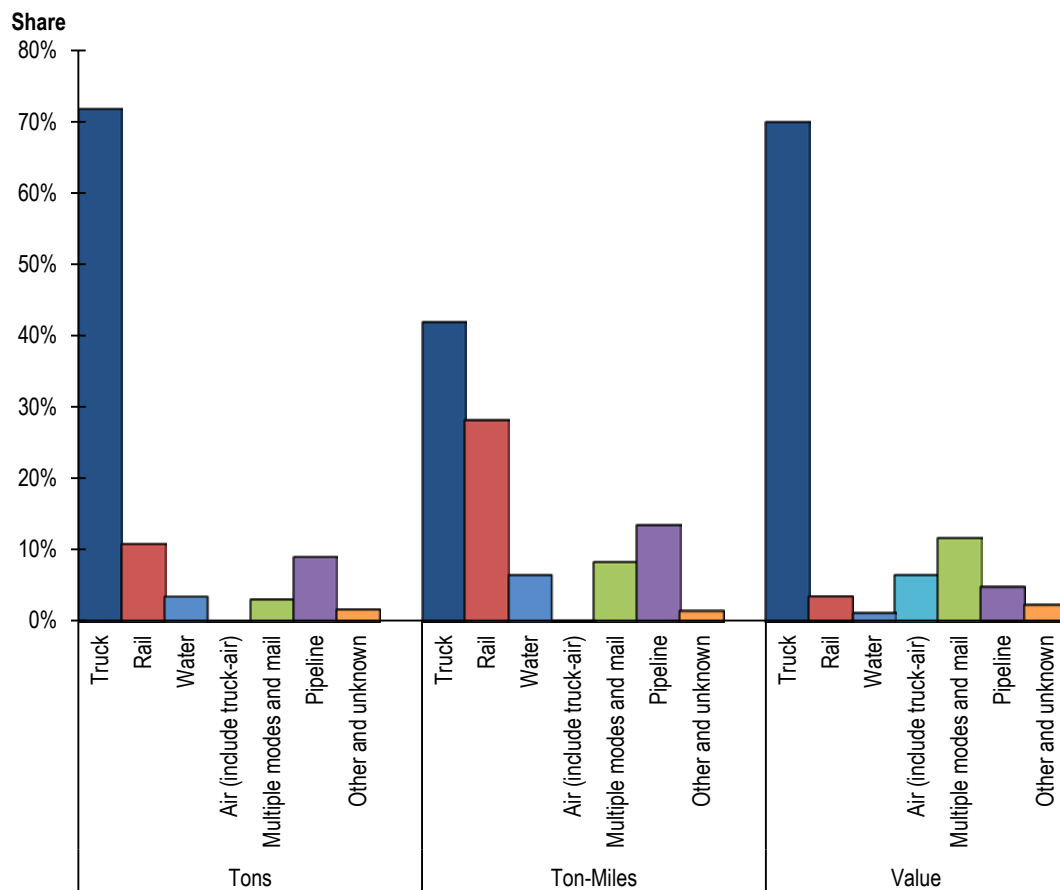


Figure 2.1. Freight transportation demand, 2010

(tons, ton-miles, and value by mode)

(Source: Cambridge Systematics, Inc. analysis of 2007 FAF3.2 data using the NREL Freight Energy Analysis Tool)

Freight demand can also be broken down by commodity. Table 2.1 shows freight tons associated with industries defined by two-digit Standard Classification of Transported Goods (SCTG) commodity codes, the level of disaggregation most commonly used in national-scale freight and policy studies.⁶

⁶ The SCTG is used to classify commodities for the Commodity Flow Survey, a periodic survey of manufacturers and other major freight shippers conducted by the U.S. DOT Bureau of Transportation Statistics and the U.S. Department of Commerce Bureau of the Census. For a description of the SCTG classifications (from two-digit to five-digit levels), see FHWA and U.S. DoC (undated).

Table 2.1. Freight Tonnage and Value by Commodity Type, 2007

SCTG2	SCTG2 Commodity	2007 Tons (Thousands)	2007 Value (Millions Dollars)
01	Live animals/fish	106,851	\$144,883
02	Cereal grains	1,475,408	\$196,227
03	Other agriculture products	436,348	\$267,929
04	Animal feed	270,333	\$96,486
05	Meat/seafood	116,145	\$327,074
06	Milled grain products	136,903	\$159,745
07	Other foodstuffs	539,309	\$553,699
08	Alcoholic beverages	140,872	\$191,629
09	Tobacco products	4,624	\$94,746
10	Building stone	57,469	\$9,795
11	Natural sands	569,898	\$8,015
12	Gravel	2,263,771	\$23,523
13	Nonmetallic minerals	375,185	\$20,747
14	Metallic ores	120,451	\$32,108
15	Coal	1,444,753	\$40,222
16	Crude petroleum	836,581	\$365,905
17	Gasoline	1,005,614	\$688,780
18	Fuel oils	744,791	\$417,475
19	Coal-n.e.c.	1,295,016	\$512,413
20	Basic chemicals	463,156	\$340,388
21	Pharmaceuticals	20,912	\$880,159
22	Fertilizers	230,038	\$59,623
23	Chemical products	148,078	\$403,550
24	Plastics/rubber	224,336	\$578,252
25	Logs	517,410	\$22,180
26	Wood products	416,536	\$231,531
27	Newsprint/paper	162,616	\$134,600
28	Paper articles	105,157	\$142,865
29	Printed products	55,453	\$205,763
30	Textiles/leather	70,178	\$696,089
31	Nonmetal mineral products	1,392,666	\$247,564
32	Base metals	422,247	\$556,705
33	Articles-base metal	205,439	\$572,938
34	Machinery	185,914	\$1,759,415
35	Electronics	78,108	\$1,429,934
36	Motorized vehicles	190,635	\$1,267,189
37	Transport equipment	8,361	\$228,458
38	Precision instruments	7,440	\$386,806
39	Furniture	50,046	\$233,481
40	Miscellaneous manufacturing products	111,720	\$691,728
41	Waste/scrap	1,324,523	\$130,846
43	Mixed freight	342,411	\$1,061,482
99	Unknown	205,034	\$237,649

(Source: Cambridge Systematics, Inc. analysis of 2007 FAF3.2 data using the NREL Freight Energy Analysis Tool)

Freight demand can be further described by length of trip. Figure 2.2 (Cambridge Systematics, Inc. analysis of 2007 FAF3.2 data using the NREL Freight Energy Analysis Tool) shows the distribution of domestic freight ton-miles of travel by distance group for all modes (except pipeline) in 2007. The segments within each column show the relative contribution of each mode to the ton-miles of travel in each distance group. Most shipments moving less than 100 miles and majority of shipments moving less than 500 miles are handled by truck. Rail dominates the longer-haul markets between 500 and 1,500 miles.

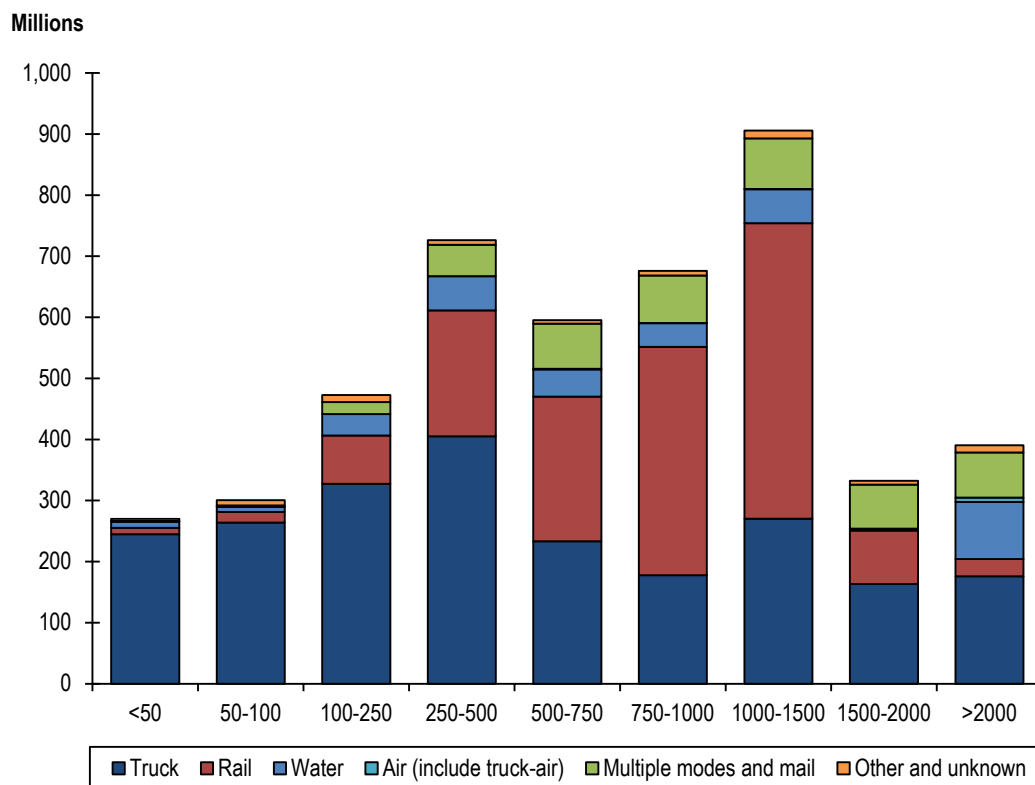


Figure 2.2. Domestic freight ton-miles of travel by distance group, 2007 all modes (except pipeline)

(Source: Cambridge Systematics, Inc. analysis of 2007 FAF3.2 data using the NREL Freight Energy Analysis Tool)

Finally, freight demand can be mapped as freight flows. Figure 2.3 shows estimated truck freight flows measured in daily truck traffic in 2007 [FAF version 3.1 (FHWA 2010b)]. (Wider bandwidth lines indicate greater flows.)

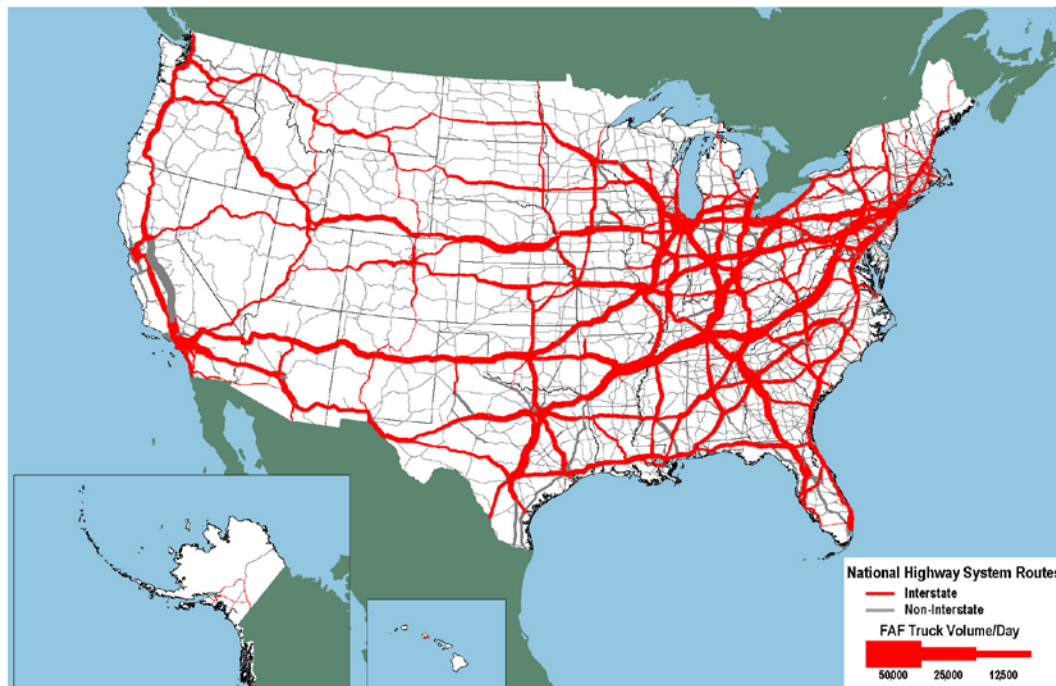


Figure 2.3. Freight truck traffic on the National Highway System, all commodities, 2007

[Source: FAF version 3.1. FHWA (2010b)]

Freight flows can be further broken down by commodity type (e.g., chemicals, auto parts), by origin and destination (typically economic region, county, or major port), and by mode. As an example, Figure 2.4 maps the flows of lumber, wood, and paper products moving by rail through Portland, Oregon (Oregon Department of Transportation 2003).

The information about freight transportation demand can be paired with information about fuel sales to estimate fuel consumption by mode, as shown in Figure 2.5 (TRB 2011b). The data show that freight transportation accounts for about 26% of all petroleum-based fuels (gasoline, diesel, etc.) consumed in the transportation sector, which itself is 97% dependent on petroleum-based fuels.

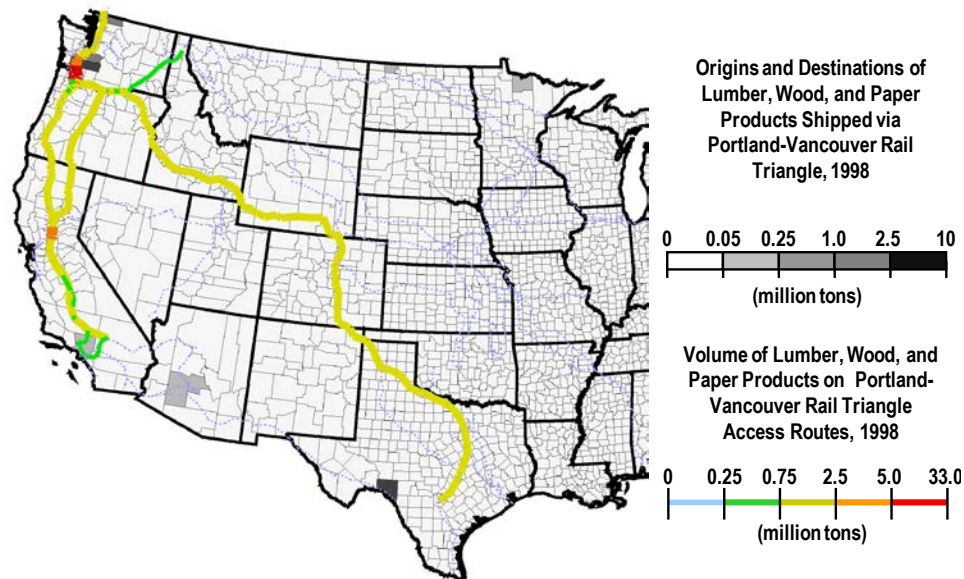


Figure 2.4. Lumber, wood, and paper products flows

(Oregon Department of Transportation 2003)

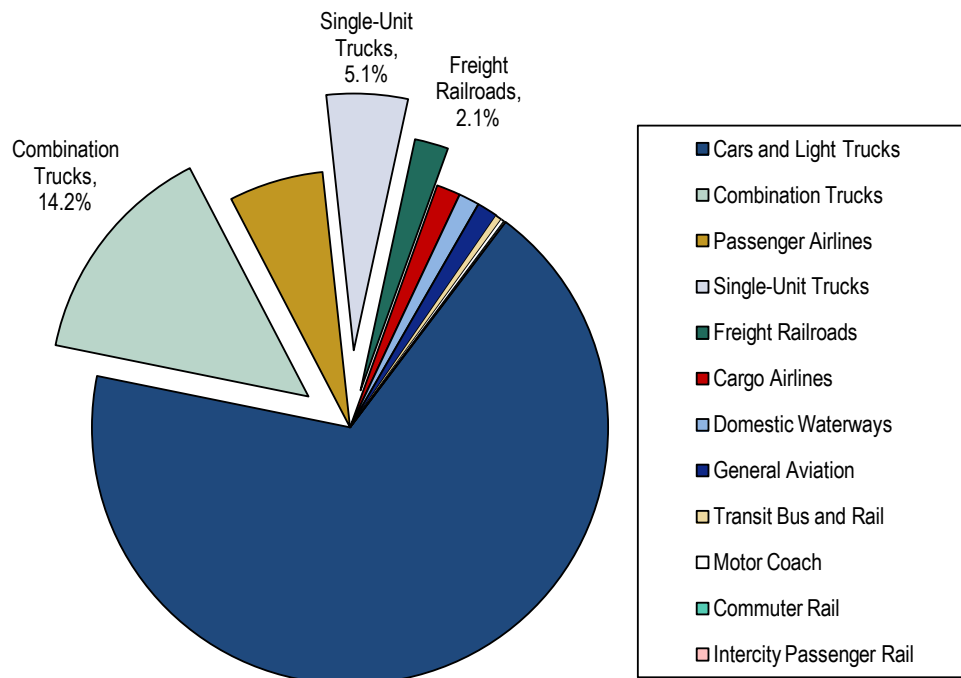


Figure 2.5. Petroleum fuel consumption by U.S. domestic transportation mode

[Source: (TRB 2011b)]

Note: The total represents consumed gallons of gasoline, diesel, and jet fuel, irrespective of energy density. Mode totals were calculated through various government and industry sources for the most recent year in the period covered. Fuel used by pipelines, international aviation, and international maritime are excluded.

Freight transportation demand is projected to grow from 18.9 billion tons in 2007 to 27.5 billion tons in 2040, and by extrapolation, to nearly 30.2 billion tons in 2050.⁷ The FAF projections are based on macro-economic projections of production, consumption and trade by industry sector and reflect post-recession expectations about domestic and global economic growth rates. The freight projections are demand driven; they are not constrained by transportation capacity or supply. They assume that if demand grows for a commodity that is shipped by truck today, then the additional tonnage will also be shipped by truck. This is a conservative approach to freight demand forecasting that allows analysts to apply different assumptions about how the future supply and pricing of freight transportation services might shift freight shares among the modes.

Demand-drive forecasts are used as a starting point for freight transportation policy studies because, as a general rule, freight transportation is primarily a derived demand. Growth in freight transportation demand tracks the projected growth in population and economic activity. More people and more economic activity translate almost directly into increased demand for food, clothing, housing, energy, as well as manufactured goods, and the subsequent transportation of these goods to consumers. Improvements in transportation technologies and changes in the relative quality and pricing of truck, rail and other modal services can affect overall demand, but these effects are typically second order and redistributive.

The projected mode shares in 2040 are shown in Figure 2.6 (Cambridge Systematics, Inc. analysis of 2007 FAF3.2 data using the NREL Freight Energy Analysis Tool). While all modes of transportation will experience significant growth in this scenario, trucking's share of freight transportation – when measured in tons and ton-miles – is projected to continue to grow at the expense of rail and waterborne freight, reflecting anticipated structural changes in the U.S. economy that favor the production and shipment of higher-value-added and more time-sensitive goods and a preference for using trucks to move such goods.

If these projections are realized, the trucking industry as a whole (heavy-, medium- and light-duty trucks) could experience increases in fuel consumption ranging from 11% to nearly 30% between 2009 and 2030, depending on assumptions made about the rate of improvement in truck engine fuel efficiency.⁸ Changes in truck fuel efficiency will increase or decrease overall demand. Deteriorating fuel efficiency that drives up the cost of trucking services will tend to dampen demand and shift freight to other modes. Conversely, improving fuel efficiency that reduces the cost of truck services will tend to increase overall demand. Both trends will also be greatly influenced by consumer preferences for service and shippers' and freight carriers' strategies for managing total logistics costs through redesign and relocation of supply chains and distribution networks. The fuel and emissions impacts of the projected demand and modal shares will also be affected by shippers' and carriers' approaches to minimizing their corporate carbon emissions in response to consumer preferences and market competition. The FAF projections do not explicitly account for these evolving shifts in business and consumer behavior.

As will be discussed further in Section 4, which deals with freight demand projection methods, national freight demand is typically estimated using historical trend data and macroeconomic forecasts of industry sector production and household consumption. These models have limited capability to consider the effect of substantial shifts in fuel prices and transportation mode selection. As noted, if a commodity is shipped by truck today, freight demand models assume that the commodity will continue to be shipped by truck in the future regardless of changes in fuel prices and fuel types. Conversely, the national energy demand projections have limited capability to consider the effects of changes in freight demand, relying primarily

⁷ The FAF provides projections to 2040. We extrapolated the FAF projections to 2050 for the NREL Freight Energy Analysis Tool.

⁸ The recently published Transportation Research Board Special Report 307 (TRB 2011b) projects increases in the range of 11% if engine efficiencies are improved significantly. The Energy Information Administration's *Annual Energy Outlook 2009* and *Annual Energy Outlook 2010* reports project increases in the range of 30% or more with limited improvements to engine fuel efficiencies (U.S. EIA 2009, 2010).

on historical trend data and projections of truck-miles of travel and engine fuel consumption rates (gallons per ton-mile). These shortcomings are well recognized, but have not yet been addressed.

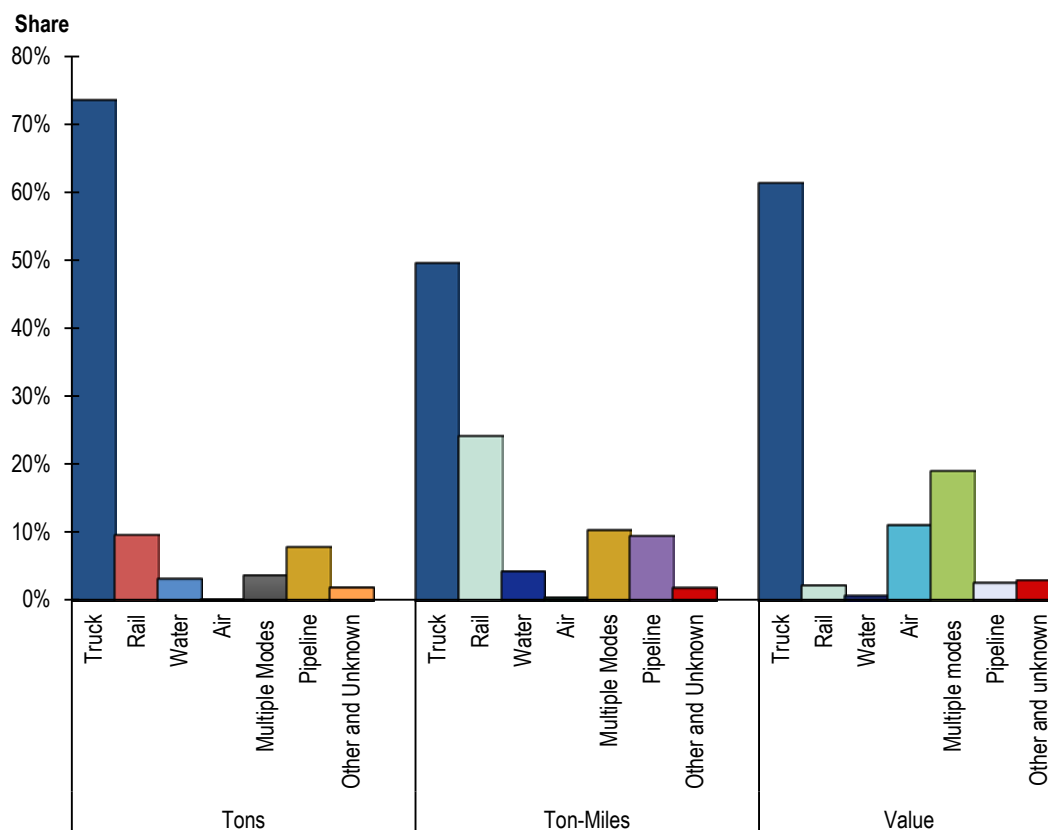


Figure 2.6. Freight transportation demand, 2040

(tons, value, and ton-miles by mode)

(Source: Cambridge Systematics, Inc. analysis of 2007 FAF3.2 data using the NREL Freight Energy Analysis Tool)

2.1.1. Breakdown of Operating Costs

Figure 2.7 shows the marginal cost per mile of operating a truck in early 2010 (American Transportation Research Institution 2011). Figure 2.8 shows the industry-wide estimate of railroad operating costs in early 2012 (Association of American Railroads 2012a).⁹ The data are not directly comparable because of the differences in the dates and the underlying accounting and reporting procedures. However, the data provide a general indication of the relative importance of fuel costs in the operation of truck and rail services.

⁹ The category “Other” includes purchased services, portions of administrative expenses and property taxes.

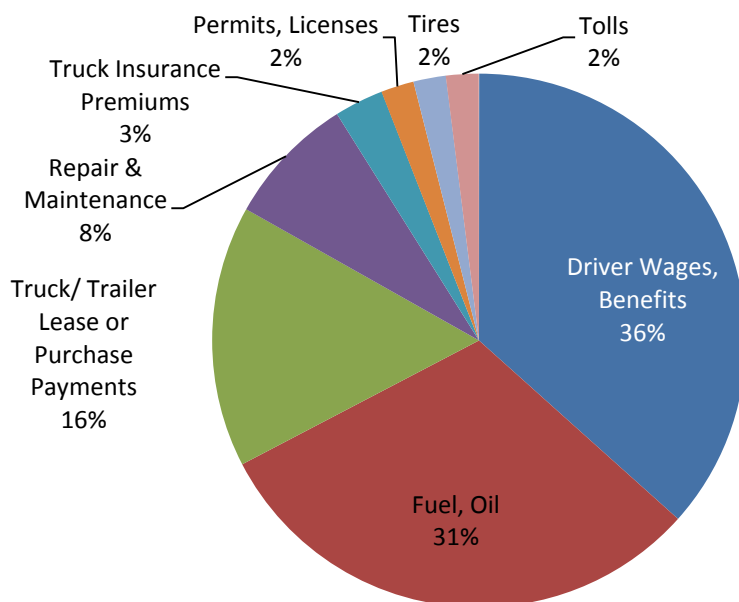


Figure 2.7. Trucking marginal operating costs per mile, Q1 2010

(Source: American Transportation Research Institution 2011)

For trucking, fuel costs in early 2010 accounted for 31% of marginal operating costs per mile, driver labor costs for 36%. These proportions have varied considerably in recent years, with fuel accounting for 38% in 2008 and 28% in 2009. The cost and volatility of fuel prices in the past decade as well as increasing interest by shippers in decreasing fuel costs and carbon emissions from goods movement have been major factors pushing the motor carrier industry to search for more fuel-efficient operational and technical solutions. As reported by the U.S. Environmental Protection Agency's (EPA's) SmartWay Transport Partnership program, which works with the shipping and trucking community to reduce fuel use and emissions from goods movement, these solutions can include cleaner and more efficient engines and transmissions, more aerodynamically clean truck shapes (including nose cones, skirts and gap fairings), idle reduction technologies, low rolling resistant and single-wide tires, lower weight components and aluminum wheels, driver training, and more efficient head-haul and back-haul routing and dispatching (EPA 2012a, 2012b).¹⁰ Energy efficiency opportunities for trucks and other non-light-duty vehicles are reviewed in another report in the Transportation Energy Futures series.

¹⁰ EPA's SmartWay Transport Partnership is a government-industry collaboration to accelerate the adoption of advanced technologies and strategies to improve fuel efficiency and reduce GHGs and other emissions from the freight sector, including trucks.

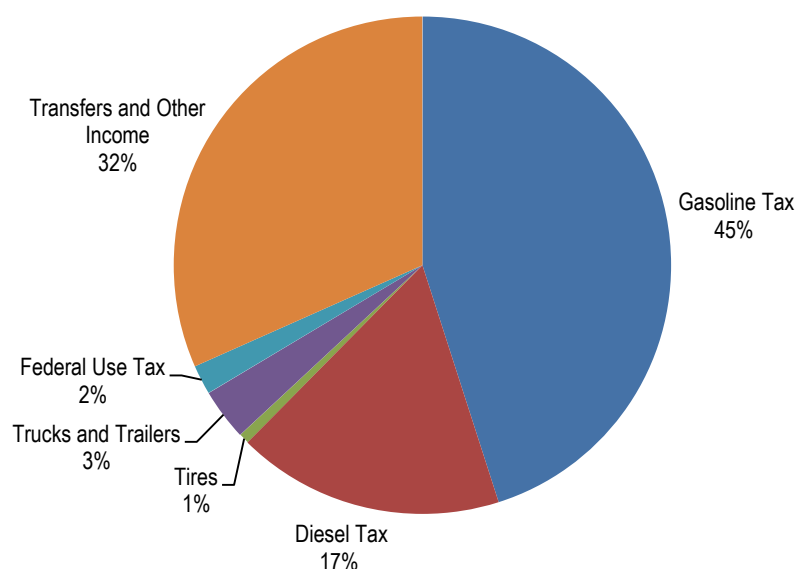


Figure 2.8. Rail operating costs, Q1 2012

(Source: Association of American Railroads 2012a)

Note: "Other" includes purchased services, casualties and insurance, loss and damage, taxes other than income and payroll, and general and administrative expense.

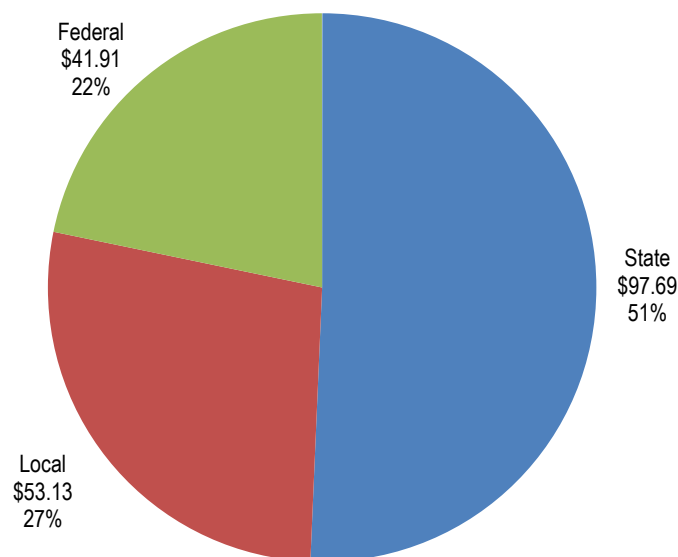
Railroads spend relatively less on fuel, reflecting the economies of scale and corresponding fuel savings that are achieved by hauling very large volumes of freight over long distances. In 2008, railroads consumed approximately 320 Btu per ton-mile, compared to trucking, which used approximately 1,390 Btu per ton-mile for heavy-duty truck operations.¹¹ The difference in fuel use is reflected in the generally higher price of trucking services and the generally lower price of rail services, but the services provided by truck and rail also differ substantially in load capacity, routes and destinations served, frequency of service, transit time and reliability of travel time.

The other major difference between trucking and rail operating costs is the accounting of infrastructure costs—for trucking, the cost of construction and maintenance of highways, bridges and tunnels, and for rail, the cost of construction and maintenance of rail lines, bridges, and tunnels. Trucking pays for its highway infrastructure through motor fuel taxes, registration fees, vehicle and tire sales taxes, and tolls. Trucking shares these costs with automobiles and light trucks. Both trucks and passenger cars “pay as they go” because the public sector generally finances the initial construction and ongoing refurbishment and pays off the costs over time with annual fuel tax receipts.

By contrast, the railroads finance construction and refurbishment of the rail infrastructure through their own revenues and private sector bonds. Freight railroads are very capital intensive. The railroad industry estimates that 17% of revenues are invested in capital, about five times the amount invested by manufacturing industries (Association of American Railroads 2012b). One consequence is that railroads tend to be very conservative about investing in new rail lines and expanded services, attempting to balance the risk of long-term capital costs against fluctuating short-term market demand and revenues.

¹¹ Btu (British thermal units) per ton-mile is a measure of energy intensity. These estimates are from Energy and Environmental Research Associates for rail based on data reported in Bureau of Transportation Statistics, Table 4-25 (RITA 2012); and for trucks based on data reported in *Transportation Energy Data Book*, Table 2.16 (Davis, Diegel, and Boundy 2009). The truck estimates assume 16 tons payload per truck (FHWA 2007).

Figure 2.9 shows the sources of highway funding by level of government (FHWA 2008). Federal funding, largely from federal motor fuel taxes, accounts for about quarter of highway funding; state funding, from state motor fuel, vehicle excise and sales taxes, accounts for about half; and local government funding, from property and local sale taxes, for the remaining quarter. This distribution, which evolved out of the Interstate highway program, has been relatively stable over the past several decades.



**Figure 2.9. Highway funding sources by governmental division, 2008
(in billions)**

(Source: FHWA 2008)

Figure 2.10 provides a breakdown of the federal revenue sources for highway funding (FHWA 2010a). In 2010, approximately two-thirds of federal spending on highways was funded from gasoline and diesel fuel taxes and one-third from transfers from general revenues (e.g., derived from income and other taxes). The large proportion of funding allocated from general revenues is relatively new and reflects the inability of current motor fuel taxes revenues to cover spending needs in an environment of diminished fuel consumption, higher spending on infrastructure, and resistance to higher motor fuel taxes. The federal motor fuel tax rate has not been increased since the last Congressional action in 1993; and because the federal rate is not indexed to inflation, the purchasing power of each federal motor fuel tax dollar has dropped by about one-third since 1993. This slow decoupling of fuel taxes from federal highway spending has several long-term implications. It makes it somewhat easier to pursue energy efficiency and GHG reduction policies because the loss of motor fuel tax revenues—the consequence of improved engine efficiency—is compensated for by increased funding from other non-transportation revenue sources. But it also means greater pressure on other federal revenues sources (e.g., income and sales taxes) as well as pressure to develop new revenue sources, such as vehicle-miles-of-travel-based user fees.

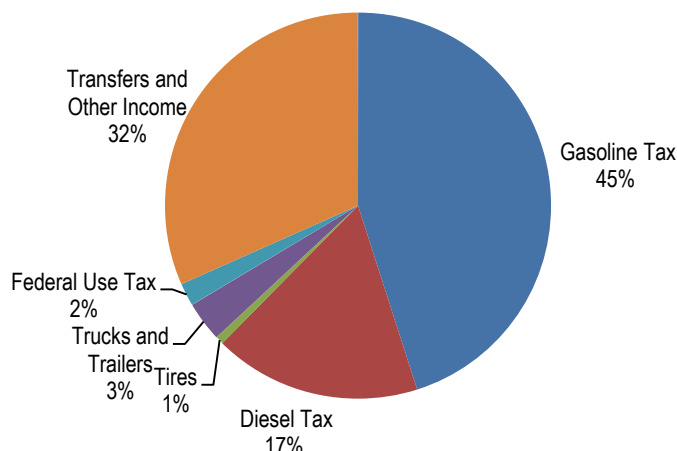


Figure 2.10. Federal revenue sources for highways, 2010

(Source: FHWA 2010a)

The next sections describe the factors that shape freight transportation demand and the models available to estimate the effects of broad shifts in energy use, fuels, and engine efficiency on freight demand.

2.2. Freight Transportation Demand Factors

Table 2.2 sets out a general taxonomy of transportation demand factors. The factors are grouped into four broad categories:

1. Economic factors, which are the primary determinants of the types and quantities of freight generated, and the location of freight production and consumption
2. Logistics factors, which shape how industries and individual firms source, make, route, and sell their products
3. Transportation factors, which affect how freight demand and business logistics plans are executed over highways, rail lines, and waterborne shipping lanes, including the infrastructure, technologies, and fuels that are used to move goods
4. Policy and regulatory factors, which set the “rules of the game” governing the economic, logistics, and transportation elements.

The taxonomy is useful for describing the factors that shape freight transportation demand and tracing their interactions. The taxonomy is not a model, only a framework. It has been constructed to highlight the factors of most relevance to a national-level study of the interaction between freight demand, fuel use, and GHG emissions, based on the authors’ professional judgment. A narrower and more detailed taxonomy might be appropriate for regional- or corridor-level freight studies.

The subsections describe each of these demand factors, their anticipated trends, and the effects of changes in the factors on freight transportation demand and energy use. The assessments of the trends draw upon available data, literature, and the opinions of informed experts and are presented as possible and probable, but not definitive outcomes.

Table 2.2. Transportation Demand Factors

Economic Factors	Consumption	Population Immigration/Migration Households Income Lifestyle
	Production	Economic Activity (GDP) Industries/Commodities Technology Labor Energy
	Trade	Trade Trade Partners/Trade Lanes
	Economic Geography	Land Use
Logistics Factors	Supply Chains	Strategies Sourcing Packaging Staging/Networks
Transportation Factors	Motor Carriers/Highways	Firms Services Volumes Trucks Highways Facilities and Access
	Railroads/Rail Lines	Firms Services Volumes Locomotives/Rail Cars Rail Lines Facilities and Access
	Shipping Lines/Marine Ports	Firms Services Volumes Ships Terminals Facilities and Access
	Air Cargo Carrier/Airports	Firms Services Volumes Planes Airports Facilities and Access
Policy and Regulatory Factors	International	Policy
	National	Plans and Programs
	State	Regulation
	Regional City/Local	Taxation

2.3. Economic Factors and Trends

This subsection discusses the impact of changes in consumption, production, trade, and economic geography on freight demand. Freight demand is commonly viewed as a dependent variable that is driven by changes in broader factors, such as population and economic activity. But the freight sector itself is also an important driving force behind these economic factors. Economic activity in the United States is largely dependent on the ability of the freight sector to deliver goods efficiently. For example, the U.S. agriculture industry, which has a high ratio of tonnage per unit of gross domestic product (GDP), has thrived in large part because of the ability of the freight system to move massive amounts of crops and animal and forest products inexpensively. Other industries, such as retailing and high-tech manufacturing, have thrived because of the ability of the U.S. freight system to reliably deliver goods and industrial parts within very narrow delivery windows. The freight system of the future will respond to the economy, but the economy will also be built around the capabilities of the freight transportation system. This section focuses on changes in the economy that create freight demand; Section 2.5 focuses on changes in the transportation system that affect economic activity. Freight demand implications of anticipated trends are authors' interpretations based on professional expertise and knowledge of the literature. In describing these trends, as shorthand the text often uses the word "will" to describe possible future events; these events are conditional and must be understood within the context of the trends and implications described.

2.3.1. Consumption

Consumption is impacted by the size of the population and the structure and changing needs of different population cohorts.

2.3.1.1. Population

Freight transportation demand and population growth are closely correlated. As an example, Figure 2.11 compares trends in population and ton-miles of railroad freight transportation (Association of American Railroads projections based on railroad traffic data and U.S. Census Bureau population data).¹² Similar patterns—but at different proportional rates—are found between population and truck, waterborne, and air freight tonnage, ton-miles, and revenues.

- Trend: In 2010, the U.S. population was 308 million. The U.S. Census midpoint projection for 2050 anticipates that the U.S. population will grow to 439 million.
 - Freight Demand Implications: A larger population will consume more food, clothing, housing, and energy, increasing the demand for freight transportation. According to the FHWA's FAF, population growth—and the corresponding growth in economic activity and trade—will translate into a 72% increase in freight transportation tonnage by 2050.
- Trend: The number of older adults and the elderly is projected to grow more rapidly than the number of children and working age adults. Under this trend, children and working age adults will still make up the majority of the U.S. population, but the number of children below age 21 will grow at a compound annual rate below 1% and the number of working age adults age 16 to 54 will grow at a slightly lower rate. In contrast, the number of adults age 65 to 84 will grow at about 2% and the number of adults age 85 and above will grow at about 3%.
 - Freight Demand Implications: Older adults preparing for retirement purchase less food, clothing, and housing than young adults forming households and raising children. With an aging population, there will be relatively less demand for housing-related commodities and freight transportation and more demand for service-related goods.

¹² Revenue ton-miles are loaded railcar ton-miles as opposed to nonrevenue or empty railcar ton-miles.

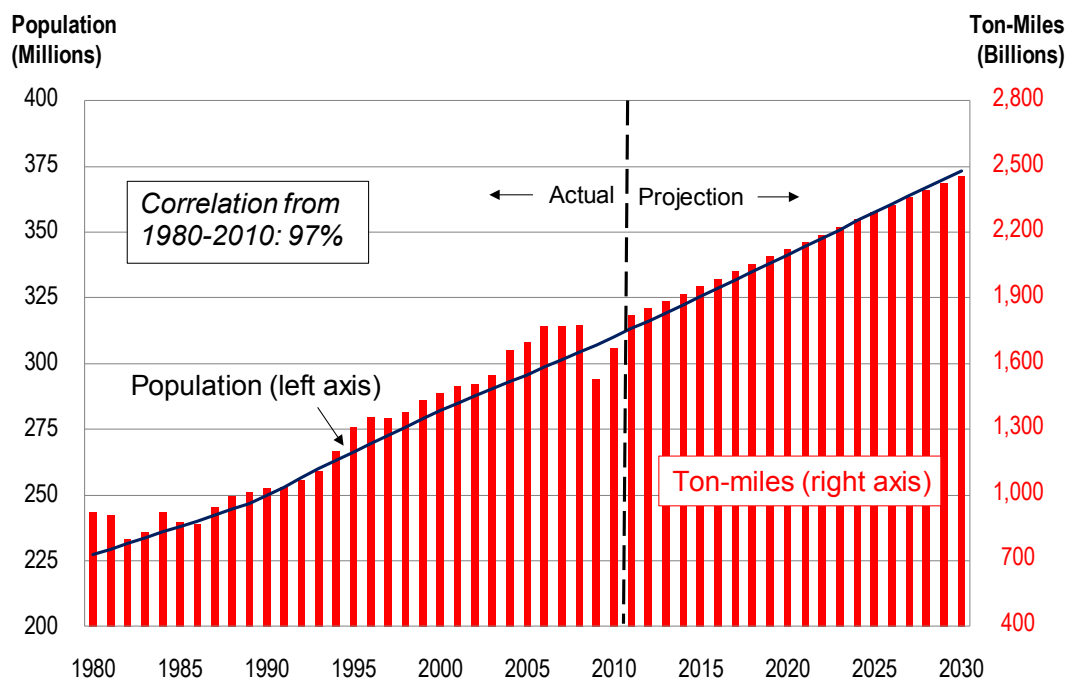


Figure 2.11. Population growth and rail freight ton-miles, 1980 to 2030

(Source: Association of American Railroads projections based on railroad traffic data and U.S. Census Bureau population data)

- Trend: Global population is projected to reach 9.3 billion by the year 2050 (ESA 2010).
 - Freight Demand Implications: Given the global reach of U.S. businesses and the opportunities to export U.S. agricultural and manufactured products, world population growth may be the ultimate driver of U.S. freight transportation demand. We are seeing this today in the increase of agricultural and natural resource exports to China and are likely to see increases in exports to South America and possibly Africa in the longer-term future.

2.3.1.2. Immigration/Migration

- Trend: Immigration rates are down because of the recession, and substantial reforms to immigration policy are unlikely in the near future. The U.S. Census Bureau projects that the annual net in-migration rates will increase gradually but consistently from 1.3 million in 2010 to over 2 million per year in 2050.
 - Freight Demand Implications: Immigration rates are not expected to have a significant effect on freight demand in the near term. However, with an aging population, policies that encourage immigration may become a necessary catalyst to future economic growth. If the United States were to encourage a higher inflow of educated, working-age immigrants with children, this could reshape the population profile, partially counteracting the projected drop in working age adults, and accelerate demand for production of housing and the freight transportation of construction and related commodities.
- Trend: Domestic migration—from rural to urban areas, and from the Northeast and Midwest to the South and Southwest—is projected to continue through 2050, but at rates less dramatic than those of the previous 50 years.
 - Freight Demand Implications: Internal migration will not significantly affect total freight demand, but changing migration patterns (e.g., the possibility of slower migration to the Southwest because of persistent, long-term water shortages) would shift freight production

and consumption patterns and impact freight volumes at international gateways and along freight corridors.

2.3.1.3. *Households*

- Trend: Since the end of World War II, the United States has experienced very high rates of household formation, substantially outpacing the population growth rate. Demographers expect that the number households will continue to increase (and the number of people per household will continue to decline) through 2050. However, multigenerational households, which are common in many other cultures, may become somewhat more prevalent in the United States because of the growth in the Hispanic and Asian-American population, which grew by 30% between 2000 and 2010 (Taylor et al. 2010).
 - Freight Demand Implications: More, albeit smaller, households would increase the demand for the production and transportation of building materials and housing goods. A substantial shift toward larger households, driven by cultural preferences or economic hardship, would slow the rate of household formation and demand for transportation of building materials, etc.

2.3.1.4. *Income*

- Trend: U.S. household and personal income is projected to increase through 2050 as GDP growth outpaces population growth.
 - Freight Demand Implications: In general, increasing affluence means increasing consumption of housing and consumer goods; however, several trends may temper this trend. An older population will invest less in housing and merchandise, and more in travel, services, and health care (Gale 1997). And smaller households, even with rising per capita income, typically invest less money in housing and merchandise. Uncertainty about the future of Social Security could lead to higher personal and family savings rates, leaving less income to spend on housing and goods.¹³ A strong countervailing influence would be public policy that more aggressively redistributes wealth, reversing the trends of past several decades. A wealthier middle class and a significant lowering of the U.S. poverty rate from the 15% recorded in 2010 could boost consumption and freight demand.

2.3.1.5. *Lifestyle*

- Trend: The culture of thrift that marked the Depression-era generation gave way to more aggressive consumption in the post-World War II generations that followed. It would appear that each generation since World War II has been more environmentally aware than the generation that preceded it, but the long-term impact of a greener, more environmentally centered lifestyle on consumption and freight demand is not clear. Forecasts to 2050 must make assumptions for at least two generations whose patterns are not yet formed, but with more of the U.S. population settling in urban areas, it is highly likely that the lifestyles of the 2050s will be different than today's. As evidence of a societal trend toward sustainability that can impact businesses, consumers, and communities, the Retail Industry Leaders Association, a trade association representing top U.S. retailers, recently issued (with contributions by BSR), its first sustainability report, highlighting the increased consideration that sustainability is garnering within the retail industry.¹⁴
 - Freight Demand Implications: The trend toward a “green” lifestyle today is expressed as a preference for more fuel-efficient cars and buildings, more locally produced food and retail goods, and more recycling. If these lifestyle preferences become more firmly ingrained by

¹³ The United States has long had extremely low individual and household savings rate by world standards. In 2008, the average savings rate of U.S. households was 2.7%, compared to 5.8% for the EU. See, for example, “Household Net Savings Rate by Country” (Census Bureau 2012).

¹⁴ See RILA (2012) for a discussion of the 2012 Retail Sustainability Report.

2050, then they could modestly reduce the demand for long-haul freight transportation. However, the strength of this trend is not clear. The trend toward a greener lifestyle could also mean more, but smaller, shipments moving among more origins and destinations as consumers seek to purchase higher-quality, lower-cost, and individually tailored “green” products. This may further accelerate web-based shopping and increase the demand for higher-service and more-energy-intensive truck and air cargo transportation, thereby limiting new opportunities for rail transportation. An increasingly urban population and lifestyle would also mean a more urban consumption pattern, including more income spent on housing and other location-related amenities and less income available for nondurable goods. Finally, recycling – at volumes sufficient to achieve significant economies of scale – typically requires development of “reverse” supply chains and creates new, additional truck and rail miles of travel. One of the highest-volume commodities “exported” from urban areas today is municipal solid waste, much of it moving in medium-distance truck hauls and long-distance rail moves.

2.3.2. Production

Production factors quantify the impact of industrial and business activity on freight demand.

2.3.2.1. Economic Activity/GDP

- **Trend:** Current projections suggest that the national economy will expand at a compound annual growth rate of 2.5% to 2.6% through 2050, with rates of 3% to 4% through 2015 and lower rates thereafter.¹⁵ The long-term average rates are considerably less than the average of about 3% experienced over the previous 30 years.
 - **Freight Demand Implications:** Short-term freight demand tracks economic activity very closely – so closely that freight indices, such as the Ceridian UCLA-Pulse of Commerce Index, are used as a proxy for overall economic performance. However, predicting freight demand based on anticipated economic growth rates is no more accurate than the underlying short- and long-term economic growth forecasts. Figure 2.12 shows four freight demand projections developed between 1998 and 2009 (Cambridge Systematics, Inc.).¹⁶ The forecasts illustrate both the severe impact of the recession on both short- and long-term freight demand and the limited ability of macroeconomic models to predict the future.

¹⁵ The growth rates reflect recent estimates by IHS-Global Insight and other macro-economic forecasters. The rates incorporate the near-term effects of the recession and the longer-term effects of slowing population and workforce growth rates on the economy.

¹⁶ The macroeconomic forecasts were prepared by IHS-Global Insight and are similar to the IHS-Global macroeconomic forecasts underpinning the FHWA’s FAF freight demand forecasts.

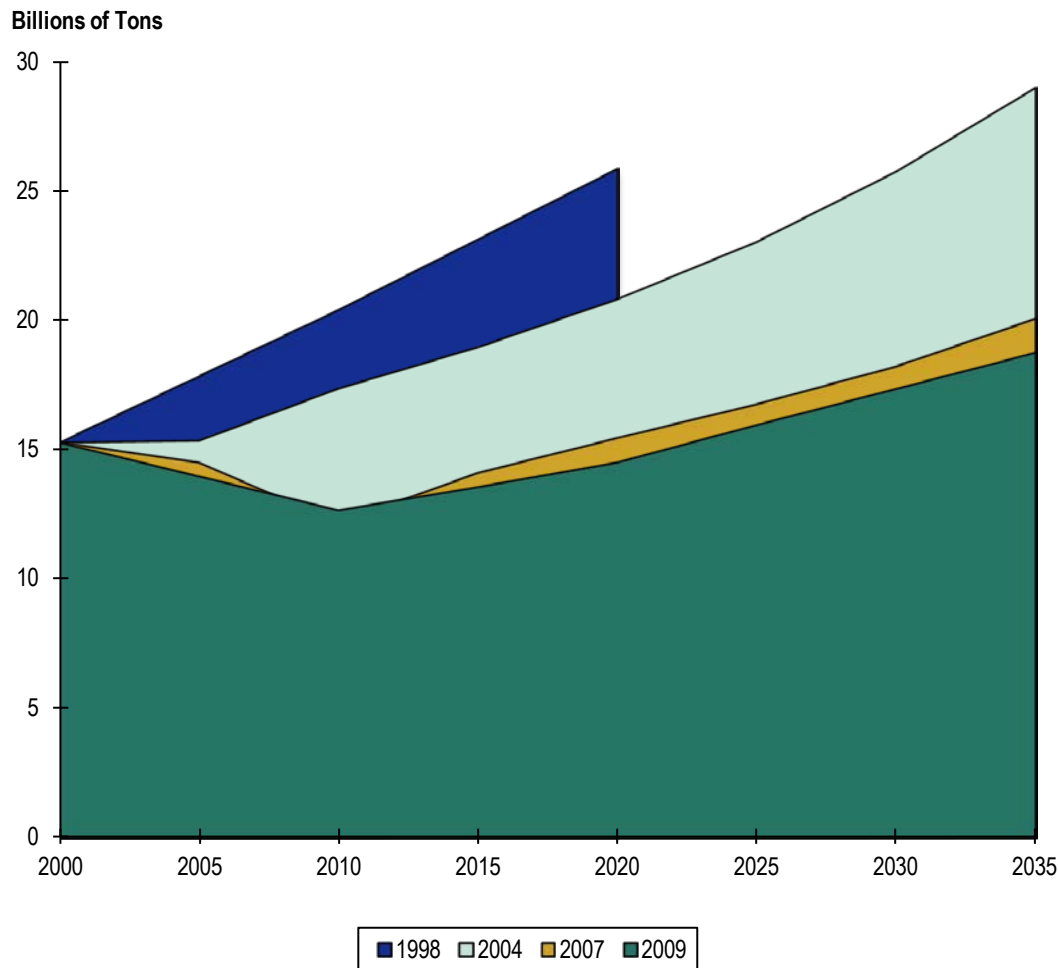


Figure 2.12. Freight transportation demand forecasts

(Source: Cambridge Systematics, Inc., based on IHS-Global Insight, Inc., Transearch data, multiple years 1998 to 2009)

2.3.2.2. Industries/Commodities

- **Trend:** The U.S. economy today is dominated by the service industry. The service sector accounts for 76.6% of GDP, industry for 22.2%, and agriculture for 1.2%. There are strong indicators that the growth of the service sector will continue, propelled by the continuing expansion of knowledge-based professional, scientific, and technical services, and by the expansion of health care and social assistance for an aging population.
 - **Freight Demand Implications:** Moderate expansion or contraction of the service sector will have a modest impact on overall freight demand because the service sector generates relatively little freight directly. However, the service industry is very dependent on the freight services provided by other sectors for the delivery of building materials, food, energy, office equipment, supplies, etc. The price and cost-effectiveness of freight transportation has a direct impact on the economic well-being and productivity of the service sector.
- **Trend:** Despite the overall dominance of the service sector in the economy, there has been a sustained effort on the part of the both political parties in the United States to prioritize exports of manufactured goods and agricultural and natural resource products. A resurgence of manufacturing will likely be concentrated in areas in which the United States has a long-term comparative economic advantage: specialized and high-tech manufacturing, agricultural chemical

manufacturing (fertilizers), pharmaceutical and medicine manufacturing, and petroleum and coal production.

- Freight Demand Implications: The agriculture sector, which accounts for a modest portion of GDP, will be the single largest source of freight tonnage growth through 2040, with a projected increase of 1.1 billion tons (Oklahoma State University undated). The growth will be driven by rising standards of living in China, which will drive up demand for exports of meat and animal feeds from the United States (Kemmsies 2011). The freight demand impacts will be felt as increased rail shipments from the Midwest to Pacific Northwest ports and increased rail and barge shipments through New Orleans and other Gulf ports. There is also the long-term potential to increase exports and trade with food-importing regions such as Africa.

Five other commodity groups are also projected to experience total tonnage growth of over 150%: precision instruments, pharmaceuticals, miscellaneous manufacturing products, chemical products, and transport equipment. Higher-than-projected growth in these areas would generate new demand for domestic interplant freight transportation as well as export freight transportation. Miniaturization and the use of composite materials in these products will continue to reduce the average weight of the products, making shipment by truck and air more cost effective. In all cases, the expansion would likely increase the demand for truck and air transportation.

2.3.2.3. Technology

- Trend: Business analysts anticipate continued and rapid innovation in manufacturing, telecommunications, computing, health and biological sciences, and energy production that will create new businesses and accelerate automation in many industries. Although still speculative, some see the current trend toward “mass customization” (e.g., assembling mass produced components to create products tailored for individual consumers) evolving into “distributed, flexible manufacturing at the point of consumption” (e.g., low-cost, small-batch, custom-made fabrication of products at the point of use accomplished by precision “printing” using nanotechnology materials).
- Freight Demand Implications: The majority of emergent industries will be producing high-value products, which implies increased demand for timely and secure delivery by truck and air. Increasing automation will reduce the number of people employed in manufacturing, but will increase output and freight demand. If realized, the introduction of entirely new methods of production using nanotechnology materials has the potential to trigger significant restructuring of supply chains for raw materials, parts, and finished products.

2.3.2.4. Labor

- Trend: Labor productivity is forecast to increase with more automation, partially offsetting slower growth in the number of working age adults. Public policy actions to raise the Social Security retirement age or prolonged periods of slow economic growth may also keep older workers in the labor force longer.
- Freight Demand Implications: Higher productivity per worker will reduce labor costs, making U.S. industries and products more competitive in global markets. This would reinforce the growth in export traffic and the demand for marine shipping.

2.3.2.5. Energy

- Trend: The U.S. Energy Information Administration’s *Annual Energy Outlook* projections and published industry estimates anticipate a steady increase in energy costs along with continued

volatility in energy prices.¹⁷ The long-term response to higher and more volatile costs is uncertain but will likely lead to diversification of fuels and sources (e.g., shift from coal to natural gas, expanded use of hydro- and nuclear-generated electricity, and development of biofuels as substitutes for petroleum-based fuels).

- Freight Demand Implications: Increasing energy costs would have different effects on each mode. For long-haul freight demand, rising fuel costs would tend to shift demand from air and truck to rail, and from rail to ship (where waterborne transport can provide competitive service). For short-haul freight demand, rising costs would shift demand from conventional diesel and gasoline powered trucks to hybrid-power trucks. A large shift away from coal would significantly reduce railroad revenues and could potentially hinder the ability of the railroads to make large-scale capital investments to expand intermodal and carload rail services. A shift away from conventional sources of ethanol to cellulosic sources would greatly expand the potential origins and destinations for renewable fuel. And finally, a consistent increase in all fuel costs would trigger a broad restructuring of supply chains and markets, as well as possibly dampening consumer spending on non-energy goods and services. Businesses would do more near- or in-sourcing, reposition plants and distribution centers, and in some cases, drop products and markets that were not profitable.

2.3.3. Trade Factors and Trends

The volume and value of international trade has grown and the number and location of major U.S. trade partners has shifted. This has redirected trade flows and forced the restructuring of ports, border crossings, and freight transportation trade corridors.

2.3.3.1. Trade

- Trend: Current data suggest resumption—following the recent recession—of the long-term trend toward globalization of trade and higher trade volumes serving the expanding economies and increasing affluence countries, such as Brazil, Russia, India, and China.
 - Freight Demand Implications: The United States can expect to see increased export of agricultural and natural resource products as well as high-end manufacturing products and services. Agricultural and natural resource exports will be supported primarily by rail and marine transportation, mostly through West Coast (especially the Pacific Northwest) and Gulf Coast ports. Trade with Brazil would expand demand for north-south freight transportation services; and trade with Russia, India, and Africa will likely flow through U.S. East Coast and Gulf ports.

2.3.3.2. Trade Partners/Trade Lanes

- Trend: Trade with China will continue to dominate the Pacific ports, but trade with South America and India will bring more import freight to the East and Gulf Coasts. This will augment the effect of the widening of the Panama Canal, which will give shippers and carriers the option of an all-water route from the Pacific Rim to the U.S. Gulf and East Coast.¹⁸ As these emerging economies grow, they will also import more goods and services from the United States, driving up total trade traffic. Because of its slower population growth rates and aging population, trade with Europe (via the Atlantic) is not expected to grow significantly. In the North American Free Trade Agreement region, harmonization of freight inspection technologies to ensure secure supply chains should

¹⁷ See for example, the recent U.S. Energy Information Administration's *Annual Energy Outlook* for 2009 and 2010.

¹⁸ The FAF and other freight demand forecasts already assume that some Pacific Rim to U.S. West Coast port traffic will be diverted through the Panama Canal to U.S. Gulf and East Coast ports. The magnitude of the shift in the longer term is not yet clear because U.S. railroads will likely lower their transcontinental rates to compete with the ocean carriers using the widened Panama Canal, and the ocean carriers will need to find sufficient export cargo at U.S. Gulf and East Coast ports to justify the cost of the Panama Canal transit fees.

help move the region toward seamless borders. Due to the superior fuel efficiency performance of maritime transportation, carriers will attempt to land trade cargo at ports that are closer to their inland destinations and will seek to limit reliance on long-haul, overland distribution.

- **Freight Demand Implications:** In the past 40 years, the primary international trade flows have been through the East Coast, the U.S.-Canada border, and the Pacific Coast, as illustrated in Figure 2.13 (based on U.S. Department of Commerce trade statistics, various years). The chart shows the approximate value of trade across each of the major border regions between 1860 and 2005. With continued globalization of trade, flows through the Gulf Coast and across the Mexican border are likely to increase with concomitant pressure to improve freight capacity at ports and the highway, rail, and inland waterway routes serving them. Trade through the Ports of Los Angeles and Long Beach will continue to grow and drive intermodal rail traffic to the Midwest, but a growing proportion of total U.S. trade will move through the East and Gulf Coasts.

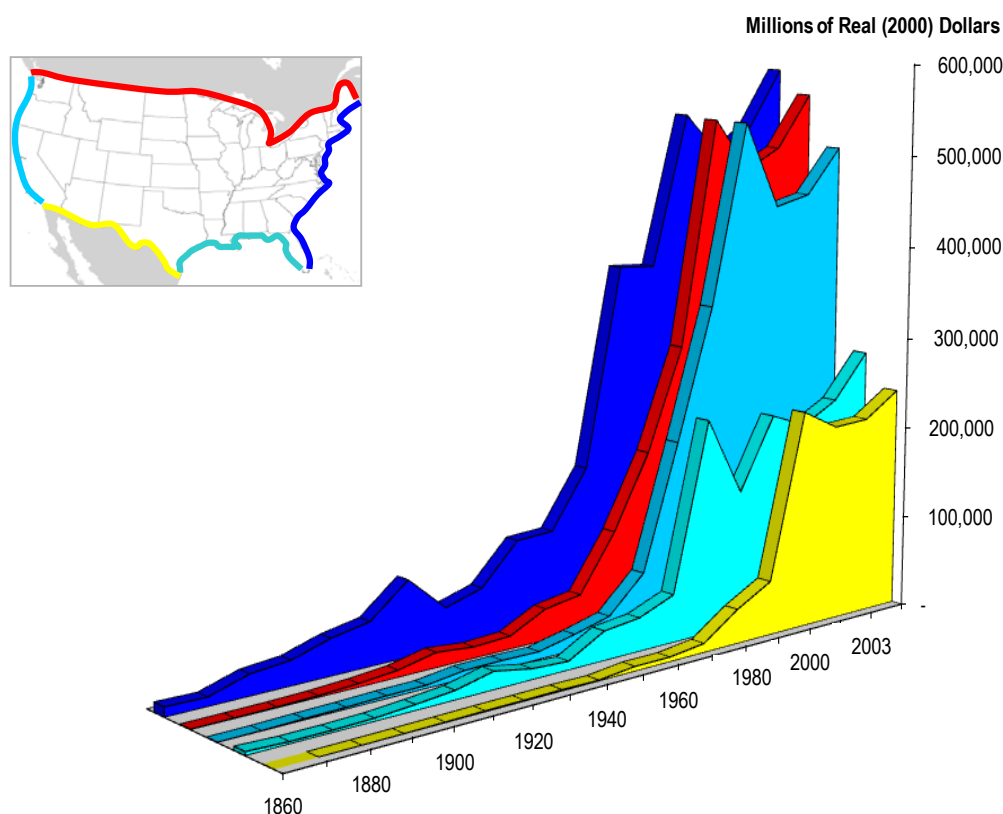


Figure 2.13. Value of trade by U.S. border region, 1860-2005

(Based on U.S. Department of Commerce trade statistics, various years)

2.3.4. Economic Geography

Economic geography refers to the physical location and distribution of economic activity. Freight systems adjust over time to mirror the economic geography of the overall economy.

2.3.4.1. Land Use

- **Trend:** The U.S. population will be more urbanized by 2050, with corresponding population declines in rural areas. In 2010, 82% of the population lived in urban areas. The annual rate of urbanization is projected to continue at 1.5% through 2015. Growth will occur in the urban cores, which will likely be the catalysts for technical innovation as they become both denser and more

specialized. However, much of the overall population growth and economic activity will occur in the secondary cities and exurban areas between them, creating mega-regions that are large agglomerations of multiple metropolitan areas (Gifford et al. undated). Mega-regions in the United States – and their global counterparts – will be the competitive trade blocs of the future. Figure 2.14 is a generalized illustration of the anticipated U.S. mega-regions along with estimates of the metropolitan GDP of the major cities in each region (Berube 2007).

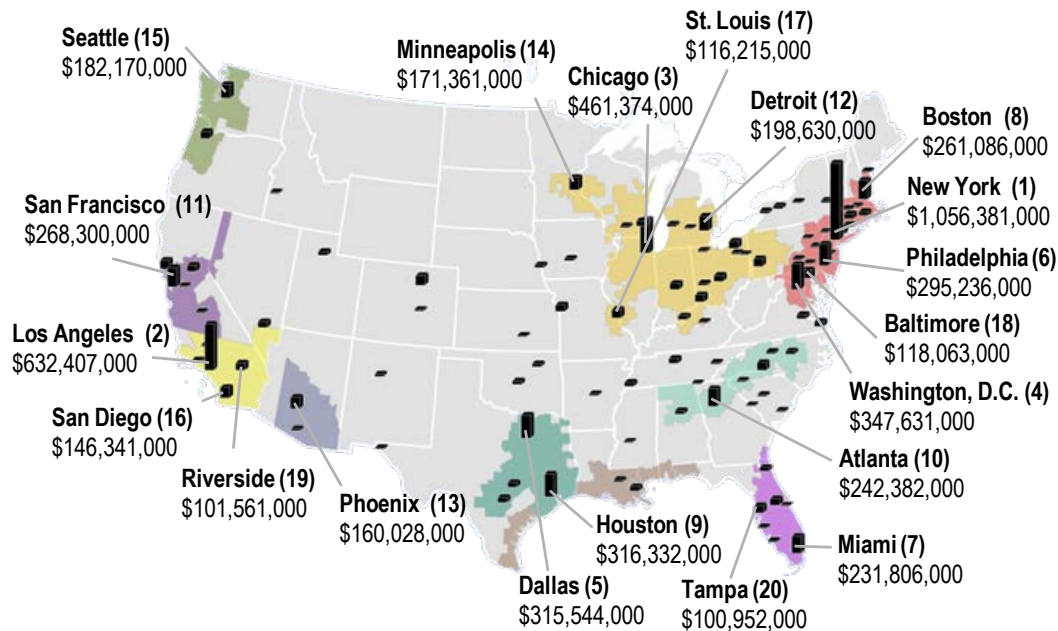


Figure 2.14. Mega-regions and “GDP” of major cities

(Source: Berube 2007)

- Freight Demand Implications: The consolidation of mega-regions could accelerate the use of rail (and some water) for long-haul shipping between regions and reinforce the dominance of trucking within mega-regions and the urban cores. It will also focus transportation services around major import/export gateways for each region and sharpen competition among national freight gateways. This effect can be seen in Figure 2.15, which shows the shift in trucking industry employment between 1990 and 2010 in response to emergence of the Ports of Los Angeles and Long Beach as the primary freight import gateway for the Southwest mega-region and the nation (based on U.S. Bureau of Labor Statistics, Employment by County and Industry for 1990–2010).
- Trend: High land costs, highway congestion, siting concerns of affected neighbors, and opportunities for economies of agglomeration will make it more attractive for complementary businesses and industries to co-locate in “freight villages” or clusters of businesses sharing common freight transportation facilities. In the 19th and early 20th century, high transportation costs made it necessary to co-locate manufacturing factories and housing. But by the mid-20th century, improved trucks and highways, greater industrial specialization, and lower tolerance for factory emissions and noise led to increasing separation of factories, offices, and homes. The current trend points to the continued separation of factories and homes, but reintegration of complementary factories, distribution centers, and freight terminals as travel times across metropolitan and mega-region areas increase.

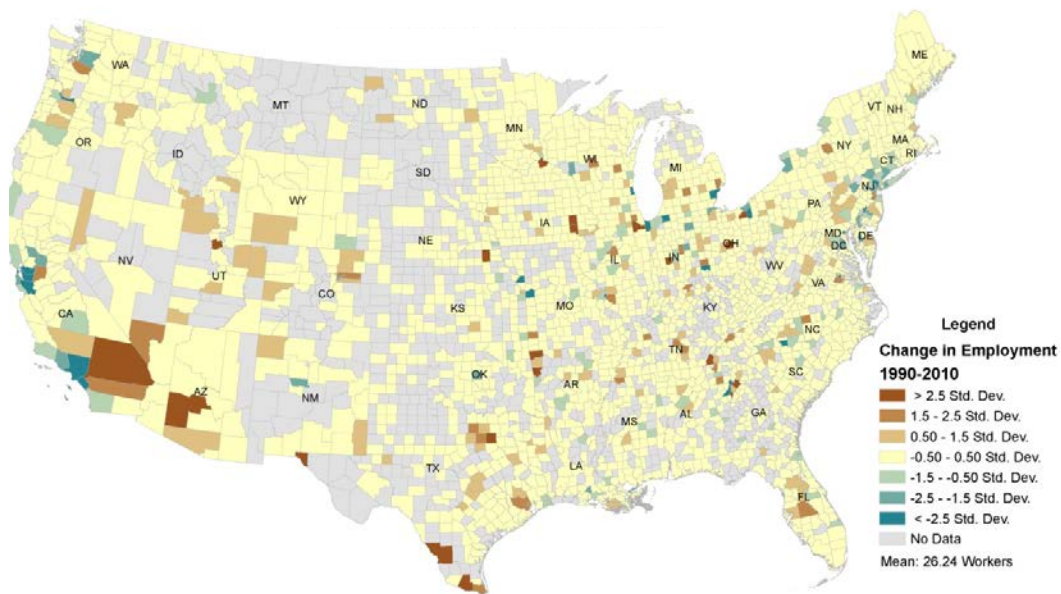


Figure 2.15. Change in trucking industry employment, 1990–2010

(Based on U.S. Bureau of Labor Statistics, *Employment by County and Industry for 1990–2010*)

- Freight Demand Implications: The geographic concentration of industries and distribution centers will create opportunities for consolidation of compatible deliveries with some reduction of freight transportation demand, energy use, and emissions. However, high land costs and relatively low transportation costs will likely maintain the observed, long-term trend toward ex-urbanization of warehousing and distribution centers. This will generate more truck-miles of travel on the major distribution corridors leading into and within metropolitan areas.
- Trend: The National Research Council, in its 2008 Special Report 290, *Potential Impacts of Climate Change on U.S. Transportation*, identifies five climate changes of particular importance to the transportation: Increases in very hot day and heat waves; increases in Arctic temperatures; rising sea levels; increases in intense precipitation events; and increases in hurricane intensity. The report concludes that the impacts of these changes will vary by mode of transportation and region of the country, but they will be widespread and costly in both human and economic terms and will require significant changes in the planning, design, construction, operation, and maintenance of transportation systems (TRB and NRC 2008).
 - Freight Demand Implications: The National Research Council report anticipates that the greatest impact of climate change for North America's transportation systems will be flooding of coastal roads, railways, transit systems, and airport runways because of global rising sea levels, coupled with storm surges and exacerbated in some locations by land subsidence. This implies an on-going need to reinforce or relocate freight transportation facilities, which will affect decisions about routing, supply chain design, and capital investment. At a minimum, this has the potential to reallocate freight transportation demand within and among economic regions. It also has the potential to shift demand for commodities, such as agricultural and natural resource products, if climate change affects the costs and productivity of regions differentially.

2.4. Logistics Factors and Trends

Logistics describe the strategies that businesses adopted to organize the chain of make-buy-sell transactions for their products and services. Four aspects of logistics are covered here: supply chains, sourcing, packaging/containerization, and networks. Selection of major factors and freight demand implications of anticipated trends are authors' interpretations based on professional expertise and knowledge of the literature. Descriptions of trends provide an understanding of the complex and inter-related nature of the freight transportation system. Trends and implications are uncertain and conditional.

2.4.1. Supply Chain Strategies

- Trend: Thirty years ago, most businesses operated *push* supply chains. Suppliers delivered materials to a manufacturer, who pushed products to a distributor or retailer, and then to the customer. Each business maintained a large and expensive inventory of critical materials and products to protect against stockouts. Today, most businesses are moving toward *pull* or on-demand supply chains (just-in-time manufacturing and retailing), replenishing whatever the customer consumes as soon as it is sold. To ensure that inventory is available, businesses are tracking customer purchases as they occur, reducing and centralizing inventory at fewer locations, and managing in-transit inventory closely. Industries that once held large inventories of products and could tolerate delays in shipment and receipt of goods now demand greater reliability and visibility, or knowledge of current status of shipments, from their freight carriers. The trend toward pull or replenishment operations is expected to continue with some adjustment for the higher risk involved in operating long and complex supply chains ("just-in-case" supply chains).
 - Freight Demand Implications: Eliminating inventory and replenishing everything in real time results in smaller shipment sizes (since units are consumed one by one) and more individual products per shipment (to make lot sizes economical to ship). This approach increases the importance of transportation over warehousing and favors the use of faster and more reliable trucking, intermodal, and air shipments over carload rail and waterborne freight shipments.
- Trend: Logistics costs declined during through the 1990s, rose through the mid-2000s, and then dropped sharply during the recession, as shown in Figure 2.16 (Wilson 2011). Logistics costs (which include the transportation, warehousing, administration, insurance, and inventory carrying costs) are projected to rise again as the economy recovers, as freight demand again presses the capacity of the freight transportation system, and as interest rates increase from the near-zero levels experienced during the recession.
 - Freight Demand Implications: Transportation costs are a relatively small percentage of the delivered price of most goods and services, constituting 1% to 2% of the gross regional product for most industries. Only in industries such as agriculture, mining, and construction do transportation expenditures approach 10%, as illustrated in Figure 2.17, which shows transportation as a percentage of GDP for the major industries in Oregon and Washington states (Oregon Department of Transportation 2003). However, rising transportation costs are closely linked to inventory carrying costs and regulatory requirements. When interest rates are high, the combined effect on total logistics costs will trigger redesign of supply chains.

This effect was noticeable in the mid-2000s, when higher fuel costs, congestion, and interest rates encouraged major retailers and others to reposition distribution centers so that they could take advantage of lower-cost transportation (primarily rail) and minimize their use of more expensive long-haul truck moves.

Increasingly, shipping customers are also looking for ways to cut carbon emissions as part of a longer term sustainability approach and finding freight strategies that cut carbon also reduce transportation costs. For example, American Shipper magazine, in partnership with the Council for Supply Chain Management, Eye for Transport, and the National Retail

Federation, published a benchmark study highlighting how businesses can assess the return-on-investment (ROI) case for sustainable goods movement (Blaeser and Whiting 2012).

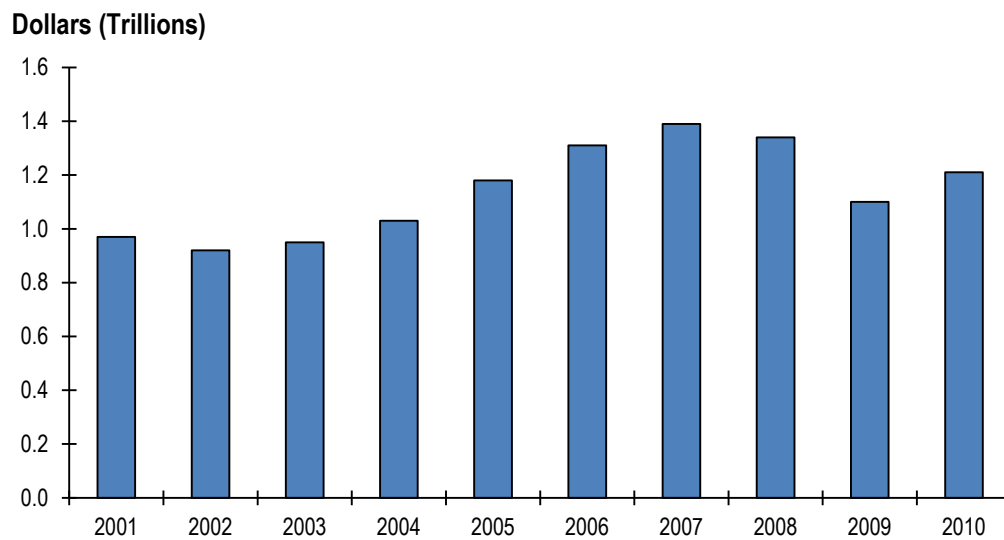


Figure 2.16. U.S. business logistics cost, 2001-2010

(Source: Wilson 2011)

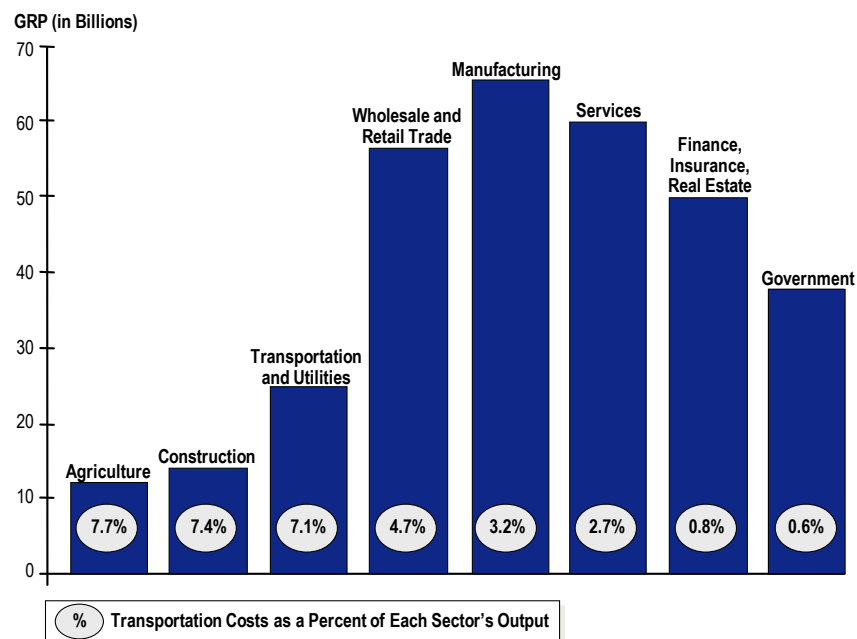


Figure 2.17. Transportation as a percentage of gross regional product for major Oregon and Washington state industries

Based on U.S. Bureau of Economic Analysis data and Transportation Satellite Account data.
(Source: Oregon Department of Transportation 2003).

2.4.2. Sourcing

- Trend: Outsourcing (that is, purchasing goods and services outside the continental United States to pursue lower labor, energy, and raw material costs) will continue as countries take advantage of

comparative economic advantage and opportunities for global trade. Countries such as China have greatly expanded the variety of commodity types they can successfully export, which has increased opportunities for U.S. outsourcing. In 2011, the United States imported more than 700 additional types of commodities from China (HS-6) that were not imported in significant volumes in 2003.¹⁹ For certain commodities, changes in labor costs, transportation costs, and network congestion will lead to selective in-sourcing (renewed production within the continental United States) and near-sourcing (increased production in Mexico and Latin America). In many cases, labor costs and legal issues [such as protection of patents and intellectual property (IP) rights] will take priority over transportation cost considerations.

- Freight Demand Implications: Changes in near-sourcing and in-sourcing are likely to have a modest impact on total freight demand, but will affect the origins, destinations (including trade gateways), and mode shares of domestic transportation. In general, near-sourcing and in-sourcing will expand the use of truck and air transportation at the expense of rail and waterborne transport.

2.4.3. Packaging/Containerization

- Trend: The introduction of intermodal containers in the 1950s and their widespread adoption in the 1980s and 1990s revolutionized the handling of freight, especially international shipments. Most manufactured goods, including automobile parts, electronics, processed foods, specialty chemicals, paints, and household and consumer goods are now moved in containers. This pattern will continue with more bulk commodities being containerized to ensure, as examples, the quality of specialized agricultural products, prevent genetically modified grains from intermixing with non-genetically modified grains, and protect the security of chemical shipments. This trend will be accelerated by the growing obsolescence of dry bulk ships and terminals.

A parallel trend is to reduce the weight of products and the space taken up by their packaging. This improves the weight-to-volume ratio, making truck and rail moves more cost-effective, and reduces the volume and cost of recycling.

The final trend in packaging is toward ubiquitous use of barcoding and radio-frequency identification (RFID) transponders to identify products and track shipments. “Nested” tracking systems – where product RFID tags “talk” to box tags, which talk to pallet tags, which talk to container tags, which talk to truck or rail vehicle tags, which relay information about the status and location of the shipment to shippers, carriers, receivers, and customs and security officials over cellular and satellite telecommunications systems – will be commonplace.

- Freight Demand Implications: Advances in packaging and containerization will improve the efficiency of the freight system, reducing the energy consumed in carrying extra packaging and fielding extra shipments to make up for lost and damaged goods.

2.4.4. Networks

- Trend: Supply chains are executed over a series of links (e.g., rail lines, highways, and shipping lanes) and nodes (e.g., farms, factories, terminals, distribution centers, and other freight staging points). With improvements in the range and reliability of trucks, trains, planes, and ships and in the communications systems to control and synchronize them, the number of different supply chains in operation has increased, and supply chains have become longer and more complex. This trend is expected to continue.

¹⁹ Commodities with imports valued at over \$1 million. Gross regional product calculated from U.S. Census, Foreign Trade Statistics. The Harmonized System six-digit level (HS-6) refers to the commodity description and coding system’s tariff nomenclature at a highly disaggregated level. This level of disaggregation allows for the identification of recognizable commodity types instead of broad groupings.

- Freight Demand Implications: Higher population densities in metropolitan areas and mega-regions will make possible more economies of scale in freight shipments. Moderately populated areas that were once served by truck may now justify more efficient rail or waterborne transportation. Transloading yards, where commodities like lumber and plastic pellets are transferred from rail cars to truck, and transloading centers, where consumer merchandise is unloaded from smaller international shipping containers and reloaded in larger domestic containers/trailers in order to increase the productivity and cost-efficiency of freight moves, will grow in prominence. As shipment density grows, shippers will press for more efficient loading of containers and all-water routing to allow one-box, door-to-door deliveries and reduced re-handling costs. Distribution centers will be repositioned to reduce transportation costs, accommodate higher urban development densities, and allow for “postponement.”²⁰ Traditional, single product warehousing will be outsourced and integrated with value-added services in order to justify a higher-skilled workforce. Access to rail will become a more important feature when siting new distribution centers.

2.4.5. Supply Chain Carbon Accounting and Reporting

- Trend: Freight carriers and shippers are increasingly under pressure to address carbon risk and operational costs associated with freight. Shareholders, customers, and other stakeholders are pressuring shippers to quantify, track, report, and reduce their carbon emissions. Freight shippers are looking to their transportation providers to reduce carbon in the freight supply chain, increasingly encouraging or requiring their carriers to participate in the EPA’s SmartWay Transport Partnership program (EPA 2012b) or to engage in other carbon reporting and report card exercises. SmartWay provides a uniform, integrated framework for shippers, carriers, and logistics companies to assess and track emissions and fuel use from goods movement. SmartWay has nearly 3,000 industry partners, and is being used as a model to establish similar programs in many top U.S. trade partner regions, including China, Canada, Mexico, and the European Union. The trend of assessing and tracking carbon emissions from freight transportation and goods movement is expected to continue.
- Freight Demand Implications: If industry works to optimize carbon efficiency and improve freight performance it could affect freight demand and accelerate mode shifting. Shippers working to optimize performance could also drive carriers to accelerate efficiency gains through advanced technologies and operational practices. Efforts to reduce the carbon footprint of supply chains will likely lead to renewed consideration of near-sourcing and in-sourcing and further accelerate efforts to introduce engines that use less carbon-intensive fuels.

2.5. Transportation Factors and Trends

The following section provides an overview of factors and trends specific to transportation systems and modes that will impact the ability of the future network to accommodate freight growth. Selection of major factors and freight demand implications of anticipated trends are authors’ interpretations based on professional expertise and knowledge of the literature. Descriptions of trends provide an understanding of the complex and inter-related nature of the freight transportation system. Trends and implications are uncertain and conditional; the use of the word “will” does not assert certainty about future outcomes, but is merely used as shorthand (instead of “if...then”).

²⁰ Postponement refers to the practice of importing a shipment of goods, storing all or most of the goods in a large, centrally located warehouse or distribution center near the port of entry, and then later allocating and forwarding portions of the shipment to different final destinations as market demand dictates. The objective is to reduce the transportation costs of shuffling and repositioning small lots of goods among widely dispersed markets.

2.5.1. Freight Systems

- **Trend:** The successful introduction of a new mode of freight transportation is a rare event. Rail and steamships were both introduced in the early 1800s. Modern trucking began in the early 1900s, high-volume air cargo services in the mid-1900s, and containerization in the late 1900s, as illustrated in Figure 2.18. There have been no new freight transportation modes successfully deployed since that time. Nevertheless, the freight transportation industry is in the midst of a radical technological shift, this time driven by adoption of information and communications technologies that have revolutionized how shippers and carriers monitor and control the movement of freight shipments, freight vehicles, and freight networks.
 - **Freight Demand Implications:** The continued evolution and application of RFID shipment tags, on-board vehicle and trailer/container sensors, traffic monitoring systems, database technologies, global positioning systems, telecommunications, and precision dispatching and routing systems will significantly improve the productivity of all freight transportation systems. The benefits will be seen in less down time for maintenance, more efficient routing and fewer vehicle miles traveled (VMT) per delivery, more timely and accurate intermodal transfers, less damage and loss, and fewer injuries and fatalities.

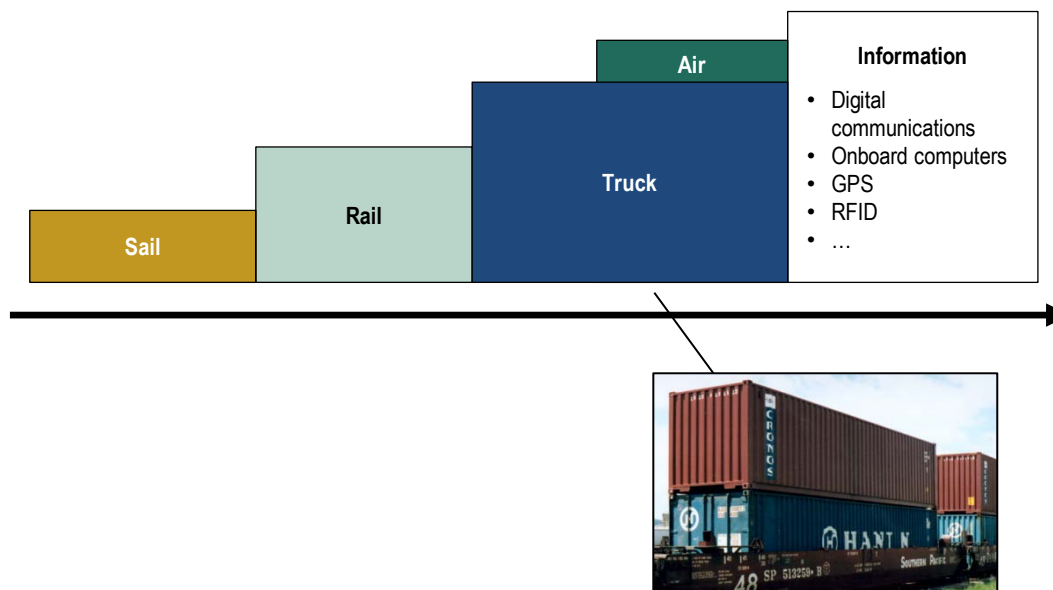


Figure 2.18. Freight transportation systems

2.5.2. Motor Carriers/Highways

- **Trend:** The trucking industry will see further consolidation and restructuring.
 - **Freight Demand Implications:** The industry has been aggressive in incorporating global positioning systems and other tracking and shipment management technology into their operations; however, most trucking companies are small (approximately 80% of motor carrier firms own 5 to 10 trucks) and effective use of the technology requires sophisticated staff and managers. Small, independent trucking companies will continue to exist; however, they will contract to large carriers or subscribe to dispatching or load matching services to ensure that capital is utilized effectively. Information-technology-intensive firms will generally prosper at the expense of less information-technology-intensive firms – a trend that will favor large firms. Structural shifts in the economy that generate more high-value, lower-weight, time-sensitive goods should mean that the overall demand for trucking will be high. Driver

shortages are not expected to be an intractable problem, but will be a recurring issue given the unregulated economic entry and boom-and-bust nature of the industry. Nevertheless, price competition with rail (because of the higher fuel cost and labor shortages incurred by long-haul trucking) will squeeze some transcontinental truckload operations out of business.

- Trend: There will be a continuing move towards greater specialization of trucking equipment with hybrids and eventually all-electric trucks used for local pickup and delivery trips and drayage (i.e., trucking of containers from port terminals to warehouses), with longer and heavier diesel-powered trucks reserved for intercity and heavy-load movements (i.e., over-the-road, truckload and less-than-truckload operations). All classes of truck will see improvement in miles traveled per gallon.
 - Freight Demand Implications: In the light- and medium-truck classes [under 10,000 pounds gross vehicle weight (GVW), and 10,000 to 26,000 pounds GVW, respectively], there will be a greater penetration of hybrids and all-electric vehicles. Heavy-duty, long-haul trucks (26,000 pounds GVW to 80,000+ pounds GVW) will see relatively slower improvement in productivity, gallons per mile, and emission reductions because of technological barriers and the need to maintain a high load-to-vehicle weight ratio. There will be a push for use of more, longer combination vehicles (a single tractor hauling two trailers) along with demands for higher weight-capable trucks (e.g., 97,000 pounds GVW and higher, with the weight distributed over more axles and tires). The push for larger vehicles will face state and local resistance to the operation of longer and heavier trucks on local streets because of safety and pavement damage concerns. Figure 2.19 shows one estimate of the projected miles traveled per gallon for freight trucks (TRB 2011b).

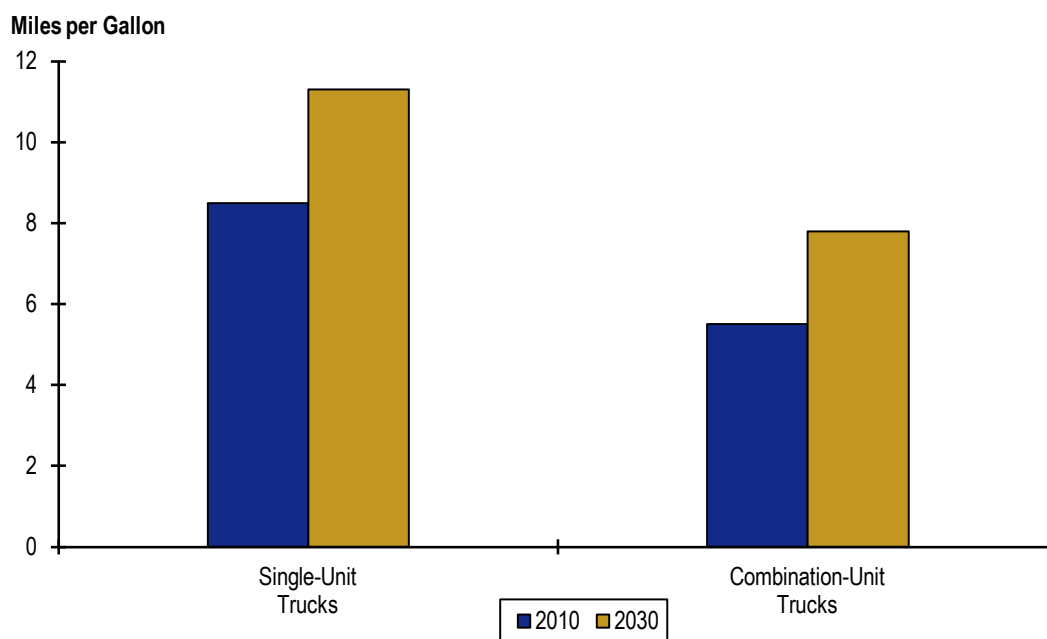


Figure 2.19. Projected miles per gallon for freight trucks, 2010 and 2030

(Source: TRB 2011b)

Note: Chart is based on data from "Figure 4.8, Projected Growth (Miles per Gallon) for New Trucks and the Overall Fleet of Single-Unit and Combination Trucks, 2010-2030."

- Trend: There will be adequate funds for preservation and maintenance of existing highways, limited funds for capacity expansion, and almost no funds for major new Interstates that are not

constructed as toll roads. While congestion has abated because of the economic recession, severe highway congestion bottlenecks will reemerge as the economy and freight demand recover.

- Freight Demand Implications: Carriers will invest heavily in dispatching and routing systems to avoid congestion, and reposition urban truck terminals, service areas, and truck stops to improve delivery efficiency and offset rising land costs and local impacts. However, higher overall network congestion will likely offset the gains in fuel efficiency and routing and dispatching, driving up the delivery cost of many goods and services. Some existing service lanes (trip origin/destination pairs and connecting routes) will become uneconomic due to transportation costs.

2.5.3. Railroads/Rail Lines

- Trend: The railroad industry has realized steady productivity improvements since the economic deregulation of the industry in the 1980s. The improvements have been achieved by restructuring the rail system and creating new business lines serving long-haul intermodal freight demand and coal movements out of the Powder River Basin in Montana and Wyoming, and by increasing the number of tons carried per railcar, the number of railcars moved per train, and – with more sidings and better signal systems – the number of trains moved over a line. The railroads are also upgrading track to handle heavier cars along many lines, thereby allowing more tonnage to be handled over existing corridors. These changes have resulted in much improved intermodal service along high-volume traffic lanes (e.g., between the ports of Los Angeles and the distribution centers of Chicago and Atlanta), but a slow erosion of carload service for low-volume shippers and shippers located on underserved branch and secondary rail lines. Improved intermodal service has taken long-haul trucks off the road; but the deterioration of carload and local services has put freight back into trucks and onto the road.

The rail industry has largely recovered from the recession, is profitable, and has been investing heavily to increase capacity and improve service reliability. And although unpopular with the freight railroads, the congressionally mandated system of positive train controls to reduce the risk of train crashes is a bellwether of an industry-wide shift toward more automation and greater productivity in freight rail routing and dispatching operations.

- Freight Demand Implications: The FAF projections show railroads losing market share because of structural changes in the economy that will generate more higher-value freight by 2050. However, the FAF projections do not attempt to anticipate price and service changes that might affect market shares. Current business forecasts anticipate that the freight railroads will retain their market share and perhaps capture more of the long-haul freight demand market. This would help reduce energy consumption in the long-haul freight market. Electrification is possible in some rail freight lanes, but the capital costs are so high that only a few freight rail lines may be electrified by 2050.
- Trend: Railroads have achieved financial success by rationalizing their service and tailoring operations to a select number of high-volume customers. However, flat (and possibly declining) demand for coal and limited opportunities to expand in the long-haul freight market could threaten railroad revenues and pressure the railroads to develop new services.
 - Freight Demand Implications: The freight railroads will push to expand intermodal services into 400- to 700-mile freight transportation markets. Long-haul intermodal service (over 700 miles) is profitable because the railroads can achieve considerable economies of scale in long-distance moves; however, shorter distances are less profitable and the reliability of transit times is harder to maintain. Building new services will be a significant challenge, involving redesign and repositioning of older yards as intermodal terminals and development of new, scheduled intermodal services.

2.5.4. Shipping Lanes/Maritime Ports

- Trend: Ships continue to grow in size as shipping lines seek economies of scale to reduce the unit cost of moving containers and other commodities. An expansion of the Panama Canal is underway to accommodate these larger ships. Eventually, however, the capacity of harbors to accommodate the larger, deep-draft ships will slow the growth in ship size. The supersizing of ships has already reached equilibrium in the tanker industry and a similar trend may emerge for the container fleet. Nevertheless, large investments are being made at ports along the Eastern seaboard to deepen channels and expand terminal capacities in anticipation of “New Panamax” ships that take advantage of the canal’s expansion in 2014.
 - Freight Demand Implications: The trend toward larger ships will concentrate freight movements into deep water ports with the largest ships making the highest volume ports their first port of call (both because of market demand and because offloading at the first port of call allows access to second ports of call that may have shallower channels and berthing areas). Expansion of the Panama Canal will trigger some diversion of West Coast traffic from the Ports of Los Angeles and Long Beach to U.S. Gulf Coast and East Coast ports, but the railroads will likely lower rates for transcontinental intermodal service, counteracting some of the potential diversion. By 2050, the expansion of global trade among all countries and the growth of U.S. trade with Brazil, Russia, India and China will support dedicated, all-Atlantic and all-Pacific liner (container ship) operations, making Panama Canal transits a less dominant factor in shipping costs.
- Trend: One of the more dramatic changes triggered by the rise in fuel prices and the recession is the trend toward “slow steaming” in the liner industry. Slow steaming refers to the practice of operating a liner vessel below its design speed in order to save fuel. This practice was initiated during the mid-2000s when the industry faced high fuel costs, surplus ship capacity, and dropping demand. Current indications are that the liner industry may make slow steaming a permanent feature of marine operations by integrating slower-design speeds into the construction of new vessels (Maersk Line 2011).
 - Freight Demand Implications: A consequence of slower shipping transit times is that shippers and receivers must keep more goods in inventory and more goods moving through the entire logistics chain. This increases the volume of commodities in “pipeline stock” (goods in transit) as well as in “cycle stock” and “safety stock” (goods in warehouses and distribution centers). With lower transportation costs and greater visibility of freight movements, shippers have substituted more and faster transportation for traditional warehousing, essentially turning trucks, railcars, and ships into (relatively fast) moving warehouses. This has been particularly attractive when interest rates and, therefore, the cost of holding inventory are high. If the added costs of slow steaming and port congestion are not offset by the lower costs in operating large ships, then supply chains will be reset to compensate, either by changing sources or restructuring the location and operation of U.S. domestic distribution networks.

2.6. Policy and Regulatory Factors and Trends

Policies and regulations established at the national, state, and local levels all have a direct impact on freight transportation demand, through policies and taxes that subsidize the growth of some industries and transportation modes over others, through regulations that affect the relative prices of freight transportation, and through programs that invest in transportation infrastructure. Selection of major factors and freight demand implications of anticipated trends are authors’ interpretations based on professional expertise and knowledge of the literature. Descriptions of trends provide an understanding of the complex and inter-related nature of the freight transportation system, including how relationships could change with policy and regulation. The use of the word “will” does not assert certainty about future outcomes, but is merely used as shorthand; trends and implications are uncertain and conditional, and

descriptions should be understood to mean “*if* this apparent trend continues and *if* system relationships work as expected...*then* likely outcomes are... “.

2.6.1. Policy

- **Trend:** As the economy recovers, demand for freight transportation will again press the capacity of the freight transportation system. The resulting congestion will undermine the reliability and connectivity of freight movements, which are essential to the nation’s economic well-being, and renew calls for more investment in transportation infrastructure. Federal policy recognized the importance of the Interstate Highway System program to economic development and freight transportation in the 1960s; and, in the 1980s, federal policy supported deregulation of the freight transportation industry as a means of restructuring the industry and reestablishing market rates for freight transportation services. Starting with the reauthorization of the federal funding for surface transportation by the Intermodal Surface Transportation Efficiency Act of 1991, successive reauthorizations have recognized the need for a more explicit and detailed national freight transportation policy, but made limited headway toward enacting specific policies and programs until the Moving Ahead for Progress in the 21st Century Act, which was enacted in 2012 (U.S. DOT FMCSA 2012). The Moving Ahead for Progress in the 21st Century Act mandated that U.S. DOT develop a national freight policy and goals, designate a national freight network, and produce a periodic report on the condition and performance of the national freight systems.
 - **Freight Demand Implications:** Congress may undertake a broad policy debate about the role of the federal government in transportation and the importance of maintaining national freight transportation capacity and connectivity. The Moving Ahead for Progress in the 21st Century Act is a start and foundation for more comprehensive national freight policy and supporting program. Some observers expect that within one or two reauthorization cycles (6 to 12 years) the nation will have a freight transportation policy and one or several freight investment programs in place targeted at projects of national and regional significance. Given the dominant role of trucking and highways in the U.S. freight transportation system, the policies will likely favor continued investment to maintain highway capacity for trucking.

2.6.2. Taxation

- **Trend:** There is a broad recognition that an increase in private and public investment in the freight transportation systems to keep pace with economic growth and demand is required. Funding for freight transportation improvements has lagged demand. The federal motor fuel tax was last increased in 1993, but because it is not indexed to inflation, motor-fuel-tax revenues have lost about one-third of their purchasing power. Tolling and congestion pricing may help manage demand on the most congested roadways and generate revenue to expand capacity, but tolling and pricing revenues will not be sufficient to fund projected highway preservation and maintenance nor to ensure connectivity across the national freight network since tolling and pricing are only economically viable on a small percentage of Interstate and National Highway System roads. The vast majority of freight highways do not have sufficient volumes and intensity of use to generate significant revenues through tolling.

Politically challenging fuel-tax increases and sales taxes may bridge the funding gap for a short time, but energy policies and GHG emission regulations will reduce the long-term yield from fuel taxes.

- **Freight Demand Implications:** New revenue mechanisms such as mileage-based or VMT user fees (already a partial source of revenues from the trucking industry) will likely be introduced and expanded along with freight-related user fees and taxes (e.g., port facility charges, conveyance fees at terminals, and value-added taxes on shipments) to fund critical national and regional freight projects. Mileage-based or VMT user fees have the potential to generate

considerable revenue, but unlike today's motor fuel taxes, which are collected from major oil distributors, VMT user fees must be collected from individual drivers. The cost of administering and enforcing VMT user fee programs may prove too high, limiting their effectiveness. These mechanisms will be paired with investment tax credits and other forms of public support of private sector investment to increase and accelerate private investment in rail systems and other freight infrastructure. Most of the cost will be passed along to shippers, receivers, and consumers, affecting the demand for specific commodities in ways that cannot be reliably predicted.

2.6.3. Regulation

- **Trend:** The EPA has moved to introduce new truck fuel-efficiency standards, and high fuel prices and consumer demand for "green" products have encouraged companies to adopt fuel savings strategies on their own. EPA's SmartWay Transportation Partnership program and the experience of its partners in demonstrating the fuel-saving technologies and strategies that the program tests and promotes helped to inform EPA's development of the new standards. Wal-Mart, for example, a SmartWay partner, set a goal several years ago of doubling the fuel economy of its truck fleet by 2015, and had achieved a 25% fleetwide improvement by 2008.²¹ Given the anticipated increase in truck traffic, diesel fuel consumption, and GHG emissions, it is anticipated that the federal government will consider increased truck fuel-efficiency standards and possibly GHG emission standards by 2050 (EPA 2012a).
 - **Freight Demand Implications:** The impact of stricter truck fuel-efficiency standards on freight demand will depend somewhat on the ability of engine manufacturers to meet the standards without significantly increasing the cost of truck engines and fuels. If truck costs increase substantially, rail and water could compete for some of truck's freight share, especially longer-haul freight. There will be less opportunity to shift mid-range and short-haul freight from truck to rail. If significant cost increases are persistent (lasting three to five years or more), businesses will redesign their supply chains to minimize total logistics costs, but will also pass the increased costs on to customers and consumers. Conversely, if the standards lead to technological breakthroughs and lower engine and fuel costs, then the pattern could reverse with some freight shifting back from rail to truck. It is important to note, however, that the degree of mode shift is dependent on the commodity, the availability of alternative modes, service performance, and general market behavior (e.g., how carriers respond to changes in costs, and how shippers respond to changes in rates).
- **Trend:** In the 1980s, the federal government reduced its economic (but not safety) regulation of the freight industry. The response, which played out into the 1990s, resulted in a radical transformation of the aviation industry, the railroads, and eventually the motor carrier industry. The impact on the railroad industry, which had been sliding into bankruptcy in the 1960s and 1970s, was pronounced, as illustrated by the trends in productivity, volume, revenue, and price shown in Figure 2.20. The realignment of freight transportation services and the introduction of more market- and demand-based pricing have benefited most shippers, receivers, and consumers, but it has triggered recurring proposals for reregulation from captive shippers, who are typically high-tonnage and high-volume shippers and receivers of grains, coal, and chemicals that are served by only one railroad.
 - **Freight Demand Implications:** Proposals for reregulation of the railroads have made little headway, but if they were eventually successful, would likely lead to higher rail prices and diversion of some freight traffic from rail back to truck.

²¹ Wal-Mart collaborated with EPA on testing and evaluation of fuel efficient technologies. Wal-Mart adopted a range of these SmartWay technologies on its trucks in order to reach that sustainability goal.

2.6.4. Public-Private Partnership

- **Trend:** EPA developed the SmartWay Transport Partnership program as a government-industry collaboration to accelerate the adoption of advanced technologies and strategies to improve fuel efficiency and reduce GHG and other emissions from the freight sector, including the trucking and rail sectors. The EPA reports that performance benchmarking tools, data assessment, and recognition for partner achievements have helped the freight industry to save over \$6.5 B in fuel costs, cut oil use by 55 million barrels, and reduce carbon dioxide (CO₂) by over 23.6 million metric tons since 2004. This trend is expected to continue as more shippers and carriers join this voluntary, market-based collaboration (EPA 2012a).
- **Freight Demand Implications:** This program improves the energy and emissions efficiency of freight. If fuel cost savings are passed on to customers, a rebound effect could cause freight demand to increase. Participation in this benchmarking, reporting, and recognition program will increase the transparency of carbon performance in the freight sector and help the market optimize freight operations by enabling better decision making on mode and carrier choices. The data collected through the partner process and the government-industry collaboration are expected to further inform policy making and regulations in ways that ensure more cost-effective and successful programs.

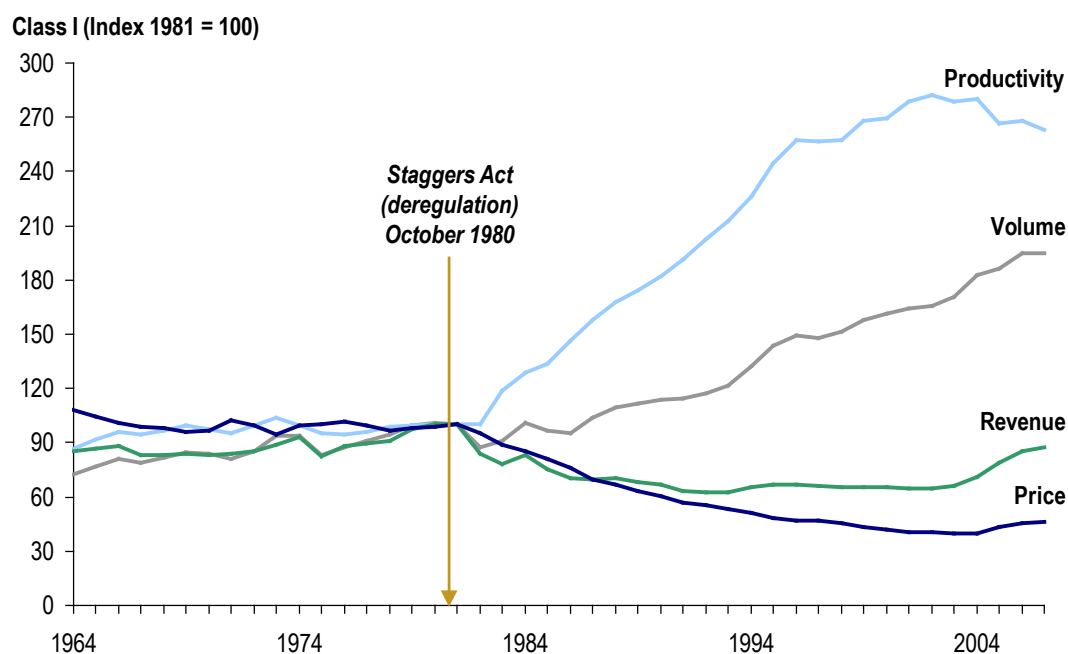


Figure 2.20. U.S. railroad performance, 1964 to 2007

(Source: Association of American Railroads)

2.6.5. Metropolitan Freight Programs

- **Trend:** The cost of picking up and delivering freight is being driven upwards by congestion and unreliable travel times in urban areas. Improving metropolitan freight mobility means preserving truck access and ensuring fast, safe, and reliable pickup and delivery operations ranging from local delivery to transcontinental truck trips. And it means restructuring some rail freight operations and removing rail bottlenecks in metropolitan areas. However, there will be few opportunities to divert freight from truck to rail within metropolitan areas. The infrastructure for urban rail freight operations has been largely torn up, and few communities are enthusiastic about having heavy-

industry rail lines and terminals as neighbors. Trucking – albeit with cleaner and quieter engines and organized to make fewer and more efficient trips – will be delivering most food, clothing, merchandise, housing materials, and other goods within urban areas for the foreseeable future.

- Freight Demand Implications: The failure of metropolitan freight transportation systems will be unacceptable because of the political and economic cost for the national economy. The primary opportunities for Congressional action would likely take the form of restructuring metropolitan planning organizations with a broadened mandate to deal with freight transportation, not just automobile and transit systems. With this will come efforts to recognize major highway bottlenecks as a national-scale problem that threatens to choke the highway freight system; introduction of roadway pricing for both automobiles and trucks to moderate demand, manage congestion, raise revenue to maintain transportation system, and reduce energy use and GHG emissions; and support for the rationalization of urban rail operations and consolidation of urban rail terminals to preserve rail service, reduce truck traffic, and minimize community impacts.
- Trend: Within metropolitan areas, more freight transportation capacity is needed at ports and gateways, and better connections are needed between those port gateways and the national highway and rail networks. The quality of access to and from ports and other major international gateways is important because it affects the cost of moving freight, determines the market area that can be served cost-effectively from the gateway, and impacts the surrounding communities. The intermodal freight connectors of the National Highway System are the first and last miles of roadway used by truckers to travel between the major highways of the National Highway System and the nation's ports, rail terminals, and air cargo hubs. They are usually local roads and often weave their way through older industrial and residential neighborhoods. They are critical links, but often the weakest links, in the freight transportation network. The need for intermodal connector improvements has been widely discussed since the Intermodal Surface Transportation Efficiency Act of 1991, but the issue still lacks focused attention. Without investment in the “last mile” of freight transportation on the intermodal connectors, the value of investment in national highway and rail connectivity will be much reduced.
 - Freight Demand Implications: The resumption of economic growth and the anticipated expansion of global trade may lead to federal policies and programs to partially fund improvements to intermodal port and border crossing connectors. An important catalyst will be the success or failure of U.S. export initiatives to prompt significant growth in trade.

2.7. Summary

Table 2.3 provides a summary of the trends and freight demand implications by freight demand factor. The trends are described by their anticipated direction and the certainty associated with the trend projection. For example, under “Population,” the anticipated direction is “growing [population] with relatively more elderly and fewer working adults” and the certainty of this projection is rated as “good.” As noted, the assessments of the trends draw upon available data, literature, and the opinions of informed experts, but reflect the authors’ best professional judgment about their likely direction, magnitude, incidence, and significance, and are not intended to suggest certainty about future outcomes.

The freight demand implications have been collapsed to show the likely impact in four dimensions: 1) freight tonnage; 2) freight commodity types (or mix of commodities); 3) freight VMT (as a proxy for fuel use and GHG emissions under the very broad assumption that an increase in VMT will generate some corresponding increase in fuel use and GHG emissions); and 4) freight mode. A blank cell indicates that the factor does not have a direct and readily discernible effect. For example, while it is clear that the ongoing shift in supply chain strategies from *push* to *pull* operations has the direct effect of increasing freight VMT and shifting modal shares, it is less clear that this shift has a direct impact on commodity

tonnage and mix. Over time, a change in supply chain strategies will influence tonnage and commodity mix, but the table does attempt to trace out the complexity of the secondary and equilibrium effects.

The table should be read as a summary of trends that underpin the 2007 to 2040 FAF freight demand projections. As such, the trends represent the “most likely” trajectory for freight demand assuming the continuation of current policies, technologies, trade patterns, etc. Many other alternative futures are possible.

For the purposes of the Transportation Energy Futures study and making first approximations of energy and GHG emission effects, the factors most likely to shape freight demand between now and 2050 were considered to include the following:

- Economic Factors:
 - Population and income
 - Economic growth rate (GDP)
 - Trade volume and partners
 - Urbanization and mega-region concentration.
- Logistics Factors:
 - Supply chain restructuring in response to changes in economic geography and differences in modal transportation costs.
- Transportation Factors:
 - Petroleum fuel availability and cost.
- Policy and Regulatory Factors:
 - Truck engine efficiency and GHG emissions standards
 - Federal funding for freight infrastructure.

These major economic, logistic, transportation, and policy and regulatory factors will directly influence freight transportation demand, with national, state, and local levels of government each playing distinct roles. These factors provide the context in which efforts to reduce energy use and GHG emissions will operate, and these possible policy actions are considered next.

Table 2.3. Summary of Trends and Freight Demand Implications by Factor

Freight Demand Factors			Trend		Freight Demand Implications			
			Direction	Certainty	Tonnage	Commodity Types	VMT	Mode
Economic Factors	Consumption	Population	Growing with relatively more elderly and fewer working adults	Good	Increases tonnage	Generates more high-value, time-sensitive goods	Increases VMT	Favors truck transportation
		Immigration/Migration	Slowing early in period, then increasing	Poor				
		Households	Continuing slow increase in the number households; fewer people per household	Fair				
		Income	Increasing per capita	Fair				
		Lifestyle	Uncertain; assume no change	Poor				
	Production	Economic Growth Rate (GDP)	Increasing GDP; faster growth rate early in period; then slowing	Good	Increases tonnage	Generates more high-value, time-sensitive goods	Increases VMT	Favors truck transportation
		Industries/Commodities	Services dominate; growth in manufacturing, agriculture, and resource exports	Good				
		Technology	Continuing innovation; more high-value products	Good				
		Labor	Fewer working adults, increasing automation	Good				
		Energy	Increasing prices and volatility	Fair				
	Trade	Trade	Increasing trade volumes	Good	Increases tonnage	Generates more resource commodity exports	Increases VMT	Favors water transportation
		Trade Partners/Lanes	Diversifying (BRIC)	Fair				
	Economic Geography	Land Use	Continuing urbanization; emergence of mega-regions	Good	–	–	Generates relatively less long-haul VMT; relatively more metro/mega-region VMT	Favors truck transportation
Logistics Factors	Supply Chains	Strategies	“Pull” (“robust JIT”)	Good	–	Increases number of individual shipments	Increases VMT	Favors truck transportation
		Sourcing	Continued outsourcing	Fair	–	–	Increases VMT	Favors water and air transportation
		Packaging	Neo-bulk containerization; less packaging overall	Good	Reduces tonnage	–	–	–
		Networks	Regionalization of distribution; increasing decentralization within regions	Good	–	–	Reduces overall VMT	Favors water and rail for long-haul;

Table 2.3. Summary of Trends and Freight Demand Implications by Factor (continued)

Freight Demand Factors			Trend		Freight Demand Implications			
			Direction	Certainty	Tonnage	Commodity Types	VMT	Mode
Transportation Factors	Motor Carriers/Highways	Firms	Continuing consolidation	Good	–	–	–	truck for local distribution –
		Services	More regional focus	Good	–	–	–	–
		Volumes	Increasing	Good	–	–	Increases VMT	–
		Trucks	Modest improvements in long-haul truck gallons per mile; Conversion of urban truck fleets to hybrid technologies	Fair	–	–	Increases energy consumption and GHG emissions, but at moderating rates	–
		Highways	Focus on preservation of pavement and bridges; limited capacity expansion	Fair	–	–	Increases VMT	Increases congestion and likely to increase trucking costs
	Railroads/Rail Lines	Firms	Stable	Good	–	–	–	–
		Services	Expansion of 400-700 miles intermodal services	Fair	–	–	Reduces overall VMT	
		Volumes	Growing, but smaller share relative to trucking	Good	–	–	Increases VMT	
		Locomotives/Railcars	Steady productivity and mpg improvements given long life of fleets	Good	–	–	Decreases energy consumption and GHG emissions	
		Rail lines	Continuing upgrades; moderate expansion	Good	–	–	–	Provides capacity for rail to keep pace with population and economic growth
	Shipping Lines/Marine Ports	Firms	Consolidation	Good	–	–	–	–
		Services	More dedicated all-Atlantic and all-Pacific services	Good	–	–	Reduces demand for transcontinental truck and rail moves	–
		Volumes	Growing	Good	–	–	–	–
		Ships	Larger; introduction of “slow steaming”	Fair	–	–	Reduces fuel use and GHG emissions	–
		Terminals	More “hubbing” at largest deepwater ports	Good	–	–	Concentrates land-side distribution around major deepwater ports; Increases regional	

Table 2.3. Summary of Trends and Freight Demand Implications by Factor (continued)

Freight Demand Factors			Trend		Freight Demand Implications			
			Direction	Certainty	Tonnage	Commodity Types	VMT	Mode
Policy and Regulatory Factors	International			–	–	–	truck VMT	–
	National	Policy	Slowly evolving national freight policies and performance measures	Fair	–	–	–	May shift some longer-haul freight from truck to rail depending on Federal actions affect the relative cost of air, truck, rail and water transport.
		Taxation	Introduction of road pricing	Fair	–	–	Reduces truck VMT	
		Regulation	Higher standards for energy efficiency and GHG emissions	Good	–	–	Reduces fuel use and GHG emissions	
		Programs	Limited capital investment; focus on competitive investment in projects of national and regional significance	Fair	–	–	Reduces truck VMT	
	State			–	–	–	–	–
	City/Local			–	–	–	–	–

Source: Cambridge Systematics, Inc.

3.0 POLICY ACTIONS

This section outlines potential federal government policy actions that could influence the demand for freight transportation as well as potential impacts, implementation issues, and assessment methods. This section is intended to inform, and is not intended to promote, propose, or oppose such actions.

3.1. Fuel Taxes

Federal Action. Increase federal motor fuel taxes on diesel and other petroleum-based fuels used in freight transportation. Because taxes are already imposed on fuels used in most transportation modes, higher fuel taxes would be straightforward to implement and administer. Moreover, the motor carrier industry is on record as favoring an increase in motor fuel taxes to support increased funding for highway and bridge maintenance and replacement that benefit freight (American Trucking Associations 2009). The major challenge to implementation would be to find innovative ways to engender and sustain broad public support for higher motor fuel taxes, which have been resisted during the past two decades.

Impacts. Increasing the federal motor fuel tax will increase the cost of fuel and, because fuel cost constitutes a large portion of the cost of operating heavy-duty freight trucks, carriers will look for ways to minimize fuel costs – buying more fuel efficient engines and vehicles, establishing more fuel-efficient routing and dispatching practices, shifting longer-haul freight to rail and water where services are available, etc. However, federal motor fuel taxes are a decreasing percentage of total fuel cost as fuel prices rise. This means that changes in the federal motor fuel tax rates *per se* – unless the changes are very large – have a diminishing impact of carrier behavior. The impact of a change in federal motor fuel tax rates would be felt most directly by trucking and somewhat less so by rail because railroads are generally exempted from the fuel excise taxes paid by truckers.²² In general, increasing petroleum-based fuel costs can be expected to shift freight demand from air to truck to rail to water, but with the degree of diversion highly dependent on the commodity, the availability of alternative modes, and service performance.

Implementation. Federal fuel taxes policies and rates were first set by Congress in 1932, and then formalized as part of the Federal-Aid Highway Act of 1956 (Weingroff 1996). The federal motor fuel tax is typically paid at the fuel distributor level, collected by the Internal Revenue Service, and deposited to the Highway Trust Fund administered by the FHWA.

Assessment Methods. The primary method for assessing the impact of fuel tax increases is estimation of price elasticity of demand using historical mode share data, revealed-preference data, or stated-preference surveys. Other parts of the Transportation Energy Futures project address modal share estimation methods. There have been numerous studies of price elasticity of demand for freight transportation, but most were done in the 1970s and 1980s and are now of limited value given the structural changes in the economy and logistics since that time. Assessment of the policy impacts of increased fuel taxes would require better and more current data to re-estimate supply chain costs. Because the cost of freight transportation is generally passed through to the customer, macroeconomic models can be used to estimate sector- and industry-wide economic effects.

3.2. Low-Carbon Fuel Standards

Federal Action. Impose low-carbon fuel standards (LCFS) on the freight transportation sector. LCFS would help attract and sustain investment in alternative fuels, potentially lowering the cost of supplying

²² The Railroad Revitalization and Regulatory Reform Act of 1976 specifically restricts the ability of state and local governments to levy taxes on rail carriers that would be discriminatory. This has implications for the types of taxes that can be levied on rail. The Supreme Court recently dealt with the interpretation of this statute in *CSX Transportation, Inc. v. Alabama Department of Revenue*, which held that a rail carrier could challenge a state law that imposed a sales tax on diesel fuel for railroads but not on motor carriers.

them over time. If fuel prices remain high as a consequence, the challenge would be to maintain freight industry and public support for the program.

Impacts. The main effect of LCFS is to reduce the GHGs emitted during fuel consumption and production by increasing the demand for and supply of alternative, low-carbon fuels. If fuel prices increase as a consequence, the standards could also cause some reduction in transportation activity and shift toward more energy-efficient freight vehicles and operations.

Implementation. The prospects for federal implementation of a LCFS are unclear. If the standards raise the price of fuel, as would be expected, the implementation challenge will be similar to that of raising fuel taxes. As with other policies to control GHG emissions, the ability to account for and verify freight transportation emissions will affect the implementation potential. The California Air Resources Board approved a LCFS for California that went into effect in January 2011. The effects are being watched as a bellwether of the feasibility of a national program.

Assessment Methods. There are no national-level studies that directly address the potential impact of a LCFS on the freight transportation industry and freight demand. As with motor fuel taxes, the key variables would be the amount of increase or decrease in fuel cost relative to future diesel fuel prices, the cost of adapting truck and rail engines to the alternative fuels, and the net cost difference by mode.

3.3. Vehicle Efficiency Standards

Federal Action. Increase heavy-duty truck engine efficiency standards to require more miles traveled and fewer GHG emissions per gallon. In August 2011, the EPA and National Highway Traffic Safety Administration announced the first regulations to reduce GHG emissions and improve fuel efficiency of heavy-duty trucks and buses. The regulations will apply to vehicles produced between 2014 and 2018; a second phase of regulations is planned for the truck model years beyond 2018 (EPA 2011).

Impacts. The EPA and the National Highway Traffic Safety Administration estimate that the combined standards will reduce GHG emissions by about 270 million metric tons CO₂-equivalent and save about 530 million barrels of oil over the life of vehicles built for the 2014 to 2018 model years, providing \$49 billion in net program benefits. The reduced fuel use alone will enable \$50 billion in fuel savings to accrue to vehicle owners, or \$42 billion in net savings when considering the costs of developing and implementing the technology. In addition to fuel savings, the agencies have estimated monetized benefits from GHG reductions, improved energy security, reduced time spent refueling, as well as possible increased driving accidents, traffic congestion, and noise. Most of these effects are directly attributable to reduced freight cost and induced demand.

Using technologies commercially available today, the majority of vehicles will see a payback period of less than one year, while others, especially those with lower annual miles, will experience payback periods of up to two years. For example, an operator of a semi-truck can pay for technology upgrades in under a year and have net savings up to \$73,000 over the truck's useful life.

In addition to the benefits from reduced GHGs, the EPA has estimated the benefits of reduced ambient concentrations of particulate matter and ozone resulting from this program. Air quality will improve and health impacts from these air pollutants will be reduced, with estimated monetized health-related benefits ranging from \$1.3 to \$4.2 billion in 2030, discounted at 3%.

In total, the combined standards will reduce GHG emissions from the U.S. heavy-duty fleet by approximately 76 million metric tons of CO₂-equivalent annually in 2030 and in subsequent years. The potential impacts of the program that are not quantified and monetized in the analysis include the health and environmental impacts associated with changes in ambient exposures to toxic air pollutants and the benefits associated with avoided non-CO₂ GHGs (methane, nitrous oxide, and hydrofluorocarbons). While these environmental benefits do not directly translate into higher freight demand, they mitigate against the future risk of community opposition, which can constrain the ability of freight facilities to

grow. Many freight facilities in urban areas, for example, cannot gain community consent to expand without meeting environmental performance targets that far exceed federal or state standards.

Implementation. EPA and the National Highway Traffic Safety Administration have worked jointly to implement this program. These agencies are expected to continue to work together when considering an expansion of the program beyond model year 2018.

Assessment Methods. The assessment of changes in vehicle and engine efficiency standards is based on estimates of annual VMT by different classes of trucks, engine efficiency and emission performance, and fleet turnover rates. Improved short-term estimates could be gained with better information on the actual duty cycles of trucks in specific supply chain operations. Estimating longer-term impacts requires projection of the relative cost changes for each mode.

3.4. Road Pricing

Federal Action. Implement road pricing through the substitution of VMT user fees for some or all of the current motor fuel taxes and support wider application of road tolling.

Impacts. Road user pricing is done today by taxing motor fuel consumption as a proxy for VMT on roadways. Interest in direct VMT user fees has grown as the revenue yield from motor fuel taxes has decreased – a function of the introduction of more fuel-efficient engines and a broad political reluctance to raise fuel taxes or index the tax rates to inflation. The impact of VMT user fees on freight demand would depend on whether the VMT fees were revenue neutral. A revenue-neutral shift would have little impact, but a shift to VMT fees that is accompanied by changes in allocation of cost responsibility could have a significant impact on trucking. National studies have long argued that heavy freight trucks operating in long-haul service pay less than their proportional share of road costs compared to light- and medium-duty trucks. A reallocation of cost responsibility to raise a greater share of fees from long-haul trucking could shift some long-haul freight from truck to rail.

Implementation. Road user pricing will likely be implemented through the states because the states have the administrative capability in place to administer and collect federal and state motor fuel taxes along with state vehicle registration fees and various federal heavy-duty vehicle sales taxes. However, the costs for administration and enforcement of a road-user pricing mechanisms, such as a mile-based or VMT user tax, could be prohibitively high. Several states are experimenting to determine the cost-effectiveness and efficiency of road pricing.

Assessment Methods. The U.S. DOT, many states, and several industry associations are conducting studies of the feasibility and economic impacts of road pricing. Most studies focus on road user and administrative costs and benefits; few have attempted to estimate the price elasticity of demand effects on freight transportation demand and supply chain operations.

3.5. Freight Operations

Federal Action. Deregulate U.S. domestic maritime shipping through repeal or modification of the Jones Act.

Maritime shipping is generally the most fuel-efficient means of freight transport. For this reason, there has been significant interest in expanding the role of domestic maritime and inland waterway shipping between U.S. ports. However, attempts to increase short-distance maritime shipping have been hobbled by the Merchant Marine Act of 1920, commonly referred to as the Jones Act, which regulates all vessels engaged in the transportation of cargo or passengers between two points within the United States, its territories, and possessions, as well as vessels engaged in dredging, towing, salvage, fishing, and other marine operations. Under the Jones Act, vessels engaged in these activities are required to be U.S.-built, U.S.-documented, U.S.-owned and controlled, and U.S.-crewed. Because ships constructed in the United States are typically more expensive than those built in other countries (due to higher labor rates and unfavorable scale economies) and U.S. merchant mariners are typically paid more than their foreign

counterparts, there is very little domestic maritime freight shipping outside of barging. A relaxation of Jones Act requirements that would allow foreign-built vessels and non-U.S. crews to service U.S. domestic container or other freight demand would permit the introduction of a new mode to accommodate future freight demand to supplement trucks and rail. Provision of shipbuilding grants for the construction of a domestic fleet would be an alternative mechanism to develop this mode of transportation within the confines of the Jones Act.

Impacts. Domestic maritime shipping is a niche freight transportation service today and serves a handful of corridors and commodity types. There have been numerous studies speculating about the potential for these services if the market were deregulated, but no definitive estimates have been made. Proponents argue that in situations where freight could be moved economically and reliably by domestic maritime operations, the increasing need for parallel truck or rail operations may be reduced, thereby helping to mitigate congestion and air quality impacts. However, it is unlikely that repealing or modifying the Jones Act, which restricts carriage of cargoes between U.S. ports to U.S.-built and -crewed ships, will result in meaningful diversion of truck or rail traffic in most locations, even those with existing access to domestic maritime services. The primary constraint to growth in short-sea shipping is the additional cost of handling the loading and off-loading of containers and trailers at ports. This makes many shipments uneconomical compared to direct truckload service.

Implementation. Implementation of policies and programs to increase short-sea shipping would be under the jurisdiction of the Federal Maritime Administration.

Assessment Methods. Estimates of the potential market for domestic maritime shipping are based on commodity flows between origin and destination pairs that can be efficiently served by waterborne shipping, market penetration rates for reasonably comparable services (e.g., in Europe), and anticipated operating costs. Estimates could be improved by more complete accounting of the role of coastal shipping in total supply chain costs.

3.6. Infrastructure Investment

Federal Action. Establish a national freight transportation policy; define a national freight system that delivers national connectivity; provide access to global markets and support a strong economy; and increase the public and private investment in highway, rail, and waterborne transportation systems.

The key elements of a federal freight program could include: 1) providing financial support to projects of national and regional significance that maintain and improve national connectivity and capacity; 2) separating freight and passenger movements on key national rail and highway corridors; 3) improving rail and truck productivity through new policies and investments, such as providing tax credits (previously extended to short-line railroads to help finance the upgrade of track for use with heavier, higher-capacity rail cars); 4) offering letters of credit and loan guarantees to railroads and state agencies to help finance the clearance of rail lines to accommodate higher, double-stack trains; and 5) allowing – where safe – the operation of larger and heavier trucks along key freight corridors and on connectors to ports and other key intermodal facilities.

Options for financing increased investment in more energy-efficient freight transportation would include short-term increases in the federal motor fuels tax, indexing the tax to inflation, introduction of a VMT user fee to fund transportation improvements, and consideration of a palette of freight-specific user fees, such as container conveyance fees to finance freight-specific improvements.

Along with investments in physical infrastructure capacity and connectivity, federal investments in traffic management and traffic information can make freight operations more efficient by reducing delays and detours.

Impacts. The intent of a federal freight program would be to focus federal aid and investment in critical commerce corridors; to leverage state investments to relieve congestion at urban Interstate interchanges (the locus of most truck hours of delay); and to improve access to port and rail intermodal terminals. The

expected outcomes would be to maintain or reduce travel times, increase the reliability of freight trip travel times, and broadly keep pace with the increases expected from population growth and economic development. The caveat that must accompany all infrastructure and operational improvements is that faster and more reliable travel times will generally induce additional trips, trips that previously were not made because they were not economically viable at the margin.

Implementation. The U.S. DOT/FHWA and the Federal Railroad Administration would be the likely organizational units involved in implementing this program.

Assessment Methods. The FHWA FAF3 national network, state highway models, and localized interchange traffic flow simulation models can be used to approximate the reductions in delay and improvements in travel time and reliability of infrastructure improvements. However, the current generation of models is geared for urban transportation analysis and especially to assess peak-period congestion. The trip tables that drive the models do not do a good job of accounting for off-peak and nighttime truck travel, which is common with many trucking operations. The models also do not deal well with assigning multiday trips, which are the norm for long-haul trucking operations. Methods are available, but are seldom applied, to approximate truck time-of-day dispatching patterns and anticipate the decisions made by drivers and dispatchers in scheduling and routing around peak-period congestion.

3.7. Trade Policy

Federal Action. Restructure U.S. trade policies to promote in- and near-sourcing of goods and commodities. Examples of trade policies aimed at redirecting make-buy-sell supply chains are “Buy America” statutes and the more recent and broader effort to expand domestic petroleum and natural gas production and alternative clean energy sources (solar, wind, geothermal, etc.) to reduce the United States’ dependence on foreign energy providers.

Impacts. The freight demand impacts of policies directed at sourcing will vary by commodity. For example, substituting U.S.-manufactured consumer goods for similar products manufactured in China would reduce the VMT and emissions associated with the manufacturing process, consolidation, and container ship movement across the Pacific, but might not reduce VMT and emissions associated with the distribution of the consumer goods within the United States. The net “life cycle” effect on fuel use and GHG emissions will also be affected by the location of raw materials and parts suppliers. If they are within the United States, the impact of these policies may be positive in reducing freight transportation demand and associated energy use and GHG emissions; if outside, the net impact might be to increase overall freight transportation demand, as parts and raw materials would need to be imported to meet demand.

Implementation. The responsibility for implementation would fall primarily with the Department of Commerce and the Department of State.

Assessment Methods. Regional input/output models could be used to approximate the first-order effects of major changes in sourcing of commodities. Estimating the longer-term effects would require a detailed economic analysis of the industries involved and their supply chains.

3.8. Land Use

Federal Action. Provide federal tax incentives for the co-location of complementary manufacturing firms, distribution centers, and freight transportation terminals.

Proximity to highways has been a critical factor in industrial real estate development since the initiation of the Interstate Highway program, but not until demand outgrew highway capacity in the mid-2000s did industrial real estate developers begin to pay serious attention to the effects of congestion on travel time, travel reliability, and cost in site selection. Tax incentives could make development (or redevelopment) of industrial and freight staging areas that are closer to city centers more economically attractive. Likewise, location-efficient mortgages, which give lower interest rates to homeowners who live in closer proximity

to their places of employment, could help reshape urban areas over time, providing greater economies of scale in freight operations and fewer truck-miles of travel.

The location of freight facilities has historically been determined at the local level. More centralized planning at the regional or state level might help promote the establishment of concentrations of freight activity (freight villages) serving multiple industries. Another key factor is the ability of local and state governments, with federal assistance, to preserve existing freight assets and freight corridors from being displaced by non-freight uses.

Impacts. As long as freight transportation costs remain low relative to other production factors, such as capital, labor, and technology, land-rent economics will generally favor the migration of industrial and transportation logistics uses to the edges of metropolitan areas. The short-term impacts are likely to be modest, but retrospective studies of the impact of federal home ownership policies since World War II, coupled with highway funding programs, are strong illustrations of the longer-term potential of tax incentives to influence the spatial form of urban areas.

Implementation. This action would likely be implemented through the Department of Treasury and the Internal Revenue Service.

Assessment Methods. Metropolitan area land use and transportation models can be used to project the impact of land use, zoning, truck parking, and pricing on settlement patterns and transportation demand. For example, the Metropolitan Washington Council of Governments (and others) has explored policy impacts to 2040 and 2050. The models do not generally address freight demand and transportation, but could be extended and calibrated to do so.

3.9. Opportunity Matrix

The opportunity matrix in Table 3.1 arrays potential federal policy actions along two dimensions: the probability of their implementation, and the likely payoff measured in terms of reduction in freight transportation energy use and GHG emissions. The allocation of the actions is based on best professional judgment, and is not intended to promote or oppose particular actions.

Table 3.1. Opportunity Matrix for Freight Transportation Energy Use and GHG Emissions Initiatives

		Potential Reduction in Freight Transportation Energy Use and GHG Emissions		
		Low	Moderate	High
Probability of Implementation	High			Increase heavy-duty engine efficiency and emission standards.
	Moderate		Increase investment in freight infrastructure. Increase federal motor fuel tax. Implement road pricing (VMT user fees).	Impose low-carbon fuel standards.
	Low	Provide tax incentives for the co-location of freight generators and terminals. Deregulate U.S. coastal shipping.	Restructure U.S. trade policies to promote in- and near-sourcing.	

4.0 FREIGHT TRANSPORTATION DEMAND PROJECTION METHODS

4.1. Overview

Freight demand projection methods have received much attention over the past decade and have employed increasingly sophisticated forecasting methodologies. These methods have helped generate better and more accurate estimations of freight demand both in terms of flow volumes as well as mode shifts. At the same time, the models have also become very “data-intensive.” The lack of current and accessible data, not analytical capabilities, is the larger problem today in estimating future freight demand. Available freight demand projection methods and models fall under the following categories:

- Macroeconomic/Commodity Models, which estimate current and future forecast freight traffic by linking economic activity to freight flows
- Time Series Models, which estimate future demand based upon extrapolations of historical freight demand data
- Behavioral Models, which include both choice- and survey-based demand models and capture how shippers select modes
- Demand/Supply Equilibrium Models, which model freight demand based on balancing demand against supply, with the costs of supply associated with acceptable levels of service
- Microsimulation and Agent-Based Models, which simulate large numbers of individual freight shipments and sum them to produce total freight flow estimates
- Supply Chain and Logistics Models, which aim to capture the relationship between suppliers and customers and the decisions made by participants in the supply chain that affect freight demand.

Because freight is a derived demand and very responsive to changes in economic activity, estimates of freight demand generally correlate with economic activity, and macroeconomic models frequently form the basis for most advanced freight forecasting models. Time series models, though crude, provide an easy way to estimate general growth of freight flows, especially when data are lacking; however, the major shortcoming of time series models is that they are not sensitive to policy changes, changes in modal services, or major investments that reduce the cost of transportation. Behavioral models provide an improvement relative to time series models and can offer the capability to estimate the shares between competing modes. Microsimulation models and supply chain/logistics models are specialized behavioral models with the former tending to be more focused on vehicle utilization decisions (equipment types and payloads and routing and dispatch patterns), whereas the latter tend to capture decisions across an entire supply chain. Demand/supply equilibrium models explicitly account for supply constraints in the transportation system that would tend to dampen demand.

This section provides detailed descriptions of freight demand projection methods, covering those that are in current use or have been developed in the past decade. It includes methods used by national transportation agencies, states, and other regional agencies from around the world. It also includes methods discussed in academic papers as well as methods used by commercial vendors. However, only methodologies that are applicable to the goals of this report, to help develop alternative future scenarios, are included. Thus the focus of this review is on models that are effective at characterizing aggregate demand at the international, national, or state level. Most of the recent work on microsimulation and agent-based models has focused on smaller area forecasting that is not appropriate to national-level demand forecasting. Supply chain and logistics models are relative newcomers to the field of aggregate demand forecasting and so most of the models that are described in the literature are conceptual and have seen limited application in practice.

The methods reviewed are:

Macroeconomic/Commodity Demand Models

- Input/Output Accounts
- FAF3
- Transearch
- Random-Utility-Based Multi-Zonal Input-Output Model (RUBMZIO).

Time Series Models

- American Association of Railroads, American Trucking Association, PIERS
- Freight Forecasting Using Economic Indices
- FTR Associates' Freight Forecasting Model
- New Brunswick Intermodal Freight Projections
- Virginia Department of Transportation (VDOT) I-81 Freight Projections
- National Freight Demand Modeling using Simple Regression.

Behavioral (Choice) Models

- Neural Network Model for Multimodal Freight Network Modeling
- Great Britain Freight Model (MDS Transmodal and UK Department for Transport 2012).

The review shows that none of the available generation of freight transportation demand models addresses all the factors that shape freight transportation demand. However, for the purposes of the study, macroeconomic input/output models and behavioral (price elasticity of demand models)—coupled with national-level freight flow assignment network models—will be the most useful because they can provide direct estimates of the impacts of key factors, such as population, economic activity, and trade patterns, on tons and ton-miles of freight demand, which can then be translated in fuel use and GHG emissions estimates. Most of the other models also address population, economic activity, and trade patterns, but execution of these models requires extensive data collection and calibration that make them less appropriate for a first approximation of impacts of national-level changes in freight demand on fuel use and GHG emissions.

The NREL Freight Energy Analysis Tool provides the capabilities to explore the first-order effects on fuel use and GHG emissions of changing:

- Commodity tonnage and mix (approximating input/output effects)
- Commodity shipment origins and destinations (approximating shifts in the origins and destinations of networks flows)
- Mode of transportation (approximating modal price elasticity effects).

4.2. Macroeconomic/Commodity Demand Models

4.2.1. Input-Output Industry Accounts

- Method name: Input/Output Industry Accounts.
- Developer/owner: Bureau of Economic Analysis (BEA) (U.S. Department of Commerce BEA 2010).
- IP rights and transparency of method and data: Interactive data freely available online. Published data methodology is available online, but dated (1992).
- Contact person: Carol E Moylan, (202) 606-9612.

- Overview of methodology: The Input-Output (IO) accounts are economic accounts that display the interdependencies among different economic sectors. The accounts are widely used as input data for freight-flow forecasting methodologies. The BEA IO accounts contain the *make* table, the *use* table, and *direct requirement* and *total requirement* tables that show the inter-industry relationships within the U.S. economy. Benchmark IO accounts are published every five years and include most detailed data from the Economic Census, with the latest one released in 2007. Another type of IO account, the Annual IO accounts, is available every year and has information on 65 industries rather than the 425 industries in the benchmark accounts.

The benchmark IO accounts are based primarily on data collected from the economic census every five years. The Economic Census data contain information on industry and commodity production, materials consumed, operating expenses, etc. Annual IO accounts employ data from a plethora of sources for each industry, which are generally industry-specific survey data (such as agriculture, retail trade), or component-specific (such as employment, tax data).

The benchmark IO accounts are prepared as follows:

- Industry and commodity outputs for the IO *make* and *use* tables are estimated with gaps in the data filled from other sources
- Commodity inputs required by an industry to produce its output are estimated
- Value added by all industries is estimated. “Value added” consists of compensation of employees, indirect business tax, nontax liability, etc.
- Detailed final-use categories are completed.

Using the IO accounts, the direct and indirect effects of changes in final uses on industries and commodities can be determined. For instance, the effect of increases in energy prices can cause a decrease in demand for driving, and therefore reduction in motor vehicle production, which can reduce production of steel, chemicals, iron, limestone, etc., and therefore ultimately reduces the commodity flow on the transportation network.

- Major inputs: Economic Census. Other data are drawn from National Income and Product Accounts, Bureau of Labor Statistics, U.S. Department of Treasury, U.S. Department of Energy, Office of Management and Budget, among others.
- Major outputs: *Make*, *use*, *direct requirement*, and *total requirement* tables. Output requirements per dollar of delivery to final demand.
- Duration: No forecast data.
- Time steps: Historic benchmark data available every five years. Annual data are also available until 2010.
- Geographic scope: U.S. national level; however, when supplemented with regional data from BEA, IO analysis can show economic effects by region. Other commercial software packages (e.g., IMPLAN) can be used for regional analysis at the county level.
- Commodity: Available in North American Industry Classification System (NAICS) code-based industries covering 17 broad commodity groups (U.S. Census Bureau 2012).
- Strengths: The IO tables provide inter-industry relationships and can help show the effect of changes in one industry on others. For example, if a future scenario specifies a change in the energy commodity mix, the IO tables can determine higher-order changes in flows of all input commodities that result from the initial change in energy commodity demand.

- Weaknesses: Application of IO to forecast freight flow, especially at the subnational level, is a major effort, requiring large amounts of regional data to obtain statistically robust IO coefficients. While the BEA IO tables do provide information about the value of goods produced and consumed in the United States (by industry sector and commodity), they do not provide information about tonnage or origin-destination information for the commodity flows. Thus, it is impossible to directly determine ton-mile or vehicle-mile freight demand from IO tables. An extension of the national IO accounts is the multiregional input-output approach. An active example of this type of model is offered by MIG, Inc. (formerly the Minnesota IMPLAN Group) as part of its IMPLAN v3 software. The IMPLAN multiregional input-output was developed by MIG and the U.S. Forest Service. In addition to many standard IO data inputs, it uses information from the U.S. Commodity Flow Survey (see Freight Analysis Framework below) to develop the origin-destination characteristics of commodity flows.

4.2.2. Freight Analysis Framework 3

- Method name: FAF3.
- Developer/owner: FHWA (U.S. DOT FHWA).
- IP rights and transparency of method and data: The data are freely available online in raw format as well as summary formats. The methodology used for both the base and future cases are detailed and available online.
- Contact person: Michael Sprung, Michael.Sprung@dot.gov.
- Overview of methodology: FAF3 is a comprehensive database of freight movements among states and major metropolitan areas by all modes of transportation. Base year (2007) data primarily comes from the 2007 Commodity Flow Survey (CFS) by the Bureau of Transportation Statistics. To overcome data suppression issues from CFS, log-linear modeling combined with iterative proportional fitting is used to provide estimates for missing cell values and reconcile estimated flows. Supplemental data from Waterborne Commerce Data, STB Public Use Carload Waybill Sample Carload, and older U.S. Commodity Flow data and other commodity-specific data (where available) are used to further improve accuracy.

In addition to overcoming the issue of data suppression, freight flows for industries that are out of scope for CFS are estimated using other data sources (primarily through existing survey data) and methods. IO tables are used in combination with these data sources to come up with final freight flows.

For forecasts, the tonnage and value forecasts are based on the long-term projection of the U.S. economy produced by IHS Global Insight. Baseline, high, and low scenarios are developed using different assumptions of future industry productions and employment for each industry drawn from IHS Global Insight's U.S. macroeconomic forecasting model.

A multistep approach was used to develop the baseline forecasts:

1. Establish national control totals by commodity.
2. Apply specific shipment growth by market and commodity.
3. Apply specific purchasing and consumption growth by market and commodity.
4. Summarize and compare the results from Steps 2 and 3 with national controls.
5. Adjust the resulting freight flows so that volumes correspond with the national control levels.

For previous domestic forecasts, IHS Global Insight's Business Market Insights database (BMI) was used to provide output and employment forecasts to 2040 using annual growth rates for region-to-region shipment forecasts. For region-to-region purchase forecasts, IO tables from IHS

Global Insight's Business Transaction Matrix (BTM) were used. The base year volumes obtained are then forecast using growth rates in BTM.

- Major inputs: CFS, output, and employment data (BTM), IO commodity data (BTM).
- Major outputs: Annual tonnages and dollars of goods transported.
- Duration: From 2007 to 2040.
- Time steps: Every five years starting from 2010.
- Geographic scope: Flows between all U.S. states and 123 FAF zones (which approximate metropolitan areas) are available, as well as the remainder of state totals. In addition, export and import flows between United States and eight foreign regions are also available.
- Commodity: Commodity information available at two-digit SCTG codes level.
- Mode: Truck, rail, water, air, pipeline, multiple modes and mail, other and unknown, and no domestic mode.
- Strengths: The method is detailed and linked to long-term macroeconomic forecasts. It is the only dataset that attempts to fully link multimodal trips.²³ Base year data are perhaps the most extensively used open-source commodity flow data.
- Weaknesses: It does not account for the effects of energy, fuels, and the environment on the input factors. General assumptions must be made on how such factors will impact employment, IO and so on. The FAF base data are updated only every five years, and, by the time of its release, three years have passed since the data were collected.

4.2.3. Transearch

- Method name: Transearch.
- Developer/owner: IHS Global Insight (2012).
- IP rights and transparency of method and data: The data must be purchased and used for specific projects with use governed by specific contract terms. Data forecasting methodology must be requested; it is not publicly available.
- Contact person: Marc Venditti, (781) 301-9325.
- Overview of methodology: Transearch is an annually published commodity flow database that can be customized for regions and provides freight flows by Origin/Destination, commodity, and mode. Base year production data start with IO tables from BEA to determine output volumes, as well as BMI databases from Global Insight. The BMI county-level sales information is used in conjunction with BEA IO tables to estimate the value of production and consumption for each commodity at the county level. The tonnages at the county level can then be determined from control totals obtained from governmental agency sources.

Various supplemental data sources are used for development of modal freight flows. Rail traffic data come from the Surface Transportation Board's Carload Waybill Sample data, and waterborne traffic from the U.S. Army Corps of Engineers. Truck flows, being the most complicated to determine, are calculated by subtracting the other modal flows from total flows. These flows are then fed into a gravity model for determination of Origin/Destination pairs. The results are supplemented with actual truck freight flow data collected from large national motor carriers who

²³The calculation of multiple modes and mail in the FAF3 is incorrect. The decision to rectify this issue or wait until the next FAF release has not yet been made as this is being written.

provide data to IHS Global Insight in a data exchange program from which the carriers obtain access to the final Transearch product.

For the forecasts, projections of supply (originating flows) and demand (destination flows) by county and four-digit STCC are developed and then constrained to a national total. The forecast uses supply and demand-side factors, including employment, output, and purchases by industry and county. It focuses on freight volumes, but a value forecast is also produced that holds the base year price as fixed. The county-to-county commodity shipments are forecast by using proprietary information from a variety of sources within IHS Global Insight, listed under major inputs below.

- Major inputs: U.S. macroeconomic data, energy service data, automotive service data, world trade service, BMI and, BTM IO tables (all from IHS Global Insight).
- Major outputs: Annual tonnages and dollars of goods transported, and also units (such as truck loads), VMT, and ton-miles.
- Time steps: Base year and future year value are usually provided.
- Geographic scope: Flows are available at county level for each of the counties within the United States and also for regions in Mexico and Canada.
- Commodity: Commodity information is available at four-digit STCC code level for more than 450 commodities.
- Mode: For-hire truckload, for-hire less-than-truckload, private truck, conventional rail carload, rail/highway intermodal, air, water.
- Vehicle and fuel categories: Trucks are broken into for-hire truckload, for-hire less-than-truckload, and private truck. No information is available by fuel type.
- Strengths: Forecasts are detailed both in terms of geography and commodity at a level not available elsewhere. Furthermore, Transearch is the only available source that categorizes truck traffic by type.
- Weaknesses: The complex nature of the forecasting methodology means it is not easy to determine the effect of energy and other factors on freight demand. In addition, the actual forecast tools that underlie the models are proprietary and not necessarily peer reviewed. Linkage between multimodal trips is limited to rail/highway intermodal.

4.2.4. *Random-Utility-Based Multi-Zonal Input-Output Model (RUBMZIO)*

- Method name: Random-Utility-Based Multi-Zonal Input-Output Model (RUBMZIO).
- Developer/owner: Lin Jing, Kara Kockelman, Yong Zhao, The University of Texas at Austin.
- IP rights and transparency of method and data: IP rights unknown, methodology transparent and detailed in published papers.
- Reference: Kockelman et al. (2005). Tracking land use, transport, and industrial production using random-utility multizonal input-output models: applications for Texas trade. *Journal of Transport Geography* 13(3), pp. 275–286.
- Overview of methodology: The RUBMZIO model combines a random-utility model with a multizonal IO model to estimate production, trade, and travel using Texas data. This model simulates trade patterns of labor and commodities among zones based on different export demands, production technologies, travel modes, and network routing options. It can be used to explore changes in location choices, production, and trade flow patterns due to different export demand and travel costs.

The structure of the RUBMZIO model consists of disutility functions between zones, production functions, and trade flow functions. Disutility functions are based on acquiring some commodity from one zone and consuming it in another zone, dependent on transportation cost. A nested logit model structure is used to determine choices between mode and origin. For this purpose, the 1997 CFS data were used. IMPLAN's industry-by-industry transaction tables are used to generate technical coefficients for estimating parameters as well. The functions are solved iteratively together to achieve an equilibrium trade pattern. Behavioral data, such as mode preferences, are required to calibrate the model, and various input data, such as export demands, are required to run the model.

One of the most important relationships determined from this model is the effect of transportation costs on trade volumes. The model predicted that a 10% travel cost increase caused a 9.8% decrease in a trade-weighted average highway travel distances and 10.1% decrease in railway travel distances. A 10% decrease in costs resulted in a 10.1% increase in trade-weighted average highway travel distance and a 10.3% increase in trade weighted average railway travel distance.

- Major inputs: 1997 CFS data, 1997 IMPLAN industry transaction tables by county, TransCAD shortest inter-county path distances by mode.
- Major outputs: Freight flow volumes on routes.
- Geographic scope: Texas's 254 counties.
- Commodity: Eighteen economic sectors.
- Mode: Truck and rail.
- Strengths: This is a highly detailed but aggregate model that combined traditional IO models with logit-based utility maximizing approach. It provides linkages between transportation costs and freight demand.
- Weaknesses: The model is calibrated using Texas-specific data that may not be applicable on a nationwide level. It is also very complex and data-intensive.

4.3. Time Series Models

Time series models forecast freight demand by using historical freight demand trends or by regression analysis of those trends and correlated economic variables. While there are many methods used, mode-specific forecasts are also provided by associations such as the American Trucking Association and the American Association of Railroads.

For the most part, the forecasts provided by these associations are straightforward extrapolations of historic trends. IHS Global Insight that uses Transearch data, government data, including the CFS, and historic industry data to develop transportation demand reports for the American Trucking Association. The forecast covers primary shipments and domestic moves only with a time horizon of 10 years. The forecast is reported by tonnage and revenue for each mode of freight transportation.

The American Association of Railroads also produces a report based on 10-year historical rail volume data and the trends of various economic indicators. By extrapolating the relationship between real-time GDP and rail volumes, a straight line forecast can be made. Coal and grain volumes must be excluded because they vary with international market conditions and are influenced strongly by external demands not directly related to GDP. PIERS, a commercial product that reports container shipping volumes also provides short-term forecasts on container volumes, carriers, and ports.

4.3.1. Freight Forecasting Using Economic Indices

- Method name: Freight Forecasting Using Economic Indices.

- Developer/owner: Fite et al. (2002).
- IP rights and transparency of method and data: IP rights are not known. Description of methodology available.
- Contact person: Jonathon T. Fite, Accenture Consulting.
- Reference: Fite, J.T., Taylor, G.D., Usher, J.S., English, J.R., Roberts, J.N. (2002) “Forecasting freight demand using economic indices,” *International Journal of Physical Distribution and Logistics Management*, 32(4), pp. 299–308.
- Overview of methodology: This is a short-term forecast model used to predict future freight volumes in the truckload industry. The approach involves the use of stepwise multiple linear regression models that relate freight volume to a variety of economic indicators. The models are built using a large set of actual freight data provided by JB Hunt Transport for three years. The data were first analyzed using a set of national data, and then data on specific industrial and regional segments. The model development steps are outlined below:
 - Historic monthly freight demand is obtained from JB Hunt.
 - Economic and industrial indices from 107 different sources (e.g., commodity price index) for the same time period are obtained.
 - Multi-linear regression formula is used to model the cause and effect relationships between the monthly values of indicators, and monthly freight volume.
 - Indicators with the best correlation are identified and used in constructing a multivariable model linking the indicators to freight demand.
 - The model is validated, and industry- and regional-level models are developed using similar methods.
- Major inputs: Historic monthly freight demand data (JB Hunt), 107 economic and industrial indices (from various sources).
- Major outputs: Near-term freight demand in the truckload industry.
- Duration: Near-term forecast (mostly suitable for monthly predictions).
- Time steps: Monthly.
- Geographic scope: U.S. national level, regional level.
- Commodity: Represented by 13 large industrial segments.
- Mode: Truckload.
- Strengths: The model is straightforward and useful in predicting short-term freight demand in the truckload industry.
- Weaknesses: The forecast is only available for the short term and is limited to the truckload mode. Because it depends solely on the values of several economic indices to predict demand, the effect of different energy futures cannot be readily predicted using this model.

4.3.2. FTR Associates Freight Forecasting Model

- Method name: FTR Associates Freight Forecasting Model.
- Developer/owner: FTR Associates (FTR 1999).
- IP rights and transparency of method and data: Forecast data in the form of reports are available for purchase by the public. Methodology of forecast data development is briefly outlined online.

- Contact person: Eric Starks, estarks@ftrassociates.net.
- Overview of methodology: The FTR Freight Forecast Model is a short-term forecast model used to forecast U.S. freight tonnage movements based on industry economic trends. This model was first constructed in the mid-1980s and was re-estimated during 1997–1999. It is based on an estimation of the movement of heavier goods in the U.S. economy. The development of the base data and forecasts follows the steps below:
 - Total tonnage movements for different commodity/industry categories are determined regardless of mode of transportation.
 - Tonnages are moved to different levels of the country’s economic infrastructure, including extraction, basic manufacturing, and finished manufacturing, wholesale, retail, and waste/recycling.
 - Moves are distinguished by types of movements, including to the next-stage, intra-stage, imports, and exports.
 - Tonnages are then assigned to three-digit commodity categories using various data sources, including the CFS.
 - Rail, truck, pipeline, and water modes are assigned to move the tonnage. Lengths of haul are set to determine ton-mile values.
 - Annual tons and ton-miles estimates are turned into quarterly values and forecast using the historical pattern of economic forecast data, which is provided by the Center for Econometric Research of Indiana University. Modal shares are kept constant for forecast values.
- Major inputs: Economic data from the Center for Econometric Model Research (Indiana University), Economic Census Data (Census Bureau), 1993 and 1997 CFS and industry reports (U.S. Department of Commerce). Other data sources are public data sources pertaining to rail, energy, minerals fisheries, and agriculture.
- Major outputs: Near-term reports on freight volumes (tons and ton-miles) from shippers, trucking, intermodal, rail, and driver supply perspectives.
- Duration: Near-term forecast (less than five years).
- Time steps: Monthly, quarterly data, annual (up to five years).
- Geographic scope: U.S. national level.
- Commodity: Available at three-digit STCC Code level.
- Mode: Truck (includes short-haul), rail, water, and pipeline.
- Vehicle and fuel categories: Trucks are divided into truck-load, less-than-truckload.
- Strengths: The model and data are comprehensive (in terms of both modes and commodities) and provide realistic short-term forecasts based on real-time economic trends.
- Weaknesses: The method provides only short-term forecasts as market information for specific industry sectors; therefore, it is not suited for long-term planning purposes. The forecast of the model is based exclusively on industry economic forecasts and does not take into consideration shifts in mode choices, which is an important consideration for long-term forecasts.

4.3.3. *New Brunswick Intermodal Freight Projections*

- Method name: New Brunswick Intermodal Freight Projections.
- Developer/owner: J. Robert G. Brander and Frank R. Wilson.

- IP rights and transparency of method and data: IP rights not applicable; model outlined in published paper.
- Reference: Brander and Wilson (2001). Regional intermodal freight transport flows and projections. *Transportation Research Record* 1763: pp. 20–26.
- Overview of methodology: This methodology involves a trend-based extrapolation of the most likely growth scenario using a freight database, constructed for the study through data collected from truck, rail, water and marine centers, and a shipper survey. Because the scope of the study is limited to a region, current trends for each component of intermodal transport were analyzed. Uncertainties about the future planned expansions were used to determine the growth trend for intermodal traffic, and trade and GDP data for the province and nation were used as expansion proxies. By determining the relative growth of the region to the nation, a factor was determined that can be multiplied with trade and GDP growth factors to obtain adjusted regional factors. This resulted in six growth factors, covering each traffic type (container, trucking, and intermodal rail) and trade/GDP combination. The most likely scenario factor was then chosen and the factor used for straight-line extrapolation (e.g., one half the growth of intermodal rail using GDP as a proxy). This generated freight forecasts for all Origin/Destination movement pairs (out of nation, within nation, international, between Atlantic Canada).
- Major inputs: Provincial and national trade and GDP historic data, base case freight flow data.
- Major outputs: Freight flows in number of intermodal units.
- Duration: Near to medium term (1998 to 2005).
- Geographic scope: New Brunswick, Canada.
- Commodity: Represented by 13 large industrial segments.
- Mode: Railroad intermodal.
- Strengths: This is a relatively simple forecasting model that uses trade and GDP data, which are readily available. Different growth factors can be easily assumed and tested, and modal shifts can be predicted by using different modal growth rates.
- Weaknesses: This model is most suitable for regional databases because the effects of recent events on growth must be evaluated, which can be too burdensome at the national level.

4.3.4. VDOT I-81 Freight Forecasting

- Method name: VDOT I-81 Freight Forecasting (VDOT 2007).
- Developer/owner: Virginia Department of Transportation (VDOT).
- IP rights and transparency of method and data: IP rights unknown; forecasting methodology is transparent and outlined in report.
- Overview of methodology: This methodology involves forecasting freight traffic along the I-81 corridor to investigate truck-to-rail diversion potential in the future. The forecast for 2035 truck movements are developed within a Truck Trip Analyzer framework by applying a variety of economic growth rates to existing traffic counts. It is based on the premise that increases in industrial output create increases in freight demand, which translates to increases in freight traffic. The Truck Trip Analyzer model combines Virginia-specific commodity flow data with economic growth forecasts by industry developed by Regional Economic Models Inc. The development of the forecasts includes the following steps:
 - Processing existing VDOT truck counts.

- Forecasting single-unit truck trips.
- Processing state/industry output growth factors for forecasting combination truck trips.
- Developing state/industry commodity flow weights for combination truck trips.
- Forecasting combination truck trips.
- Estimating county/city truck trips.

Once the tonnage values are determined, a truck trip table is built using the 1998 Transearch database to estimate 2035 truck trips using Origin/Destination information.

- Major inputs: Regional Economic Models Inc. economic data, VDOT Truck Count Data, 1998 VDOT Transearch Database.
- Major outputs: Freight movements in commodity tonnages and truck trips.
- Duration: 2035.
- Time steps: Annually.
- Geographic scope: I-81 Study Area in Virginia.
- Mode: Truck.
- Strengths: This is a relatively simple methodology for forecasting freight tonnage as well as truck trips using economic data.
- Weaknesses: Effects of energy prices and patterns on growth rates must be determined before this method can be applied. This method works only with the Truck Trip Analyzer, but this tool can be replaced with another analyzer or modeling software.

4.3.5. National Freight Demand Modeling Using Simple Regression

- Method name: National Freight Demand Modeling Using Simple Regression.
- Developer/owner: Shi-Miao Chin, Ph.D. and Ho-Ling Hwang, Ph.D. of Oak Ridge National Laboratory.
- IP rights and transparency of method and data: IP rights unknown; model outlined in published paper.
- Reference: Chin and Hwang (2007). *National Freight Demand Modeling – Bridging the Gap between Freight Flow Statistics and U.S. Economic Patterns*. Oak Ridge, Tennessee: Oak Ridge National Laboratory.
- Overview of methodology: This methodology involves using simple regression-based estimation for quantifying national freight production/consumption by industry based on business patterns and population. It is based on the assumption that national freight demands are consistent with business patterns, and that a simple relationship exists between freight production/consumption and business patterns. It uses the 2002 CFS as the freight flow data source, the County Business Patterns data for business location and employment, etc., and the BEA IO tables to relate inter-industry transactions.

This methodology consists of estimation of regression equations for NAICS industry sectors at the state level for production and attraction. For freight production, two simple models – a linear and a power equation – are used to estimate the relationship between state-level freight shipped (y variable) and state-level annual payroll (x variable). For freight attraction, the same two equations can be used. To determine annual payroll values for freight receiving establishments (since this is not available in County Business Patterns), the IO *make* and *use* tables are utilized. By applying

“use” shares of industry sectors that use commodities produced by a given “make” industry sector, the annual payroll from industry sectors that “use” the commodities “made” by each industry can be estimated. The resulting freight demand models for the 27 industry sectors can then be used to estimate freight demand in the short run given projected annual payroll information.

- Major inputs: 2002 CFS, 2002 County Business Patterns, 2002 IIO Accounts.
- Major outputs: Freight production and demand by weight and value.
- Duration: Short term (e.g., less than five years).
- Time steps: Continuous.
- Geographic scope: National and state level; can also be disaggregated to county or zip code level.
- Commodity: Defined according to the 27 NAICS sectors.
- Mode: Truck, rail, water, air, multiple modes and mail, pipeline, other and unknown, and no domestic mode (2002 CFS modes).
- Strengths: This is a relatively simple forecasting model that estimates short-run freight flows at the national and state level. Its concept can be easily adopted and formulated using different economic factors.
- Weaknesses: This model relies on the availability of U.S. business forecasts, which may not be linked to energy demand in the future. It is not suitable for long-term scenario planning purposes and cannot predict future mode shifts.

4.4. Behavioral/Choice Models

One of the shortcomings of time series modeling of freight demand evident from the models reviewed above is its inability to model dynamic changes in improved technologies that impact relevant factors, such as cost. Behavioral-based models try to use more disaggregate data and methods that allow the incorporation of a wider range of explanatory variables using improved econometric methods.

Clark et al. (2005) provided a detailed review of aggregate and disaggregate behavioral freight demand models. Aggregate demand models use data that describe the behavioral aspects of a large group of shippers. The more advanced aggregate models are formulated using functions based on the relation between production and cost functions. Using the functions, elasticities of mode substitution and elasticity of demand for a mode can be estimated; these are found to vary across commodity groups. Nevertheless, it is found that these estimates may be understating the sensitivity of demand to price because using aggregate data can suppress a significant amount of information regarding variation in decision-making characteristics.

Disaggregate models on the other hand use data on individual decision-makers and may yield better elasticity estimates. Disaggregate models can be classified into *inventory*- and *behavior*-based models, with behavior models the most widely developed and discussed. The behavior models deal primarily with modal choice, and include discrete or joint choice and simultaneous equation, random utility models. These choice models can help analyze spatial policy issues, interaction between mode and shipment decisions, and generate elasticity estimates, but they require extensive data.

4.4.1. Neural Network Model for Multimodal Freight Network Modeling

- Method name: Neural Network Model for Multimodal Freight Network Modeling.
- Developer/owner: Peter Nijkamp, Aura Reggiani, Wai Fai Tsang.
- IP rights and transparency of method and data: IP rights unknown; method outlined in published paper.

- Reference: Nijkamp, Reggiani, and Tsang (1999). *Comparative modeling of interregional transport flows. Applications to multimodal European freight transport*. Research Memorandum 1999-2. Free University of Amsterdam, Netherlands. 1999.
- Overview of methodology: This methodology is based on the concept of artificial neural networks, which has been adapted from other fields and applied to transportation engineering. A neural network is a network based on the workings of neurons in the brain, where neurons are linked with each other through a predetermined pattern of connections. Values are sent through connections with weights. After the neural network is formulated, it goes through a learning process where the network adjusts the weights on the connections. This learning process can help the model eliminate “noise” in the data and hence reduce error associated with incorrect data. Time, cost, and distance are used as variables.

European transport data are applied to the model, which defines 108 regions in Europe and two modes (truck and rail). The same data set is also fed into a logit model and the performance by the neural network and the logit model are compared. It was found that neural network models in general are more accurate than logit models. When a sensitivity analysis between a neural network and a logit model is carried out, it was shown that neural network models were more suitable for spatial forecasting of freight flows, while logit models were more suitable for temporal forecasting.

- Major inputs: Freight flow data for Europe.
- Major outputs: Future freight flow data.
- Geographic scope: 108 regions in Europe.
- Commodity: Food and chemical products.
- Mode: Truck and rail.
- Strengths: Neural networks generate somewhat more accurate spatial freight forecasts.
- Weaknesses: Overall, neural networks do not offer significantly better results than logit models, and their complex architecture cannot be easily adapted for determining relationships between energy outlook and demand.

4.4.2. The Great Britain Freight Model

- Method name: The Great Britain Freight Model (MDS Transmodal and UK DOT 2012).
- Developer/owner: MDS Transmodal/UK Department for Transport.
- IP rights and transparency of method and data: Model developed and used by UK Department for Transport. Detailed methodology of various versions available online.
- Contact person: UK Department for Transport.
- Overview of methodology: This highly evolved model is the UK’s national freight travel demand forecasting model. Unlike other modeling systems, the software has been designed to adapt the inexpensive program to the expensive data, and not the other way around. Therefore, the model only works with one data set. The model can be used to do macro-forecasting; for example, estimating the effect of changes in GDP on freight ton-kilometers by mode in the future. It can also be used to understand national policy impacts, regional analysis, ports and port hinterlands, inland rail freight terminals, road and rail network impacts, and so on. A user-friendly interface allows users to carry out “what-if” tests related to policy variables, trend-based forecasts and changes to land use and employment.

The model follows the traditional four-step approach to modeling, but condenses it to two steps, which include matrix building and path/mode choice assignment. In addition, it has a forecasting component that combines trend- and scenario-based forecasting, where the latter is designed by the user. Economic forecasting trends provided by MDS Transmodal are used as input data for the trend forecasts. At the center of the model is the use of an F-Logit approach to choice modeling, where a route can win traffic if it is cheaper but not dominated by a similar, better alternative. This logit approach recognizes the effects of common routing elements and uses a similarity matrix to avoid selection of irrelevant alternatives to which other logit models are subject.

- Major inputs: World trade trends data model (MDS Transmodal), imports and exports by commodity, CFSs, and other modal data from various international and domestic sources.
- Major outputs: Freight flows on transportation networks in terms of tons, ton-kilometers.
- Geographic scope: UK national level.
- Mode: Truck, rail, water.
- Strengths: This is a comprehensive freight travel demand model that is based on economic, policy and trade data, and dynamic mode choice. Users can manipulate the model to produce various “what-if” scenarios on freight traffic flow total volumes as well as mode choices.
- Weaknesses: The method is highly complex and only adopted for the UK freight data.

5.0 ADDITIONAL ANALYSIS

This section provides brief descriptions of additional research that could produce better freight demand projections supporting U.S. Department of Energy policy and programmatic analysis. This report does not advocate for or against undertaking this additional research, but is intended only to identify research that might advance freight energy analysis to inform U.S. Department of Energy long-term planning.

Examine a broader range of scenarios through a more comprehensive and structured scenario analysis approach. In such an approach, “scenario landscapes” could be constructed that cover a wide range of possible values for key input variables (e.g., population, economics, technology, etc.). Some of these variables may also have probability distributions associated with their values. By combining these inputs with quantitative modeling tools, scenario landscapes can show an extensive range of possible futures and how these futures may be influenced by the policy interventions discussed in this issue paper.

Develop sketch-level maps of major industry-level supply chains. The FAF provides a snapshot of commodity flows by origin/destination and freight transportation mode; however, the FAF does not describe the underlying supply chains. Sketch-level descriptions of supply chains and distribution networks would help inform scenario development.

Disaggregate the FAF truck trip tables to create time-of-day truck trip tables. The FAF assignment process assumes that all trips are completed within a day and assigns trips to roadways assuming peak-period congestion. As a result, longer-distance trips are often routed on circuitous routes, which increase the calculated VMT and GHG emissions. In practice, many industries and carriers dispatch trucks, especially long-haul trucks, at night or at carefully engineered periods during the day so as to aggressively avoid being delayed in peak-period traffic, while using more direct routes than the model would assign.

Collect more complete and accurate data on urban freight flows and urban trucking operations. About half of all truck VMT is accrued in urban freight transportation and related construction and service operations, yet information about the patterns of urban truck freight flows, duty cycles, etc., is very limited. The national Vehicle Use and Inventory Survey (VIUS), now discontinued, covered only intercity truck trips with the latest data release in 2002. Prior to 1997, the survey was known as the Truck Inventory and Use Survey (TIUS). VIUS/TIUS were panel surveys done with the same vehicles/fleets over time and using registration data.

Collect better information on truck duty cycles to improve estimates of fuel use and GHG emissions. Trucks are used in a much wider range of operations than passenger vehicles and pick-ups, and most trucks are customized with specific types of engines, transmissions, and body elements to match specific types of freight operations (local pickup and delivery versus long-haul over-the-road transport). Better information on truck duty cycles linked to operational patterns and commodity flows would significantly improve the estimates of fuel use and GHG emissions.

Develop mega-region (multi-state) freight demand projections to more accurately reflect diverging economic and policy trends. The economies of the U.S. mega-regions differ significantly; consider, for example, the different structure and growth rates of the Northeast (Boston to DC) mega-region compared to the Pacific Northwest or the Upper Midwest regions. The NREL Freight Energy Analysis Tool follows the FAF convention of defining freight origin and destination zones by economic region. This makes it possible to tailor freight demand and modal share projections by mega-region and more accurately reflect differences among economic regions as well as differences in fuel use policy, regulation of freight transportation, and investment in freight transportation facilities.

6.0 CONCLUSIONS

As global populations and economic activity continue to grow, consumer demand for food, clothing, and manufactured goods keeps rising, requiring ever-expanding freight transportation services. This report examined existing research on factors and trends that shape freight demand, and their anticipated effect on freight demand and related energy use. The most significant factors in shaping freight demand between now and 2050 were identified as follows.

Economic Factors

- A projected U.S. population of 439 million and a global population of 9.3 billion by the year 2050 will translate into a 72% increase in U.S. freight transportation, as well as the potential for significant increases in exports to China, South America, and possibly Africa.
- “Green” lifestyle trends, including preferences for fuel-efficient cars and buildings, locally produced food and retail goods, and recycling, could modestly reduce the demand for long-haul freight transportation. However, these trends could also result in more small shipments with multiple origins and destinations, increasing the demand for energy-intensive truck and air cargo transportation.
- The consolidation of mega-regions could accelerate the use of rail (and some water) for long-haul shipping between regions and reinforce the dominance of trucking within mega-regions and the urban cores.
- High land costs and relatively low transportation costs are likely to maintain ex-urban warehousing and distribution centers, generating more truck-miles of travel on major distribution corridors leading into and within metropolitan areas.
- The agriculture sector, which currently accounts for a modest portion of GDP, is expected to be the single largest source of freight tonnage growth through 2040, with a projected increase of 1.1 billion tons.
- Five other commodity groups are also projected to experience total tonnage growth of over 150%: precision instruments, pharmaceuticals, miscellaneous manufacturing products, chemical products, and transport equipment. Higher-than-projected growth in these areas would generate new demand for domestic interplant freight transportation as well as export freight transportation.
- The majority of emergent industries produce high-value products, so demand will continue to grow for timely and secure delivery by truck and air.

Logistic Factors

- A shift toward on-demand supply chains will result in smaller shipment sizes and more individual products per shipment, which favors the use of faster and more reliable trucking, intermodal, and air shipments over rail and waterborne freight shipments.
- Higher fuel costs, congestion, and interest rates will likely continue to encourage major retailers and others to reposition distribution centers so that they can take advantage of lower-cost transportation (primarily rail) and minimize use of more expensive long-haul trucking.
- Advances in packaging and containerization will improve the efficiency of the freight system, reducing the energy consumed in carrying extra packaging and fielding extra shipments to make up for lost and damaged goods.
- Higher population densities in metropolitan areas and mega-regions will make possible more economies of scale in freight shipments.

Transportation Factors

- For long-haul freight demand, rising fuel costs will tend to shift demand from air and truck to rail. For short-haul freight demand, rising costs will shift demand from conventional diesel and gasoline powered trucks to hybrid-power trucks.
- The continued evolution and application of RFID shipment tags, on-board vehicle and trailer/container sensors, traffic monitoring systems, database technologies, global positioning systems, telecommunications, and precision dispatching and routing systems will significantly improve the productivity of all freight transportation systems.
- In the light- and medium-truck classes, there will be a greater penetration of hybrids and all-electric vehicles. Heavy-duty, long-haul trucks will see relatively slower improvement in productivity, gallons per mile, and emission reductions because of technological barriers and the need to maintain a high load-to-vehicle weight ratio.
- Freight railroads may be expected to retain their market share and perhaps capture more of the long-haul freight demand market.

Policy and Regulatory Factors

- Given the dominant role of trucking and highways in the U.S. freight transportation system, federal policies will likely favor continued investment to maintain highway capacity for trucking.
- Projected increases in truck traffic, diesel fuel consumption, and GHG emissions make it likely that EPA will consider tightening truck fuel-efficiency and emission standards by 2050. The impact of stricter standards on freight demand will depend somewhat on the ability of engine manufacturers to meet the standards without significantly increasing the cost of truck engines and fuels.

A review of possible federal policy actions determined that increasing heavy-duty engine efficiency and emission standards and imposing low-carbon fuel standards have the greatest potential for influencing freight demand and the highest probability of implementation. Newly enacted EPA and National Highway Traffic Safety Administration standards for medium- and heavy-duty vehicles are projected to reduce GHG emissions by about 270 million metric tons CO₂-equivalent and save about 530 million barrels of oil over the life of 2014 to 2018 model-year vehicles. More stringent low-carbon fuel would help attract and sustain investment in alternative fuels, potentially lowering the cost.

Policies that are likely to face greater challenges include:

- Increasing investment in freight infrastructure
- Increasing federal motor fuel tax
- Implementing road pricing (VMT user fees)
- Restructuring U.S. trade policies to promote in- and near-sourcing
- Providing tax incentives for the co-location of freight generators and terminals
- Deregulating U.S. coastal shipping.

None of the available models addresses all the factors this study identifies as vital in determining freight transportation demand. A combination of macroeconomic input/output, behavioral, and national-level freight flow assignment network models proved to be the most useful, with the capability to provide direct estimates of the impacts of key factors, such as population, economic activity, and trade patterns, on tons and ton-miles of freight demand, which can then be translated in fuel use and GHG emissions estimates. Although most of the other models address population, economic activity, and trade patterns, running these models requires extensive data collection and calibration that make them less appropriate for a first approximation of impacts of national-level changes in freight demand on fuel use and GHG

emissions. While this report provides a strong foundation of existing freight demand intelligence, many areas remain for future action. Examining a broader range of scenarios through a more comprehensive and structured analysis approach; collecting more complete and accurate data on urban freight flows, urban trucking operations, and truck duty cycles; and developing mega-region freight demand projections to more accurately reflect diverging economic and policy trends are just a few strategies for continued improvement. Accurately projecting demand and formulating sound policy will be crucial in meeting freight demand with energy efficient and low-emission freight transportation services.

APPENDIX: LITERATURE REVIEW

A.1 Overview

This literature review covers the following topics:

- Factors that shape the demand for freight transportation, including population demographics, economic activity, logistics strategies and practices, freight transportation modes and operation, and regulation
- Freight transportation demand projection methods, including data requirements, model types, and outputs.

A.2 Freight Demand

Authors of literature on the topic of freight demand generally agree that rapid growth in freight demand has been fueled by growth populations of consumers, global trade, and ever-changing logistics patterns. Research cited in this literature review address the impacts of demographic trends, such as aging population and urbanization, off-shoring and near-shoring production, customization of supply chain activities to meet customer specifications, transportation network capacity, and federal state and local government regulations on current and future freight demand in the United States.

The literature reviewed includes TRB publications and reports and studies completed by U.S. DOT, the American Association of State Highway and Transportation Officials (AASHTO), and the U.S. Army Corps of Engineers, most of which include a list and/or assessment of key factors and trends. The review also examined several journal publications and conference proceedings that provide further insight into one or more of the factors, trends, and potential future scenarios.

American Association of State Highway and Transportation Officials. *Transportation: Invest in America: Freight-Rail Bottom Line Report* (AASHTO 2002).

This report describes the nation's freight-rail system, issues, needs, and the estimated cost of addressing those needs. The Freight Rail Bottom Line Report is part of a series of AASHTO Bottom Line reports that deal with all of the major modes of freight and passenger transportation. The report discusses recent changes in demand for freight rail and identifies a number of trends and issues affecting the nation's economy and logistics networks in sum.

Beagan, Fischer, and Kuppam (2007). *Quick Response Freight Manual II*. Federal Highway Administration, Report No. FHWA-HOP-08-010.

This report provides background information on the freight transportation system and factors affecting freight demand and identifies sources of data and freight-related forecasts, and how to apply this information in developing forecasts for specific facilities and developing truck trip tables. The report provides a list and discussion of key logistics issues and tradeoffs.

Bingham (2006). "Freight Transportation Megatrends." *Freight Demand Modeling: Tools for Public-Sector Decision-Making*. Conference Proceedings 40, Transportation Research Board, National Academies Press, Washington, D.C.

This presentation reviews a comprehensive list of megatrends in demographics, consumer habits and demands, global trade, and regulations that are likely to impact demand for freight transportation in coming decades.

Case and Newman (2010). *Advances in Manufacturing Technology, VIII: Proceedings of the Tenth National Conference on Manufacturing Research*. University of Technology, Loughborough, United Kingdom.

This report provides a synopsis of discussions of current and future technological advancements in engineering, fabrication, assembly, and logistics processes, and the impacts those developments have on production capacity and freight transportation demand at the National Conference on Manufacturing Research held in the United Kingdom in 2010.

Castro and Kuse (2005). "Impacts of Large Truck Restrictions in Freight Carrier Operations in Metro Manila." *Journal of the Eastern Asia Society for Transportation Studies*, Vol. 6, 2005.

This document assesses the impacts of peak-period large truck restrictions on the operating behaviors of motor carriers in Manila, Philippines, and discusses some of the unintended impacts of regulations. The study found that because many receivers refused to shift delivery windows, motor carriers changed their vehicle fleets, purchasing smaller trucks that were not subject to the restrictions so they could continue to make deliveries during the peak period. This resulted in lower productivity and more vehicles on the roads during peak periods.

Corbett and Winebrake (2008). *The Impacts of Globalisation on International Maritime Transport Activity: Past Trends and Future Activity*. Organisation for Economic Cooperation and Development.

This report discusses the symbiotic relationship between globalization and maritime shipping, projected growth in maritime, and the energy and environmental consequences that maritime shipping has on global, regional, and local ecosystems. The report presents suggestions on how the environmental impacts of maritime shipping may be limited without hindering economic activity.

Deitz and Orr (2006). "A Leaner, More Skilled U.S. Manufacturing Workforce." *Federal Reserve Bank of New York Current Issues in Economics and Finance*, Volume 12, No. 2, 2010.

This article highlights the contraction of employment in the manufacturing sector and the rise of technology and productivity between 1980 and the mid-2000s in the United States.

Knight, K. (2008). *The Implications of Panama Canal Expansion to U.S. Ports and Coastal Navigation Economic Analysis*. Institute of Water Resources, United States Army Corps of Engineers.

Demonstrating the impacts of infrastructure capacity enhancements on freight transportation demand, this report presents anticipated impacts on maritime cargo volumes, port traffic, and potential bottlenecks in the landside transportation networks that may occur on the U.S. East Coast when the Panama Canal expansion is completed.

Rodrigue (2006). "Transportation and the Geographical and Functional Integration of Global Production Networks." *Growth and Change*, Vol. 37, No. 4, July 2006.

This article examines the trends of globalization and geographic decentralization of sourcing, gateways, and distribution hubs and discusses impacts of these trends on primary and secondary trade lanes.

Sheiner, Sichel, and Slifman (2006). *A Primer on the Macroeconomic Implications of Population Aging*. Finance and Economics Discussion Series, Divisions of Research and Statistics and Monetary Affairs, Federal Reserve Board, Washington, D.C.

This paper examines the aging trend in the U.S. population and discusses the macroeconomic consequences. The paper concludes that population aging will lead to a reduction in per capita consumption and workforce participation.

TRB (2003b). *Freight Capacity for the 21st Century: Committee for the Study of Freight Capacity for the Next Century*. Transportation Research Board Special Report 271.

This report contains a summary of the proceedings of the Committee for the Study of Freight Capacity for the Next Century in 2002. The committee outlined factors contributing to growing freight transportation demand, such as new railroad and port infrastructure, productivity growth, increasing population urbanization, and wealth. The report cautions that, if infrastructure capacity addition lags traffic in the

long term, a system breakdown could occur. The report advocates for a comprehensive federal government freight program that adheres to a list of guiding principles.

A.3 Freight Demand Projection Methods

The literature indicates that agencies at all levels of government have been working to develop analytical capabilities to estimate demand for freight transportation in their jurisdictions. These agencies have adopted different approaches, depending upon the geographic scope, variables they wish to track and data availability. These approaches vary somewhat with each application, but generally align with one of the following groups of models:

- Time series models that estimate demand based upon extrapolations of freight demand based upon historic trends (Cohen, Horowitz, and Pendyala 2008; Veenstra and Haralambides 2001).
- Behavioral models, which include both choice- and survey-based demand models, and capture how companies perceive and select from the many available freight choices (de Jong, Gunn, and Walker 2004).
- Commodity-based and IO models that estimate current and forecasted freight traffic generation and distribution by linking economic activity to associated commodity flows, and converting those flows to truck and rail trips (Kim et al., 2004) (Sorratini 2000; Lawrence and Kleinman 1997).
- Supply chain and logistics models that aim to capture the relationships between suppliers and customers and the decisions made by participants in the supply chain that affect freight demand. This approach is based largely upon proprietary information regarding private-sector supply chain and operations data (Jinghua, Hancock, and Southworth 2003).
- Network design models that private sector companies use for locating factories, distribution centers, warehouses, and other freight-generating facilities. Network design planning is very challenging given its scale, complexities, and decision interdependencies.
- Hybrid models that combine aspects of two or more of these approaches. (Cambridge Systematics, Inc. 2007b) (Fischer et al. 2005).
- This literature review summarizes the major recent meta or summary studies, primarily published by the Transportation Research Board, that offer comparative analysis of the types of approaches listed above, descriptions of data sources that currently are available, and describe existing future needs for freight data and modeling tool capabilities. This review also contains summaries of academic journal articles and research papers that describe representative applications of modeling approaches, particularly those that have experimented with incorporation of atypical analysis tools and data sources.

TRB (1997). *A Guidebook for Forecasting Freight Transportation Demand*. National Collaborative Highway Research Program (NCHRP) Report 388. Transportation Research Board, National Academy Press, Washington, D.C.

This report provides reference information on freight transportation planning processes, techniques, tools, data, and applications. The guidebook appendices include, among other resources, a list of factors that impact freight demand, freight demand forecasting studies, freight data sources, descriptions of survey procedures, statistical forecasting techniques.

FHWA (1999). *Guidebook and Statewide Travel Forecasting*. Prepared for the Federal Highway Administration by the Center for Urban Transportation Studies University of Wisconsin-Milwaukee.

This guidebook reviews the state of the practice of statewide travel forecasting current in 1999. The guidebook stresses that it is not possible to create a one-size-fits-all model to deal with every possible

situation, and that sometimes a simple application of a growth factor based on historic trends is more effective than an elaborate network analysis.

Clark et al. (2005). *A Survey of the Freight Transportation Demand Literature and a Comparison of Elasticity Estimates*. Navigation Economics Technologies Program (NETS) of the Army Corps of Engineers.

This report reviews several model approaches that estimate freight demand elasticities and finds that elasticities vary greatly by commodity and by region of the country. The study concludes that the functional form of models impacts the elasticity estimates.

Cohen, Horowitz, and Pendyala (2008). *Forecasting Statewide Freight Toolkit*. National Collaborative Highway Research Program (NCHRP) Report 606. Transportation Research Board, National Academy Press, Washington, D.C.

This report reviews the component steps of statewide freight models – generation, distribution, mode choice, and assignment. The report provides public and proprietary data sources for economic forecasting, commodity flow forecasts, and truck VMT data. The report suggests collecting on-the-ground data samples, such as truck counts and origin-destination surveys, to validate freight model outputs.

de Jong and Ben-Akiva (2007). “A Microsimulation Model of Shipment Size and Transport Chain Choice.” *Transportation Research Record Part B: Methodological*, Volume 41, No. 9.

This report summarizes an effort to develop a disaggregated behavioral model that simulates logistics decisions regarding shipment size and mode of transportation. The report argues that the traditional four-step modeling approach has difficulty capturing the factors, such as firm-to-firm relationships and distribution center requirements, which influence shipper and carrier decisions.

Fischer et al. (2005). “Innovative Framework for Modeling Freight Transportation in Los Angeles, California.” *Journal of the Transportation Research Board*, No. 1906, 2005.

This report proposes a modeling approach for Los Angeles County that combines logistics chain modeling and tour-based truck modeling elements to evaluate freight transportation demands and the impacts of transportation investments. The authors argue that logistics chain models improve basic commodity flow models because choice models are built into every step of the logistics chain. The report concludes with a suggestion that adding a tour-based model capability to capture service vehicles and local pickup and delivery activities would be a desirable feature for future development.

Fite et al. (2002). “Forecasting Freight Demand Using Economic Indices.” *International Journal of Physical Distribution and Logistics Management*, Vol. 32, No. 4, 2002.

In this article, the authors develop an approach to predict future freight volume and trade imbalances in the truckload trucking industry using stepwise linear regression models that relate historic freight data from a large motor carrier fleet to a variety of economic factors.

TRB (2006). *Proceedings of the Freight Demand Modeling: Tools for Public-Sector Decision-Making: Transportation Research Board Conference Proceedings 40*. 2006 September 25–27, Washington, D.C. Transportation Research Board, National Academies Press, Washington, D.C.

This report provides a summary of presentations and breakout sessions on several topics concerning current practices in freight demand modeling, emerging developments and international examples of modeling methodologies, analytical needs of public-sector agencies, and roles for developing those needed capabilities. Highlights of interest to this research include:

- A presentation by Paul Bingham that lists key megatrends in consumer demands, global trade, and regulations that will influence future freight demand

- A series of case studies of international stateside freight demand modeling efforts, including a model for Oregon that incorporates a land use model
- Findings that frequently or continuously collected national freight data and modeling tools that link econometric, transportation, logistics decisions, and economic geography are desired to support decision-makers.

Holguín-Veras and Patil (2008). *A Multicommodity Integrated Freight Origin-Destination Synthesis Model*. Springer Science and Media.

This paper presents an effort to develop and test an origin-destination synthesis model that combines a commodity-based model and a complementary model of empty trips. The results of the study show that the integration of the two models produced results that closely matched observed traffic counts. The authors suggest that the model could be used to estimate origin-destination matrices.

Holguín-Veras et al. (2001). *An Assessment of Methodological Alternatives for a Regional Freight Model in the NYMTC Region*. New York Metropolitan Transportation Council, New York, New York.

This report assesses various urban freight transportation modeling methodologies, including data requirements, staff requirements needed to maintain the models, computer hardware requirements, cost to develop and maintain, and conceptual validity.

Jinghua, Hancock, and Southworth (2003). *Simulation of Regional Freight Movement with Trade and Transportation Multinetworks*. Transportation Research Record No. 1854.

This report presents a microsimulation model that incorporates three simulation components: 1) a freight traffic simulator; 2) a supply chain decision-making simulator; and 3) a pseudo-real-time simulator. The model was designed to evaluate the effects of information technologies and logistic strategies on freight demand. The discussion of conclusions speculates that trends in technology, such as Internet auctioning of vehicle space, could be an influence that increases load factors, despite the decline in load factors brought on by just-in-time logistics.

Kornhauser and Morris (2003). *Urban Goods Movement Model for Manhattan*. New York Metropolitan Transportation Council, New York, New York.

The authors of this report describe the development of an urban freight model that takes a “land use-based approach,” using building characteristics, such as rentable square footage, to develop trip generation estimates.

Lawrence and Kleinman (1997). *Development of a Freight Forecasting Model to Forecast Truck Flow Between NJ Counties Themselves and Between NJ Counties and Other States*. New Jersey Department of Transportation.

This report summarizes an effort to develop a freight forecasting model to estimate truck flows at the county-to-county level. The effort used demand factors, including population, employment, earned income, total personal income, and commodity flow data to develop a gravity model based not on population alone, rather on a combination of many consumption variables.

Mizutani et al. (2006). “International Freight Transport Demand Forecasting by SCGE Model.” *2006 Intermediate Input-Output Meeting*, Sendai, Japan, July 26–28, 2006.

This paper highlights two steps to forecasting international freight demand: first, forecast trade; and second, calculate corresponding freight transport volume. To forecast international trade, this paper discusses a concept to append a “Capital Flow” model to a standard equilibrium model to track changes in international investments. The theory argued is that investments are constantly shifting to countries which offer higher returns on investment.

Pearson et al. (2005). *A Comprehensive Commodity/Freight Movement Model for Texas*. Texas Transportation Institute, on behalf of Texas Department of Transportation.

This report summarizes an effort to develop a statewide commodity flow model in the State of Texas. A key element of the approach required the disaggregation of statewide commodity flow data to the county level, based upon demographics. Travel surveys were administered and the data were used to estimate load factors and truck trip generation.

Regan and Garrido (2002). *Modeling Freight Demand and Shipper Behavior: State of the Art, Future Directions*. University of California, Irvine Institute for Transportation Studies.

This report serves as a synthesis of research in freight demand and an assessment of the advantages and disadvantages of several aggregate and disaggregate demand estimation methods at the urban, interregional, and international levels. The report also reviews research in shipper behavior modeling and evaluate the opposing forces of disintermediation and disintegration of supply chains.

Chin and Hwang (2007). *National Freight Demand Modeling: Bridging the Gap Between Freight Flow Statistics and U.S. Economic Patterns*. Transportation Research Board 86th Annual Meeting Compendium of Papers (2007).

This paper describes the national freight demand models covered by the 2002 Commodity Flow Survey. The CFS model estimation framework hinges largely on the assumption that a relatively simple relationship exists between freight production/consumption and business patterns for each industry defined by the three-digit NAICS industry codes. The paper concludes that the CFS freight demand models could be enhanced with capabilities to disaggregate origin-destination tables to county or zip code levels or to assess regional economic impacts associated with service interruptions.

Sorratini (2000). "Estimating Statewide Truck Trips Using Commodity Flows and Input-Output Coefficients." *Journal of Transportation and Statistics*, Vol. 3, No. 1, 2000.

This document describes an effort to model statewide truck trips using commodity flow data and input-output coefficients to derive freight production and attraction. The summary concludes with the acknowledgment that empty movements are absent from the analysis, and hence, results do not calibrate well to observed truck counts.

Southworth et al. (2010). *The Freight Analysis Framework, Version 3: Overview of the FAF3 National Freight Flow Tables*. Federal Highway Administration.

This report provides an overview of the data products included in the FAF3 database, improvements to the commodity flow matrix over previous versions of FAF, lists of geographic zones and transportation modes, a summary of the flow matrix construction process, and a summary of the methodological approaches to estimating flows of specific commodities and international flows.

TRB (2003a). *A Concept for A National Freight Data Program*. Transportation Research Board Special Report 276.

This report advocates for the establishment of a national freight data program that is reliable, consistent, and comprehensive. The program's purpose would be to support decision-making through pinpointing problems and prioritizing policies and investments. The committee envisioned a modular database that leverages existing data sources to the extent possible. The database would include data on: origin and destination; commodity characteristics, weight and value; modes of shipment; routing and time of day; and vehicle/vessel types and configurations. The report suggests roles for the U.S. DOT and other stakeholders in implementing and maintaining the program.

TRB (2011a). *How We Travel: A Sustainable National Program for Freight Data*. Transportation Research Board Special Report 304.

This report presents existing sources of freight and passenger data at the federal, state, and local levels and proposes a travel data system that can support public and private decision-making. Within this document is a comprehensive list of commodity flow, foreign trade, air traffic, highway performance, and commercial vehicle and use data available in the public and private domains. The report presents the cost of maintaining public data and the frequency with which the data are updated.

Veenstra and Haralambides (2001). "Multivariate Autoregressive Models for Forecasting Seaborne Trade Flows." *Transportation Research Part E*, Volume 37, 2001.

This article describes the use of multivariate autoregressive time series models to produce long-term trade flow forecasts of four commodities: crude oil, iron ore, grain, and coal.

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