



I-95 Corridor Coalition

FREIGHT PERFORMANCE MEASUREMENT

*Measuring the Performance of Supply Chains
across Multistate Jurisdictions*

White Paper



March 2016

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White Paper

prepared for:

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sponsored by:

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Executive Summary

This white paper reports on the feasibility of measuring transportation supply chain performance. A supply chain is an end-to-end path of freight moves. A supply chain may be a trip accomplished by a single truck move or a trip accomplished by a combination of truck, rail, ship, airplane or pipeline freight moves. A supply chain may be a short trip within a single metropolitan area, state or region, or a long trip spanning regions and continents.

Information on how supply chains perform from the perspectives of shippers, carriers and receivers is critical to knowing if supply chains are working or failing, and that information is, in turn, critical to determining if and where public investment might improve freight system performance and support economic competitiveness and growth.

The research examined five supply chains:

- **Retail.** Target Corporation supply chain moving consumer goods from the Ports of Los Angeles/Long Beach and Seattle/Tacoma through Chicago to a retail store in metropolitan New York;
- **Automobile Manufacturing.** General Motors supply chain moving automobile parts from suppliers in Michigan and Ontario, Canada, to an automobile assembly plant in Tennessee;
- **Food Products.** Perdue Farms, Inc. supply chain moving processed chicken from the Delaware-Maryland-Virginia (Delmarva) region to a food wholesaler in New York City;
- **Agriculture.** Soybean export chain from a farm in Illinois to a Louisiana port; and
- **Electronics.** Panasonic supply chain moving electronic parts and finished equipment between manufacturing and assembly facilities in San Diego, California, and Tijuana, Mexico.

The case studies were selected to cover the major U.S. regions and profile supply chains of different lengths and modes. They focused on the domestic portion of the supply chains, measuring freight movement along highways and rail lines and through ports, but not the time spent within private-sector warehousing or distribution facilities.

The case studies were used to determine if performance measures and metrics that are common across supply chains—travel time, travel-time reliability, cost, safety and risk—were reasonably available and cost-effective for public sector use. The study concluded that it is feasible and practical to map representative supply chains and measure their high-level performance.

Based on the findings and conclusions of the case studies, discussions with members the U.S. Department of Commerce Advisory Committee on Supply Chain Competitiveness, and the advice of the study sponsors and technical advisory committee, two sets of recommendations are provided—general and programmatic. The general recommendations are:

- Use transportation supply chain performance measures to inform freight transportation policy and target strategic investments in the freight transportation system. Failure to do so means less competitive industries and lost economic opportunity;
- Use travel time, travel-time reliability and cost as the key measures of supply chain performance. These measures are common across supply chains and can be scaled up or down for national, multi-state and metropolitan use. Safety and risk should be considered, but the data for generating valid and reliable measurements are not yet available;
- Provide standardized analytical methods and tools to cost-effectively measure end-to-end supply chain performance. There are multiple data sources and methods for measuring supply chain performance. Research and guidance is needed on the most valid and reliable sources and methods;
- Apply supply chain performance measures at the industry-, metropolitan-, state and multijurisdictional-, national- and North American-levels; and
- Disseminate supply chain performance information routinely to public- and private-sector supply chain stakeholders.

To advance the implementation of the general recommendations, the following are recommended programmatic actions:

- Establish a national supply-chain performance-measurement initiative. The nation needs a sustained program to understand how well the highway, rail and other networks support the timely and cost-effective completion of freight trips and whether those trips satisfy the needs of business and industry to compete and grow in national and global markets;
- Establish the initiative as a cooperative public-private enterprise. The Federal government, though the Department of Transportation and the Department of Commerce, should take lead responsibility to catalyze the initiative and provide a central point for integrating and disseminating supply chain performance information. The focus of private sector participation should be at the state and local level, ensuring that supply chain information is accurate and effectively incorporated into state and metropolitan planning organization (MPO) decisions about freight transportation investments;
- Direct research at improving the state of knowledge and the state of practice. Critical topics include: selecting a representative “market basket” of supply chains for measurement; determining an appropriate level of data granularity; obtaining data on urban freight stages; and correlating supply chains with freight traffic volumes;
- Provide policy direction, funding eligibility and competitive grant opportunities to encourage coalitions of states and metropolitan planning organizations (MPO) to undertake pooled projects to map out supply chains; and
- Develop model data acquisition contracts that MPOs, state departments of transportation and regional coalitions can use to purchase data from private sector suppliers, and encourage joint purchasing programs to take advantage of economies-of-scale in purchases.

- Produce an on-line guide and on-line seminars for transportation and economic development professionals that describe available data sources, analysis methods and applications.
- Pilot a benchmarking program that provides ongoing information about the performance of representative supply chains to the public and private sector shippers and carriers.

1.0 Introduction

The objective of this study was to demonstrate the feasibility of measuring transportation supply chain performance. A supply chain is an end-to-end path of freight moves. It may bring raw materials from mines to manufacturers, finished consumer products from manufacturers to wholesalers and retailers, food from farms to supermarket shelves, or building materials from suppliers to construction sites.

A supply chain may be a trip accomplished by a single truck move or a trip accomplished by a combination of truck, rail, ship, airplane or pipeline freight moves. A supply chain may be a short trip within a single metropolitan area, state or region, or a long trip spanning regions and continents.

Information on transportation supply chain performance is needed to fill a gap in state and multistate freight and economic development planning and investment. The public sector is accustomed to looking at the freight transportation system performance in terms of network and corridor capacity, infrastructure condition and safety. As a consequence, transportation planners and engineers tend to focus on the average condition and performance of a system or facility, not on the performance of an individual trip or shipment moving through the network from the perspective of a freight trip. Moreover, because their jurisdiction is often limited to a single state or metropolitan area, it is difficult for public sector planners and engineers to assess the end-to-end performance of supply chains, many of which extend across state and national boundaries.

The Council of Supply Chain Management Professionals defines a supply chain as "the material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user, for which vendors, service providers and customers are the links."

(<https://cscmp.org/research/glossary-terms>)

This study focused on the transportation elements of supply chains, especially, the highways, rail lines and ports that are the focus of most public sector policy, planning, regulatory and investment programs.

As a result, opportunities to make strategic investments in the freight transportation system that directly improve supply chain performance are often missed. The result is a less cost-effective freight transportation system, less competitive industries and lost economic opportunity. Information on how supply chains perform from the perspectives of shippers, carriers and receivers is critical to knowing if supply chains are working or failing, and that information is, in turn, critical to determining if and where public investment might improve freight system performance.

Information on transportation supply chain performance is also needed to support national freight system planning and reporting. In MAP-21 (Moving Ahead for Progress in the 21st Century Act), Congress declared that "It is the policy of the United States to improve the condition and performance of the national freight network to ensure that the national freight network provides the foundation for the United States to compete in the global economy..." Congress called for—

- Development of a national freight strategic plan;
- Designation of a national freight network;
- Preparation of a freight conditions and performance report; and
- Establishment of performance measures for states to use to assess freight movement on the Interstate system.

Congress specified that all four actions were to be informed by performance measures.

The findings and recommendations of this report are intended to—

- Provide information and preliminary guidance on data and methods for measuring supply chain performance;
- Outline issues involved in purchasing and using supply chain data while protecting confidential business information;
- Provide information on freight system performance from the perspectives of freight shippers, carriers and receivers; and
- Define issues that must be researched and methods that must be developed over the next five to eight years to provide more comprehensive and better integrated freight performance measures.

It is anticipated that the recommendations will help state departments of transportation (DOT) and metropolitan planning organizations (MPOs) measure the freight system performance along corridors, through metropolitan areas, across multi-state regions and among trading partners. The recommendations should also assist the Federal Highway Administration (FHWA) and state DOTs in setting performance goals and measures for the Interstate Highway System and other freight facilities.

The study was sponsored by the I-95 Corridor Coalition, the Federal Highway Administration (FHWA) Office of Freight Management and the U.S. Department of Commerce Advisory Committee on Supply Chain Competitiveness.

The I-95 Corridor Coalition is an alliance of transportation agencies, toll authorities, public safety agencies and related organizations along the Atlantic Coast from Canada and the States of Maine and Vermont to the State of Florida. On behalf of its members and working with the FHWA and other U.S. DOT agencies, the Coalition has championed and funded research and programs to improve knowledge of freight-transportation demand, make cost-effective investments in freight transportation infrastructure, and support safe and reliable freight operations. (<http://www.i95coalition.org/>)

The Coalition's Intermodal Committee, represented by co-chair Deborah Bowden of Maryland DOT, provided programmatic oversight for this project. The I-95 Corridor Coalition Freight

Mobility, Safety and Mobility Program Coordinator, Marygrace Parker, served as Project Manager, overseeing the consultants' work and coordinating the technical advisory committee that reviewed the report's findings and recommendations. The technical advisory committee members, who provided guidance on the project scope of work and selection of supply chain case studies, were: Christina Casgar, the Goods Movement Policy Manager for the San Diego Association of Governments (SANDAG); Bruce Lambert, Executive Director of the Institute for Trade and Transportation Studies; and George Schoener, Executive Director of the I-95 Corridor Coalition.

The FHWA Office of Freight Management and Operations provided funding for the research and access to the FHWA's new National Performance Management Research Data Set (NPMRDS), a national data base of truck travel speeds and times. The Freight Office is part of the FHWA Office of Operations. The Freight Office is charged with promoting efficient, seamless and secure freight flows on the U.S. transportation system and across international borders—freight flows that are critical to the wellbeing of the nation's economy and global connectivity. (<http://www.ops.fhwa.dot.gov/freight/index.cfm>)

U.S. Department of Commerce's 45-member Advisory Committee on Supply Chain Competitiveness provided a forum for discussion of the use of supply chain measures in the private sector, and policy guidance on the supply chain issues of critical interest to shippers and receivers, especially those serving global export markets. The Committee advises the Secretary of Commerce on the elements of a comprehensive national freight infrastructure and freight policy that support U.S. export growth, foster national economic competitiveness, and improve U.S. supply chain competitiveness in the domestic and global economy. (<http://trade.gov/td/services/oscpb/supplychain/acsccl/>)

2.0 Approach

There are thousands of supply chains serving hundreds of different industries. The objective of this study was to show that supply chain performance measurement could be applied—in practice as well as in principle—to a broad range of industries and supply chains and produce information to inform public sector investment in freight transportation systems. To this end, the research used a case study approach, measuring the performance of representative supply chains serving five different industries. The industries and the representative supply chains were:

- **Retail.** Target Corporation supply chain moving consumer goods from the Ports of Los Angeles/Long Beach and Seattle/Tacoma through Chicago to a retail store in metropolitan New York;
- **Automobile Manufacturing.** General Motors supply chain moving automobile parts from suppliers in Michigan and Ontario, Canada, to an automobile assembly plant in Tennessee;
- **Food Products.** Perdue Farms, Inc. supply chain moving processed chicken from the Delaware-Maryland-Virginia (Delmarva) region to a food wholesaler in the Queens borough of New York City;
- **Agriculture.** Soybean export chain from a farm in Illinois to a Louisiana port; and
- **Electronics.** Panasonic supply chain moving electronic parts and finished equipment between manufacturing and assembly facilities in San Diego, California, and Tijuana, Mexico.

The case studies were selected and researched under following guidelines:

- **Include a broad range of industries.** The case studies covered five industries: retail trade, automobile manufacturing, food manufacturing, agriculture and electronics manufacturing. The industries were chosen in consultation with FHWA, the I-95 Corridor Coalition and the Advisory Committee on Supply Chain Competitiveness;
- **Cover the major U.S. regions.** The structure and performance of supply chains vary by region, state and metropolitan area. The case studies were selected to cover the U.S. East Coast, Midwest and West Coast regions. The types of data and methods used by MPOs, state DOTs and multi-state regional transportation coalitions must be applicable and consistent across the United States. Accordingly, the study's technical advisory committee members were also chosen to represent the interests and perspectives of MPOs, state DOTs and regional coalitions in the East, Midwest and West;
- **Investigate supply chains of different lengths and modes.** The case studies examined local, regional, transcontinental and cross-border supply chains served by trucks, railcars and barges. The research budget did not allow for investigation of supply chains

that used ships and pipelines, but anticipated that the findings would be generally applicable to those modes as well;

- **Use measures and metrics that are common across supply chains.** The suggested measures were:
 - Travel time—measured in days (or hours) of transit and dwell time;
 - Travel-time reliability—measured as the 95th percentile of travel time in days (or hours). This measure was suggested because it is consistent with the measure used by FHWA, state DOTs and MPOs in transportation planning and traffic congestion management;
 - Cost—measured in current dollars;
 - Safety—measured by fatality and injury rates; and
 - Risk—measured by operations delays (e.g., from weather, customs, work zones and other local conditions), cargo loss and damage, capacity expansion delays (e.g., delays created by permitting and reviews), and disruption (e.g., storms, infrastructure failure, labor disputes and political actions);
- **Focus on the domestic portion of the supply chains.** The study focused on the domestic portions of the supply chains, recognizing that all the case study supply chains—especially the retail import and soybean export chains—have an international origin or destination leg. The domestic focus was intentional because the immediate intended use of the supply chain performance measures is to inform Federal, state and local freight policy, programs and investments;
- **Measure freight movement along the public and quasi-public freight transportation system links and nodes.** The research measured freight movements along highways and rail lines and through ports. It did not measure the time that freight shipments spend within private-sector warehousing or distribution facilities. The time that shipments spend within warehouses and distribution centers affects the overall time required to move freight through a supply chain, but the dwell time within these facilities is determined and controlled by private-sector business decisions and market conditions. The public sector will usually not have access to this information, so no attempt was made to explicitly identify or report dwell-time within private-sector production and warehousing facilities;
- **Report the high-level performance of the supply chains.** While it is possible and may eventually be desirable to measure supply chain performance over short distances and periods of time, the focus of the research was to measure the high-level performance of the supply chains; that is, movement across major links and nodes on quarterly or annual basis. The case studies did not attempt to duplicate the day-by-day and hour-by-hour performance tracking done by the shippers, carriers and receivers. That level of detail,

usually treated as confidential business information, is not needed to support most public policy, program and investment decisions; and

- **Address supply chain performance, not modal and network performance.** The case studies measured the performance of trips across highway, rail and port networks; they did not measure the performance of the modes as such. Assessment of the condition and performance of the nation's highways, rail lines and ports is critically important to MPOs, state DOTs and the FHWA in making program and investment decisions. Likewise, it is important that transportation agencies understand the social, economic and environmental impacts of truck, rail and port operations. However, modal condition and performance reports are available, and the methods for estimating economic and environmental impacts are well researched and described. This study focused on the missing layer—information about the performance of the freight trips from the perspective of the shippers and carriers.

3.0 Case Studies

3.1 Introduction

The five case studies are described in this section. Conclusions about the feasibility and practicality of measuring supply chains are summarized in Section 4.0. The study recommendations are presented in Section 5.0.

3.2 Retail Industry Case Study

The first case study examined a Target Corporation supply chain moving containerized consumer goods from the Ports of Los Angeles/Long Beach and Seattle/Tacoma through Chicago to a retail store in Metropolitan New York.

3.2.1 Industry

Consumer spending accounts for two-thirds of U.S. gross domestic product (GDP). Retail sales are a principal source of this spending. Excluding food services, retail sales account for about one-quarter of the nation's GDP.

The retail industry is a primary driver of U.S. imports. Although statistics on total imports for the retail industry alone are not published, five of the nation's top ten importers of containerized goods are retailers.

Target Corporation is the nation's fourth largest retailer of consumer goods, operating 1,800 retail stores throughout the United States and is the nation's second largest importer of containerized goods. Target buys from foreign and domestic vendors and supplies its stores from more than two dozen regional distribution centers (DC) across the United States.

The consumer goods sold in Target stores move along several paths from vendor to store:

- Imported goods are sourced chiefly from China and other countries in Asia. The goods arrive by container ship at U.S. West Coast and East Coast ports. From the ports, the imports may:
 - Move to an international DC near the port, where the goods are transloaded from standard 40' marine containers into larger 53' domestic containers, and then moved by truck to regional DCs near the destination stores; or
 - Move to a de-consolidator facility, generally located near the port, where the goods are also transloaded from the marine containers to domestic containers or truck trailers, and then moved directly to regional DCs near their final destinations or to a regional DC by way of the international DC (an Inland Point Intermodal or "IPI" shipment).
- Domestic goods likewise may move along three paths. They may move:

- Directly from the vendor to a regional DC near the destination stores, or in the case of many food products, to one of several regional DCs dedicated to handling food products;
- From the vendor to domestic consolidators situated around the country, and then to the regional DC; or
- From the vendor directly to the store, typically for food products where the vendor is a wholesaler or local producer.

Internet orders for home delivery are usually routed from the port (or from the domestic vendor) to one of several fulfillment centers, which function as regional DCs dedicated to Target's web business. In some cases, overseas and domestic vendors may ship directly to a home. This aspect of the retail business is changing, however, with responsibility for home delivery increasingly shared among fulfillment centers, regional DCs and stores.

Imported goods that are destined for stores beyond the local port region usually move by intermodal rail. However, imported goods destined for stores near the port will most often be trucked to a regional DC, and then trucked to the local store.

Shipments of domestically produced goods and foods move mainly by truck, but may move by intermodal rail if the shipments are traveling more than 300-500 miles. Store deliveries from regional DCs are made by company trucks or by for-hire motor carriers contracted to Target.

The staging of goods through distribution centers and the use of multiple delivery paths is designed to accommodate a wide range of product types, volumes and store activity. Most important, it allows Target the flexibility to direct and re-direct specific products to individual stores, thereby more rapidly matching supply to local demand and improving Target's ability to compete cost-effectively for market share.

3.2.2 Representative Supply Chain

The case study examines one channel typical of Target's import supply chain: the movement of consumer goods from the Ports of Los Angeles/Long Beach and Seattle/Tacoma through Chicago to a retail store in Metropolitan New York. (Target utilizes two ports on each coast as a matter of policy to reduce the risk of delays at any one port.) The case study focused on the Seattle-to-Chicago and Chicago-to-Metropolitan New York legs of the supply chain. The destination store in Metropolitan New York is one of many in New Jersey; it is served from a regional DC in Chambersburg, PA. The supply chain paths are illustrated in Figure 3.1 with an inset showing the path within the Seattle/Tacoma metropolitan area.

Figure 3.1 Retail Supply Chain
Target Case Study



The chain has nine stages of travel that must be measured:

- Seattle-to-Chicago:
 - Truck from the Port of Seattle, Washington, to the international DC in Lacey, Washington;
 - Truck from the international DC in Lacey, Washington, to the railhead in Seattle, Washington; and
 - Intermodal rail from Seattle, Washington, to Chicago, Illinois, for a rail carrier interchange (from a western railroad to an eastern railroad).
- Los Angeles-to-Chicago:
 - Truck from the Port of Los Angeles to the international DC in Rialto, California;
 - Truck from the international DC to the railhead in San Bernardino, California; and
 - Intermodal rail from San Bernardino, California, to Chicago, Illinois, for a rail carrier interchange (from a western railroad to an eastern railroad).
- Chicago-to-New York:
 - Intermodal rail from Chicago, Illinois, to Harrisburg, Pennsylvania;
 - Truck from the railhead in Harrisburg, Pennsylvania, to the regional DC in Chambersburg, Pennsylvania; and, finally,
 - Truck from the regional DC to the Target store in Clifton, New Jersey.

3.2.3 Data Sources and Analysis Methods

Data to measure the supply chain's performance came from four sources, described below and listed in Table 3.1:

- Import container dwell times in the West Coast ports were estimated using National Automatic (vessel) Identification System (NAIS) data, collected by the U.S. Coast Guard and made available through the U.S. Army Corps of Engineers. The NAIS captures the dwell time spent by ships at port container terminals. For lack of specific data on container dwell time, ship dwell time was used as a very rough approximation of container dwell time within the terminal;¹
- Truck travel times were calculated by the American Transportation Research Institute (ATRI), which maintains a database on truck movements across the United States and

¹ Conclusions about the strengths and weaknesses of the data sources and analysis methods are summarized in Section 4.0.

portions of Canada and Mexico. The trucks are tracked by on-board GPS and satellite systems and reported to ATRI by participating motor carriers. For this project, ATRI stripped the data of confidential business information and compiled the truck travel times in a custom analysis;

- Rail intermodal travel times were obtained from TransCore, a commercial inventory-tracking and freight-management services provider. The travel times include transit time over the rail lines and dwell time at terminals and rail interchange points; and
- Cost data for truck and rail intermodal were obtained from Chainalytics, a private supply-chain benchmarking consortium of major U.S. shippers.

Sufficient data on transit and dwell times data were available from these sources to calculate average travel times and travel-time reliability. Travel-time reliability was calculated as the 95th percentile time; that is, the time period that encompasses 95 percent of all the observed travel times.

Table 3.1 Retail Supply Chain Measures
Target Case Study

Links and Nodes	Sources	Notes
West Coast port (Seattle)	U.S. Army Corps of Engineers	NAIS data
Dray move	ATRI, Chainalytics	
Transload or Consolidation Center		
Dray move	ATRI, Chainalytics	
West Coast rail intermodal terminal	TransCore, Chainalytics	
Rail move	TransCore, Chainalytics	
Midwest rail intermodal interchange	TransCore, Chainalytics	
Rail move		Available for purchase
East Coast rail intermodal terminal		Available for purchase
Dray move	ATRI, Chainalytics	
East Coast Regional Distribution Center		
Truck delivery move	ATRI, Chainalytics	
Retail Store		

The Corps of Engineers and the commercial and private providers shared their data free of charge as a contribution to this study. In the case of TransCore, the shared rail data were limited to the lane from Seattle through the Chicago interchange. Data for travel onward to the Harrisburg railhead and for the supply chain leg from the Port of Los Angeles to Chicago, were available for purchase. To keep within the study budget, the additional data were not

purchased. The researchers judged that the data provided for the Seattle-to-Chicago leg were sufficient to demonstrate that travel time data was available for the other rail trips.

No readily available data were found to estimate safety and risk performance. Target officials reported that they consider safety and risk in their supply chains. Safety performance criteria, such as maximum number of tolerated vehicle maintenance or driver hours-of-service violations, are routinely written into their contracts with for-hire carriers and are part of the performance reviews of their in-house carriers. Fleet safety performance is reported by the Federal Motor Carrier Safety Administration and state motor carrier regulatory agencies, but is not routinely reported by supply chain. Risk and risk mitigation are assessed in designing and operating supply chains, but the data are specific to Target's operations and are treated as confidential business information.

3.2.4 Performance

The travel time, travel-time reliability and cost data for the retail supply chain case study are set out in Table 3.2. Safety and risk measures were not available and so are not reported. The table shows rail travel time and cost for the Seattle-to-Chicago leg but not the Chicago-to-New York leg; data for the latter were available, but not purchased for the study.

The results are specific to the locations in Target's supply chain (or within a reasonable radius for truck times). Target officials confirmed that the results are generally consistent with their experience and should approximate the experience of other retailers who operate similarly arrayed supply chains. Because the performance measures do not incorporate dwell times in Target's warehouses and distribution centers, the results are only representative of—not identical to—what the company experiences in its day-to-day or longer-term operations.

There were several limitations to the data that are worth noting as points for future research on measuring supply chain performance:

- Port dwell time is measured as the turnaround time for container ships at port terminals; that is, the time during which all inbound shipments are discharged and outbound shipments loaded. For lack of specific data on container dwell time, ship dwell time was used as a very rough approximation of container dwell time within the terminal. Ship dwell time is not a measure of the dwell time of specific containers bound for Target's distribution centers, rather it is a measure of the time the ship spends within the port. The reported dwell time does not differentiate time spent unloading, and does not directly or even necessarily reflect time spent in Customs clearance and time spent by a motor carrier picking up a container and clearing a terminal exit gate. Actual container dwell times could be longer or shorter than the NAIS observations. Many ports track containers through their facilities and have the ability to report ship and container dwell time in more detail, but these data were not available for this case study. Detailed information on container movement within a terminal is valuable for improving operational efficiencies within a port or terminal, but the information is not necessarily required to assess overall supply chain performance. Data on the total dwell time for containers within a port or terminal would suffice for most assessments of overall supply chain performance.

- Costs are limited to U.S. inland transportation. Marine costs, including port charges, are not presented.
- Target's store deliveries are accomplished by its in-house fleet or by carriers providing comparable and dedicated services under contract. Chainalytics does not capture Target's costs, but instead provided common carriage costs for the same lanes and equipment type as proxies.
- TransCore supplied a single dwell-time reliability factor for both the West Coast and Midwest rail terminals, but informed the researchers that most of the variation in terminal dwell time was accounted for by the interchange of containers between the western and eastern railroads in Chicago. In the table below, all the variance in rail dwell time is assigned to the Midwest (Chicago) rail intermodal interchange to avoid overstating dwell-time reliability at the West Coast rail intermodal terminal.

Table 3.2 Retail Supply Chain Performance
Target Case Study

Links and Nodes	Transit Time/ Dwell Time (Hours)	Reliability (95% travel time)	Cost (2014\$)
West Coast port (Seattle)	36	86	
Dray move	1.0	1.4	\$299
Transload or Consolidation Center			
Dray move	1.0	2.25	\$308
West Coast rail intermodal terminal	20		
Rail move	104	154	\$3,178
Midwest rail intermodal interchange	71	160	
Rail move	<i>See Note.</i>	<i>See Note.</i>	
East Coast rail intermodal terminal	<i>See Note.</i>	<i>See Note.</i>	
Dray move	1.1	1.4	\$318
East Coast Regional Distribution Center			
Truck pickup and delivery move	6.0	9.5	\$775
Retail Store			
Totals	<i>See Note.</i>	<i>See Note.</i>	\$4,878

Note: The table does not display estimates for transit/dwell time and reliability for these links and nodes because the data were not purchased for the study.

End-to-end costs for the Seattle to New Jersey move totaled nearly \$5,000 per shipment. Intermodal rail accounted for 65 percent of the total cost; the three truck drayage moves—at roughly \$300 apiece—accounted for 19 percent; and final delivery in the New York/New Jersey

metropolitan region accounted for the remaining 16 percent. The \$3,178 rail cost figure is for the through shipment from Seattle to New Jersey and incorporates the Midwest interchange. The table does not display the totals for transit/dwell time and reliability because the additional data for the Chicago-to-Metropolitan New York stage were not purchased.

Setting aside the missing Chicago-to-New York data, the inland transit time totals 240 hours or 10 days. The time required for 95 percent reliability totals 435 hours (allowing at least 20 hours for West Coast rail dwell) or 18 days. The time buffer between average and 95% performance is an extra 81 percent or 8 full days, with 71 percent of the end-to-end variability attributable to the rail move. The time required to interchange the containers between rail carriers in Chicago was the single largest source of delay. A full set of performance data for all three stages of the supply chain would presumably tell a similar story.

3.2.5 Lessons Learned

Performance data are available to measure the movement of imported consumer goods from the Ports of Los Angeles/Long Beach and Seattle/Tacoma through Chicago to a retail store in Metropolitan New York.

Estimating truck travel times and travel-time reliability required that ATRI define the routes and then collate and process the data; this took time and expense. However, ATRI reported that once routes have been defined and the analytical procedures established, performance reports can be generated routinely and reasonably cost-effectively. Similarly, rail intermodal travel time and travel-time reliability data are available from TransCore and could be produced routinely. And while not set up currently as a standard report, the U.S. Coast Guard NAIS data are available through the Corps of Engineers as a first approximation of port dwell times. Conversations with Chainalytics and other data suppliers established that cost data are available, although not as standard commercial products. In all three cases, a key task in setting up an ongoing performance measurement program for this or a similar retail supply chain would be to negotiate appropriate terms for the routine production and purchase of the data.

The findings of this case study underscore the criticality of measuring combined multimodal performance. The majority of the costs and the great majority of the performance issues for this supply chain were in the rail moves, not the highway moves. Measuring highway travel alone will not suffice for multimodal supply chains. Second, the largest performance challenge was in Chicago, a place that is neither the origin nor the destination of the goods. And third, the supply chain used five distinct stages from port to store (six, if rail interchange in Chicago is counted separately). These stages involve two distribution centers, four rail terminals (allowing two for the interchange) and a port terminal. None of these facilities functions independently; many of the goods they handle move onward to a destination outside the state in which the facility is located. At each stage and facility, local conditions and performance affect the overall performance of the supply chain. Consumers benefit only if the supply chain, which spans the nation and is supported by many jurisdictions, functions as an integrated whole.

3.3 Automotive Industry Case Study

This case study documented a General Motors supply chain moving auto parts from suppliers in Warren, Michigan, and Ontario, Canada, to an auto assembly plant in Spring Hill, Tennessee.

3.3.1 Industry

In 2014, the economic output value of the U.S. automotive industry was \$455 billion, accounting for 2.8 percent of GDP and 3.2 percent of personal consumption. The gross output value of motor vehicles and parts was \$600 billion in 2013, making it the fourth largest sector within U.S. manufacturing.

Motor vehicles and parts are hugely important in the NAFTA market, representing almost \$200 billion in cross-border trade in 2014. They were the largest export to Canada (and the second largest import to the United States from Canada) and the largest import from Mexico (and the fourth largest export to Mexico from the United States).

General Motors (GM) is the top U.S. auto maker and the nation's fifth largest manufacturer. It was responsible for 2.9 million new vehicle sales in the United States in 2014—the best year for the industry since 2006—capturing 17.8 percent of the national market. GM operates 17 assembly plants in North America: 12 in the U.S., three in Mexico and two in Canada. The company has nearly three dozen other factories that produce component parts for its assembly plants. These factories operate alongside an extensive network of independent Tier 1 suppliers, many of which are concentrated between the Great Lakes and the Piedmont region of the Southeast.

The supply chain for auto parts inbound to GM assembly plants is accomplished chiefly by trucking the parts from the suppliers to the assembly plants. Most suppliers are within a two-day driving distance of an assembly plant, and many are within overnight range or closer. While outbound shipping of finished vehicles is done primarily by rail, the industry's famously demanding, just-in-time production environment precludes use of rail for inbound auto parts. (Internationally-sourced parts are the exception.)

Auto parts are moved from domestic and Canadian suppliers to GM assembly plants along one of three paths:

- Direct from a single, large-volume supplier to an assembly plant as full truckload shipments;
- From several, moderate-volume suppliers along a regular collection route, with the truck stopping to make several pickups in order to assemble a full truckload; and
- From multiple, low-volume suppliers along several collection routes to a truck cross-dock consolidation center, and then by full truckload to the assembly plant.

Parts from Mexican suppliers follow a similar pattern (typically with fewer collection routes), but may also make use of intermodal rail, especially for combined loads from multiple suppliers. Intermodal rail is used for cross-border shipments from Mexico because it is more efficient and less time-consuming. Shipment by truck across the border requires a hand-off of the trailer from the Mexican carrier to the U.S. carrier and processing of the driver, tractor and trailer through customs, immigration and safety inspections. Handling and processing is simpler and faster by rail. (Trucking across the border from Canada to the United States does not require a hand-off—the same driver and equipment runs the entire trip—and the customs, immigration and safety inspections are more streamlined. As a result, Canadian cross-border trucking offers superior service to rail and is preferred by automobile manufacturers.)

Overseas vendors supply a small volume of parts. Parts originated overseas usually arrive in marine containers, which are trucked directly to the assembly plant, to one of the cross-dock centers for staging to multiple plants, or to an intermodal railhead providing service from West Coast ports. Air cargo service is seldom used to move parts provided by domestic suppliers and is used sparingly to obtain parts from overseas suppliers. It is, however, used for both domestic and international shipments for some high-value and time-sensitive components.

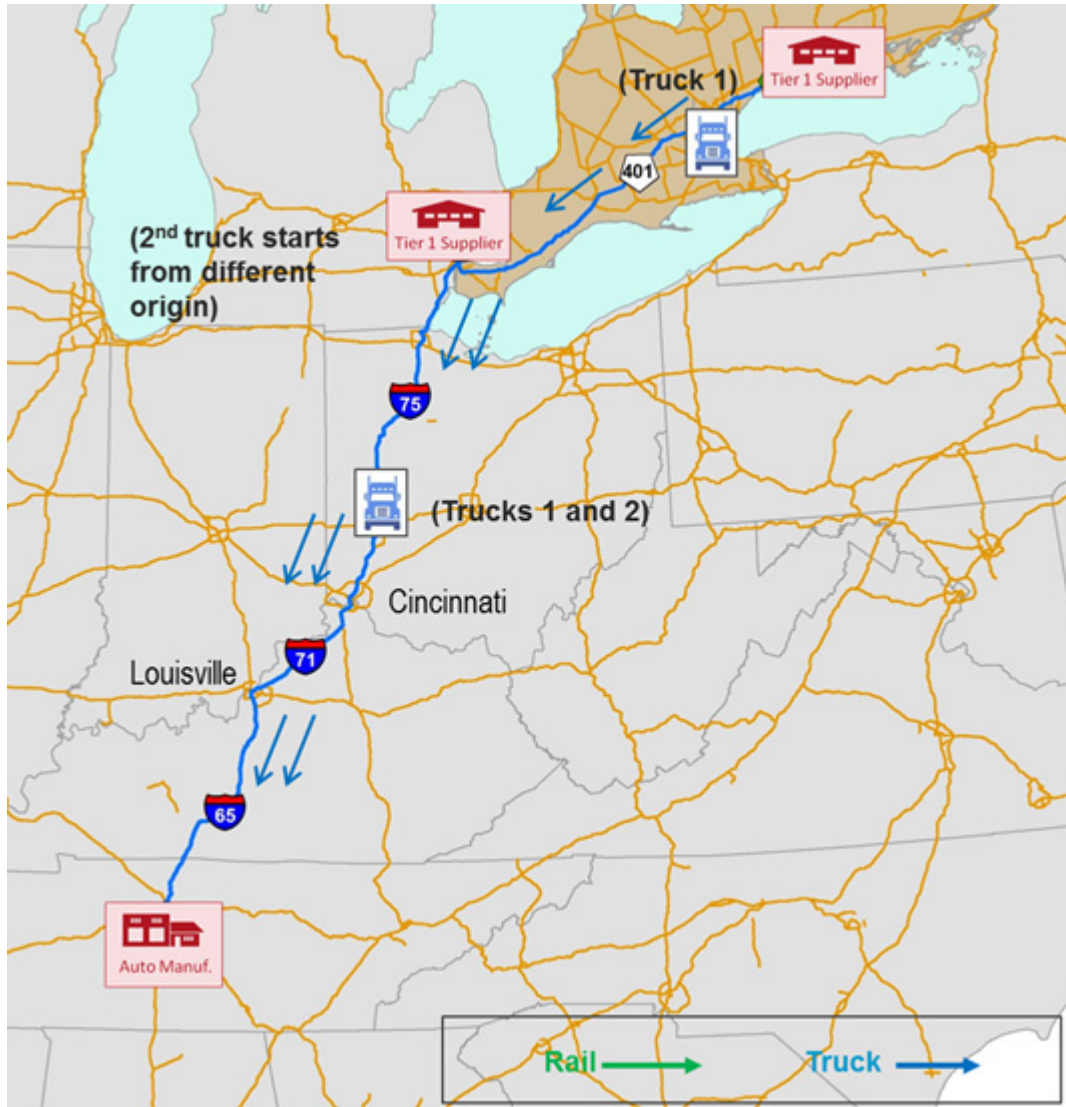
3.3.2 Representative Supply Chain

The General Motors Spring Hill plant is located south of Nashville, Tennessee. At the time of this report, the plant assembled Chevrolet Equinox crossover vehicles. The Equinox is built on the Theta Unibody vehicle platform, which was developed in Canada. Canadian assembly plants are the primary production points for the Equinox, with Spring Hill acting in an overflow role. Because of this, the Equinox parts used at Spring Hill come primarily from vendors in Ontario and nearby locations in the Great Lakes states. (In the future, GM intends to use the Spring Hill plant to assemble the new version of the Cadillac SRX and to manufacture the new, fuel-efficient, small-displacement Ecotec engines.) Spring Hill offers a good case illustration of an automotive supply chain because of its location in the Southeast, where a number of new auto plants have located in recent years, and its dependence on close integration with NAFTA and domestic suppliers.

The Spring Hill supply chain is illustrated in Figure 3.2 with the inset showing the path through the Detroit/Windsor metropolitan area. The supply chain has two legs, both served by full truckload shipments:

- **Cross-border:**
 - Truckload shipments from Canadian Tier 1 suppliers in Ontario cross into the United States over the Detroit/Windsor Ambassador Bridge and then follow Interstates 75, 71 and 65 to Spring Hill, Tennessee; and
- **Domestic:**
 - Truckload shipments from U.S. Tier 1 suppliers in the vicinity of Warren, Michigan, follow Interstates 75, 71 and 65 to Spring Hill, Tennessee.

Figure 3.2 Automotive Supply Chain
General Motors Case Study



3.3.3 Data Sources and Analysis Methods

Data to measure the performance of the supply chain came from two sources, both of which provided coverage of the U.S. and Canadian segments and are listed in Table 3.3 for the domestic trip and in Table 3.4 for the cross-border trip:

- Truck transit times were obtained from ATRI, which compiled them in a custom analysis for this project; and
- Truck cost data were reported by Chainalytics.

Table 3.3 Automotive Supply Chain Measures
General Motors Case Study – Domestic

Links and Nodes	Source	Notes
Parts Supplier Plant, Chatham, Ontario		
Truckload move (through)	ATRI, Chainalytics	
General Motors Assembly Plant, Spring Hill, TN		

Table 3.4 Automotive Supply Chain Measures
General Motors Case Study – Cross-Border

Links and Nodes	Source	Notes
Parts Supplier Plant, Chatham, Ontario		
Truckload move	ATRI, Chainalytics	
International border crossing		Time spent at the border crossing is included in truck transit/dwell times
Truckload move	ATRI, Chainalytics	
General Motors Assembly Plant, Spring Hill, TN		

3.3.4 Performance

The travel time, travel-time reliability and cost performance measures for the domestic and cross-border paths are reported in Table 3.5 and Table 3.6, respectively. All the segments of both paths were captured. The results show that end-to-end costs were a bit over \$1,000 per shipment and essentially equivalent from the Canadian and U.S. origins.

Because ATRI receives data from participating motor carriers that track their door-to-door truck trips, ATRI was able to report separately on the travel time from Chatham, Ontario, to the international border crossing at the Ambassador Bridge, and also on the truck travel time onward from the Ambassador Bridge to Spring Hill, Tennessee. ATRI did not report the travel

time/dwell time at the international border crossing, but could provide that information. The analysis would require geo-fencing of the border-crossing; that is, definition of appropriate start and end points for the border-crossing zone. The starting points would typically be at the end of the longest-observed entry queue, and the end point would be the location beyond the exit gate where trucks regain posted road speeds.

Table 3.5 Automotive Supply Chain Performance
General Motors Case Study – Domestic

Links and Nodes	Transit Time/ Dwell Time (Hours)	Reliability (95% travel time)	Cost (2014 \$'s)
Parts Supplier Plant, Warren, MI			
Truckload move (through)	20.5	24.2	\$1,041
General Motors Assembly Plant, Spring Hill, TN			
Totals	20.5	24.2	\$1,041

Table 3.6 Automotive Supply Chain Performance
General Motors Case Study – Cross-Border

Links and Nodes	Transit Time/ Dwell Time (Hours)	Reliability (95% travel time)	Cost (2014\$)
Parts Supplier Plant, Chatham, Ontario			
Truckload move	1.5	3.0	\$1,052
International border crossing	↓	↓	
Truckload move	18.4	23.2	
General Motors Assembly Plant, Spring Hill, TN			
Totals	19.9	26.2	\$1,052

The average travel distance from Chatham, Ontario, to Spring Hill, Tennessee, is 50 miles longer than from Warren, Michigan, to Spring Hill (549 miles versus 499), yet the average transit time from Chatham to Spring Hill was slightly shorter. Achieving 95 percent reliability in the travel time, however, required a buffer that is two-and-a-half hours longer for the Chatham to Spring Hill trip than for the Warren to Spring Hill Trip. The total buffered time for the Chatham trip was higher than the average transit time by almost one-third. This reflects the impact of traffic congestion approaching the Ambassador Bridge and the time required for customs, immigration and safety clearance at the border station. (As a rule, most carriers that work regularly for GM and other major companies participate in pre-clearance programs that

provide expedited customs, immigration and safety clearance of drivers, their trucks and routine shipments.)

As with the retail industry supply chain, the results are specific to GM's Spring Hill supply chain. The results are representative of—not identical to—what the GM sees in its day-to-day and longer-term operations.

3.3.5 Lessons Learned

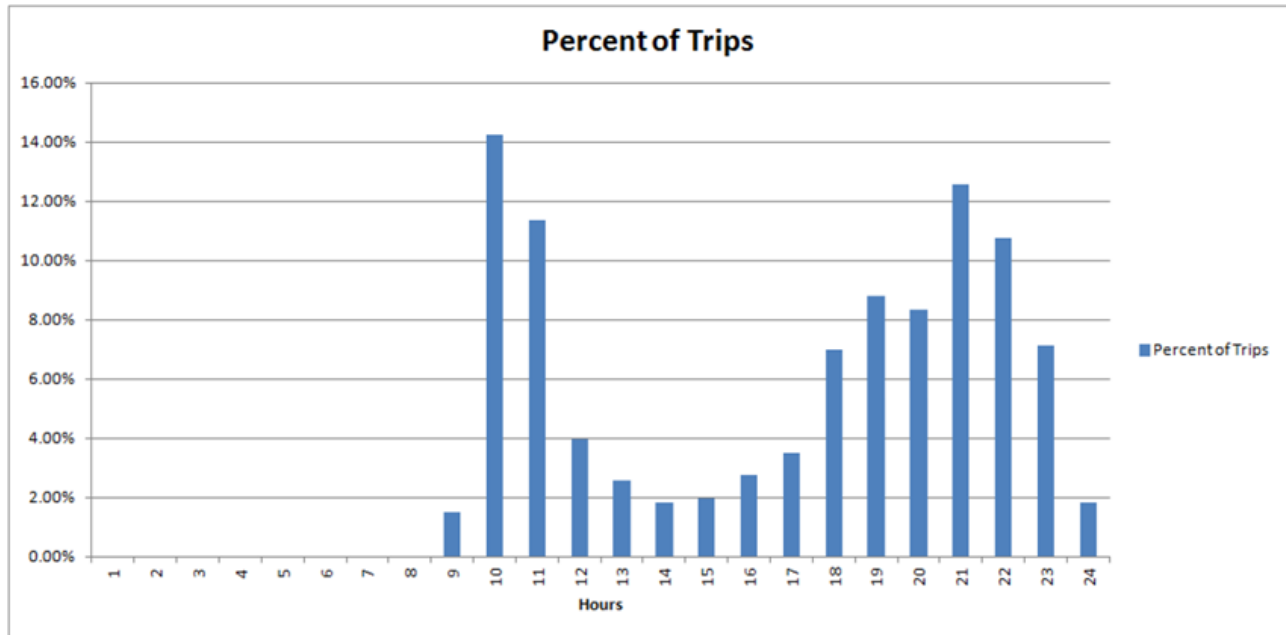
The results of the case study show that it is feasible to measure the end-to-end performance of an automotive manufacturing supply chain. The automotive industry is economically important, highly competitive and acutely sensitive to logistics performance. Being able to reasonably track the performance of automotive supply chains over time and use that information to target and tailor freight transportation system improvements is an important opportunity for MPOs, state DOTs and Federal agencies interested in fostering economic development and jobs through transportation improvements.

The case study revealed several issues that warrant future attention. First, complete measurement of the Canadian and U.S. legs of this supply chain was possible only because travel time and cost data were available for truck trips in Canada as well as in the United States. When GM shifts Spring Hill to production of the Cadillac SRX, Spring Hill will be drawing upon Mexican auto parts suppliers, and the geography of its supply chain will shift radically. Cost data for truck and rail shipments originating in Mexico are generally available, but truck and rail travel time data are less available.

Although technically possible to track some truck shipments across Mexico from transponders on U.S. trailers, ATRI currently can only report truck transit times from the U.S.-Mexican border to U.S. domestic locations. Likewise, the FHWA National Performance Management Research Data Set (NPMRDS) only reports truck travel speeds and travel times on Mexican roads that are within five miles of the U.S.-Mexico border and on Canadian roads that are within five miles of the U.S.-Canada border. Using NPMRDS data alone, it would not have been possible to construct a complete picture of truck travel times from Chatham, Ontario. Similarly, rail transit times from Mexico to the U.S. border are not currently available for at least one of the principal rail carriers used by GM. These gaps suggest the need for a common measurement and reporting of truck and rail travel times for supply chain performance measurement across NAFTA.

The case study revealed a second issue, which is accounting for the impact of driver hours-of-service (HOS) regulations on overall supply chain travel time performance. Because ATRI compiled its data by following the path of individual trucks traveling from Ontario and Michigan to Spring Hill, ATRI's analysts were able to detect a bi-modal distribution of travel times—one peak at 10 hours and another at 21 hours—as shown in Figure 3.3.

Figure 3.3 Hours-of-Service Effect on Travel Times for 499-Mile Trip from Warren, MI to Spring Hill, TN
General Motors Case Study



The distance from Chatham to Spring Hill is 549 miles and the distance from Warren to Spring Hill is 499 miles. These distances are at the limit of what a truck driver can travel in an 11-hour work shift, the maximum time allowed under the Federal HOS regulations. A rested driver with a full complement of driving hours available can complete a trip from Chatham or Warren within a ten-hour period. However, a driver with fewer hours remaining on his or her service log must shut down partway through the trip to rest. This increases the total elapsed travel time by a factor of two. From a supply chain performance perspective, even the travel-time reliability of a truck dispatched with a rested driver is at risk. The trip cannot be done in much less than ten hours and any delay—whether caused by rush-hour congestion on the Interstates or a traffic incident near the Ambassador Bridge—is enough to push the driver over the 11-hour limit, doubling the trip time.²

This finding would not have been apparent when analyzing NPMRDS data or similar data provided by other private sector firms that track and report travel speeds and travel time by route segment. Adding up the route segment travel times would suggest an average end-to-end trip time of about ten hours with a large buffer time, but would not reveal the two distinct travel-time modes. MPO, state DOT and FHWA analysts using NPMRDS data to evaluate truck trips should be aware of the possibility of HOS effects when assessing longer-distance supply chains or supply chains operating through very congested corridors.

² The truck travel-time data do not differentiate between trucks with one driver and trucks with two drivers. High-value and time-sensitive loads are often moved by team drivers, with the second driver taking over when the first driver reaches the maximum allowed driving hours.

3.4 Food Products Industry Case Study

The third case study looked at a Perdue Farms, Inc. supply chain moving processed chicken meat from the Delmarva Peninsula to a food wholesaler in the Queens area of New York City.

3.4.1 Industry

The food manufacturing industry employed 1.7 million American workers and contributed \$235 billion to the nation's GDP in 2013.³ An estimated 818.3 million tons of food products, worth \$1.1 trillion, were transported on the nation's freight transportation network in 2012.⁴

Most shipments of food products are within the United States. International imports and exports represent three percent and five percent, respectively, of processed food products moved in the United States. However, these shares are expected to grow to six percent and seven percent by 2040, as charted in Figure 3.4. Rapidly-growing, middle-class, overseas and NAFTA consumer markets are driving the demand for U.S. food products. The increasing number of foreign-born residents in the United States and the rising popularity of many ethnic food products among the U.S. population at-large are also contributing to the growing demand for imported and exported food products.

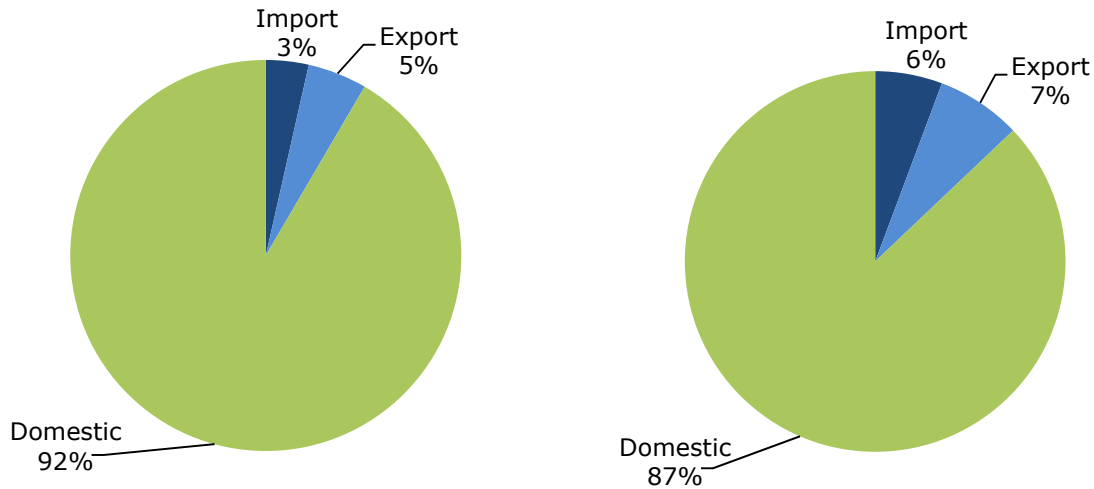
This demand represents an economic development opportunity for U.S. food processors. The domestic supply chains of U.S. food producers are closely intertwined with their international export supply chains, so an understanding of the performance of domestic food supply chains will be important in meeting domestic demand and also in facilitating the growth of U.S. food exports.

³ U.S. Bureau of Economic Analysis, "Table 6.4D. Full-Time and Part-Time Employees by Industry," <http://www.bea.gov/iTable/iTable.cfm?ReqID=9&step=1#reqid=9&step=3&isuri=1&903=193> (accessed June 12, 2015); U.S. Bureau of Economic Analysis, "Value Added by Industry," <http://www.bea.gov/iTable/iTable.cfm?ReqID=51&step=1#reqid=51&step=51&isuri=1&5114=a&5102=1> (accessed June 12, 2015).

⁴ U.S. Department of Transportation, "Freight Analysis Framework Data Tabulation Tool," <http://faf.ornl.gov/fafweb/Extraction0.aspx> (accessed June 12, 2015).

Figure 3.4 Domestic, Imported and Exported Tons as Shares of All Food Product Shipments Moved in the United States

2012 (Left) and 2040 (Right)



Source: U.S. Department of Transportation, “Freight Analysis Framework Data Tabulation Tool,” <http://faf.ornl.gov/fafweb/Extraction0.aspx> (accessed June 12, 2015).

3.4.2 Representative Supply Chain

Agriculture and food production are the lifeblood of the economy of the Delmarva Peninsula, which is shared by Delaware, Maryland and Virginia. Poultry production, in particular, accounts for a large percentage of the agriculture and food products industry in the region. In 2014, nearly 1.9 million tons of poultry meat was produced on the Delmarva Peninsula.⁵ Chicken hatcheries, farms, poultry production facilities and product consolidation facilities are located throughout the Peninsula region.

Perdue Farms, Inc.’s supply chain was used as the representative supply chain. Perdue’s supply chain is typical of the path used by several of the major Delmarva producers of broiler chickens, which are raised and processed on the Peninsula and then transported to consumer markets in the Mid-Atlantic and New England regions.

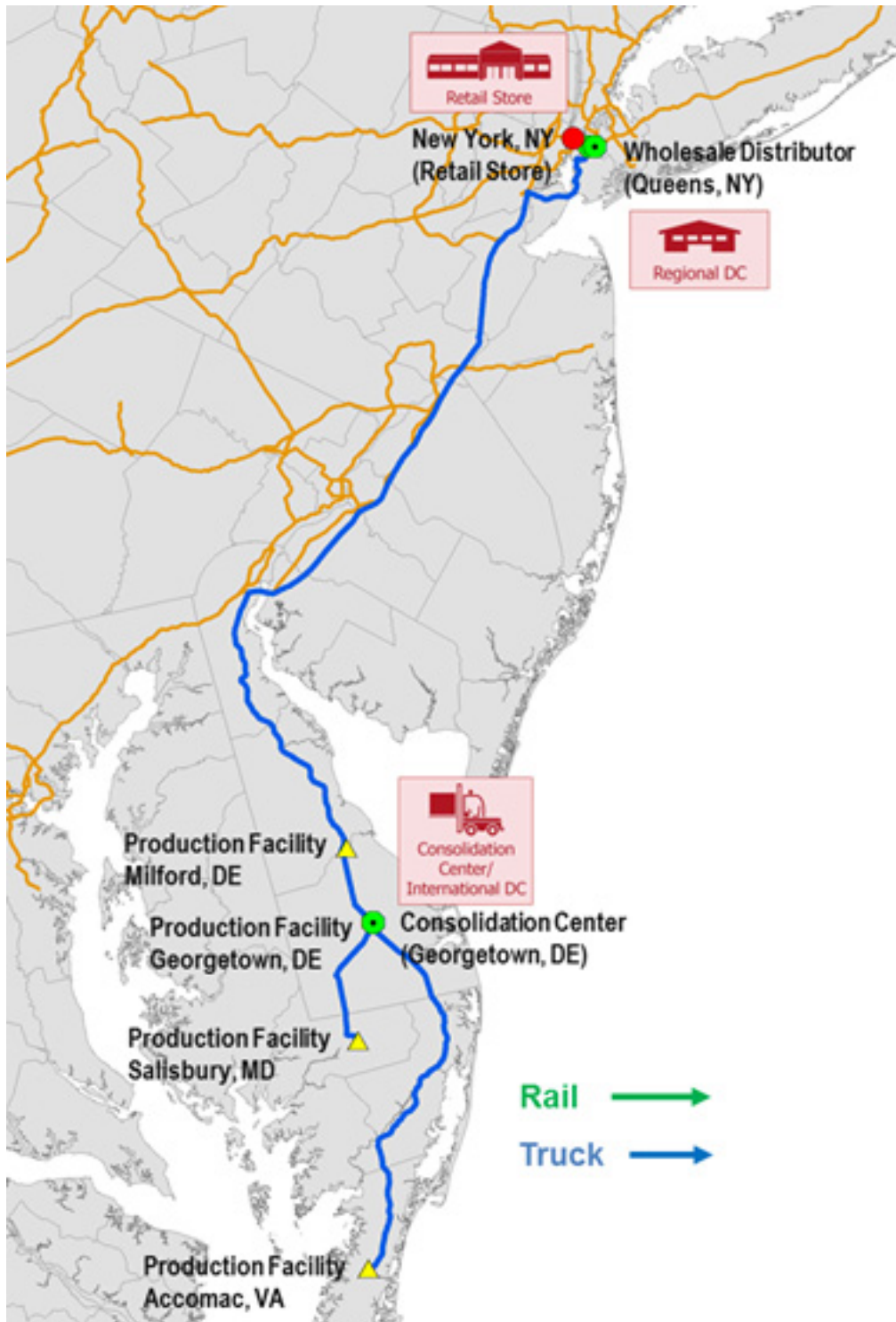
The case study focused on the transport of processed chicken from the Peninsula to markets in New York City. Local trips were not analyzed for the case study. These local trips include shipments of chicks from hatcheries to farms and shipments of mature chickens from farms to production facilities within the Delmarva Peninsula. Local trips also include the movement of the majority of the 111 million bushels of chicken feed (i.e., corn, soybeans and wheat) that is grown on the Peninsula.

⁵ “2014 Facts about Delmarva’s Meat Chicken Industry,” Delmarva Poultry Industry, Inc., https://www.dpicken.org/faq_facts/docs/FACTS14.pdf (accessed June 11, 2015).

Chickens raised on Perdue-affiliated farms on the Delmarva Peninsula are sent by truck to one of four production facilities that Perdue maintains on the Peninsula. These facilities are located in Milford and Georgetown in Sussex County, Delaware; in Salisbury in Wicomico County, Maryland; and in Accomac in Accomack County, Virginia. Once processed, broilers from all four production facilities are transported by truck to a single consolidation center located in Georgetown, Delaware. Truckloads of the processed chicken are then transported to wholesale distribution centers or directly to large retail or institutional customers throughout the Northeast and Mid-Atlantic states. A small share of processed chicken is sent north to the Port of New York and New Jersey or south to marine terminals in Norfolk, Virginia, for international export. All shipments are made by truck because the distances are relatively short and the temperature of each shipment can be closely controlled and monitored.

Perdue's supply chain is mapped in Figure 3.5. The path analyzed of this case study is from the Perdue Farms production facility in Accomac, Virginia, to the Georgetown consolidation center, and then onward to an ethnic foods wholesaler in the Maspeth area of Queens, New York.

Figure 3.5 Food Products Supply Chain
Perdue Case Study



3.4.3 Data Sources and Analysis Methods

The Target and General Motors case studies used American Transportation Research Institute (ATRI) data to estimate truck travel times. The ATRI data track the movements of individual trucks and then aggregate the trip data to calculate typical travel time. This case study explored the use of a publicly available data source, the FHWA National Performance Management Research Data Set (NPMRDS) database, to estimate truck travel time and travel-time reliability over the supply chain route. The NPMRDS provides truck travel speeds and times for individual roadway segments. The times for the individual roadway segments are then cumulated to estimate the overall trip time. This approach requires more computation, but the travel times reflect the travel times of all trucks on a highway segment, not just the travel times for trucks reporting data to ATRI. Cost data for the truckload moves were obtained from Chainalytics. Table 3.7 lists the data sources.

Each of the roadway segments from Accomac, Virginia, to Maspeth, New York, is identified by a traffic message channel (TMC) location code. (Roadway segments are typically defined by direction with the beginning and end points set at intersections or interchanges.) The individual roadway segments making up the route from Accomac to Maspeth were identified and linked in proper sequence to define the travel path. The length of the travel path was calculated as the sum of the individual segment lengths. Data on traffic speeds by time of day for each roadway (TMC) segment were extracted from the NPMRDS database. The data covered a period of 243 days spanning the months of July 2013 through February 2014.

Table 3.7 Food Products Supply Chain Measures
Perdue Case Study

Links and Nodes	Source	Notes
Production Facility, Accomac, VA		
Truckload move	NPMRDS (FHWA) data Chainalytics (commercial) cost data	Truck travel time data sparse; used all vehicle travel times as proxy; computation intensive Chainalytics cost data for temperature controlled TL move
Consolidation Facility, Georgetown, Delaware		
Truckload move	NPMRDS (FHWA) data Chainalytics (commercial) cost data	Truck travel time data sparse; used all vehicle travel times as proxy; computation intensive Chainalytics cost data for temperature controlled TL move
Distribution Facility, Brooklyn, NY		

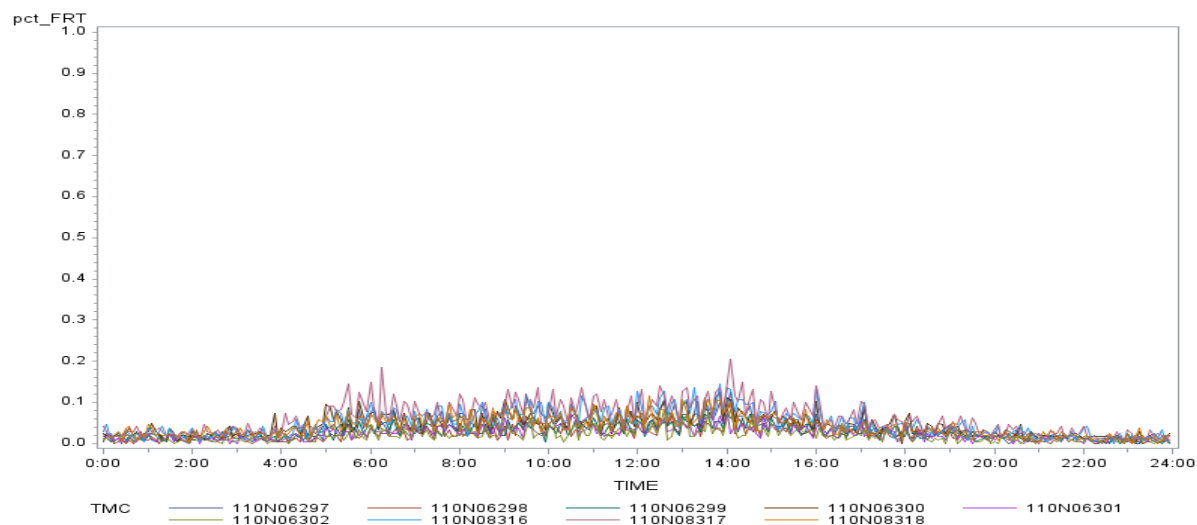
A “vehicle trajectory” method was used to calculate the travel time on each route in the Perdue supply chain. The vehicle trajectory method constructs a time-space matrix of travel times at each TMC location for each 5-minute interval over the day and then “traces” the vehicle trip, applying the travel times corresponding to the precise time and location at which a vehicle is expected to traverse the route (TMC) segment. For example, if a truck leaves the production facility at 8:00 a.m. and the travel time to cross the first route (TMC) segment at that time is 10 minutes, then the travel time to cross the next TMC location would be estimated based on the 8:10 a.m. travel time on the second route segment and so on. The trajectory method attempts to more closely model the actual travel times experienced by truckers as they traverse the roadway system. The trajectory method also allows the analyst to approximate the travel time based on the actual truck dispatch time. This is important because a truck dispatched from Delmarva in the early morning will encounter more peak-hour traffic in the New York area than a truck dispatched in the mid-morning or late evening.

The NPMRDS tracks the travel speed and travel time of automobiles and trucks separately. Truck speeds are reported as “freight” travel speeds and times. The researchers had planned to use the NPMRDS freight travel times for the case study, but determined that the number of freight (truck) observations in the database were too few to construct a statistically reliable, day-to-day analysis. The number of freight observations on the state and local roads (that is, off the Interstate highways) was especially low. On the routes between the production and consolidation facilities on the Delmarva Peninsula, freight travel times were available for less than 50 percent of the time period epochs. This is due to the low volume of trucks equipped with probes using these routes.

Figure 3.6 shows the density or availability of freight observations on one of the arterial routes between the production and consolidation facilities located in Delaware. Availability is shown as a percentage, calculated as the number of epochs (five-minute intervals) for which truck speeds are present divided by the total number of epochs in the 243-day observation period.

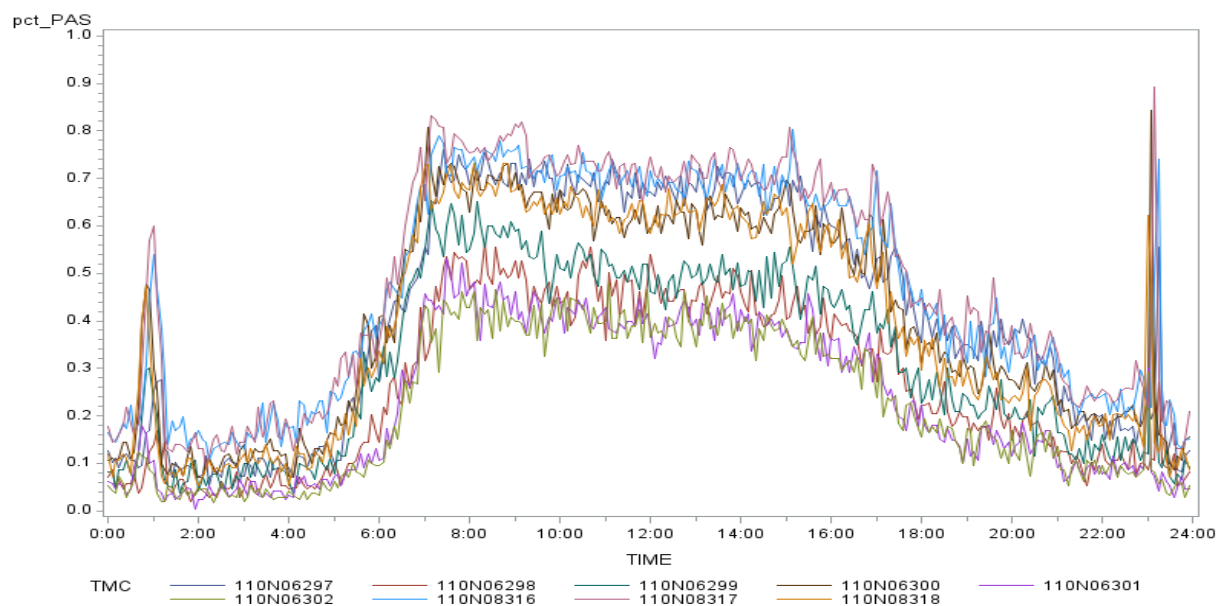
To compensate for the lack of robust freight data, passenger-vehicle travel speeds and times were used as a proxy for truck travel speeds and times. Figure 3.7 shows the corresponding percentages for passenger automobile observations. The analysis was done using all five-minute travel times for all 243 days on the route segments from the production facility in Accomac to the consolidation facility in Georgetown, and from the consolidation facility in Georgetown to the distribution facility in New York.

Figure 3.6 Freight Travel Time Data Availability on Route between Production and Consolidation Facilities in Delaware



Source: FHWA NPMRDS data.

Figure 3.7 Passenger Travel Time Data Availability on Route between Production and Consolidation Facilities in Delaware



Source: FHWA NPMRDS data.

3.4.4 Performance

Table 3.8 summarizes the travel-time results for the two stages of the Perdue supply chain: from the production facility in Accomac, Virginia, to the consolidation facility in Georgetown, Delaware (81 miles); and from Georgetown to the distribution center in Maspeth in Queens (204 miles). The “free flow travel time” is the 85th percentile travel time during the period from 7:00 a.m. to 9:00 a.m. on weekends on each route; that is, the travel time observed when there is little or no traffic congestion.

Table 3.9 shows the “travel-time index” results. The travel-time index is the ratio of observed travel time divided by the free flow travel time. It is calculated by five-minute interval for each route. A travel time value of 1.1 means that the observed travel time is ten percent greater than the free-flow travel time. If the observed travel time is lower than free-flow travel time, it is adjusted to the free-flow travel time; therefore, the minimum travel time index for any five-minute interval is 1.00.

The average travel time from the production facility in Accomac, Virginia, to the consolidation facility in Georgetown, Delaware, was 94 minutes or 1.6 hours. This was about seven minutes longer than the free-flow travel time and translates to a travel-time index of 1.08 or eight percent over the free-flow time. Ninety-five percent of trips are likely to occur within 104 minutes or 1.8 hours, which is about 17 minutes or 20 percent longer than the free-flow travel time.

The longer stage from Georgetown, Delaware, to Maspeth, New York, experienced greater travel time and more variability in the travel time. The average travel time was 223 minutes or 3.7 hours, which was 13 percent longer than the free-flow travel time. The 95th percentile travel time was 264 minutes or 4.4 hours and was 34 percent longer than the free-flow travel time.

Table 3.8 Travel Times in Minutes

Route	Length	Free-Flow Travel Time	Average Travel Time	5 th Percentile Travel Time	95 th Percentile Travel Time	Standard Deviation
From Production Facility in Accomac, VA to Consolidation Facility in Georgetown, Delaware	80.78 miles	86.805	94.028	85.748	104.23	6.857
From Consolidation Facility in Georgetown, DE to Distribution Center in Maspeth, NY	204.24 miles	197.87	223.172	198.55	264.42	23.338

Table 3.9 Travel Time Indexes

Route	Travel Time Index	95% Travel Time Index
From Production Facility in Accomac, VA to Consolidation Facility in Georgetown, DE	1.08	1.20
From Consolidation Facility in Georgetown, DE to Distribution Center in Maspeth, NY	1.13	1.34

Table 3.10 summarizes the travel time, travel-time reliability and cost for both stages and for the overall supply chain trip. Total travel time for a shipment from Accomac, Virginia, to Maspeth, New York, averages 5.3 hours with 95 percent of the trips completed within 6.2 hours.

The variability in travel time on this route directly affects the cost of transporting food products. Because congestion can extend travel time by 20 percent on the first leg and 34 percent on the second leg of the trip, a substantial “buffer” must be built into the transportation rates to cover the cost of potentially-longer travel times. Using supply chain cost data from Chainalytics, the estimated cost to transport processed chicken products from the processing facility to the distribution center was \$1,466 based on the 95th percentile travel time of 6.2 hours.

Table 3.10 Food Products Supply Chain Performance
Perdue Case Study

Links and Nodes	Transit Time/ Dwell Time (Hours)	Reliability (95% travel time)	Cost (2013\$)
Production Facility, Accomac, VA			
Truckload move	1.6 hours	1.8 hours	\$580
Consolidation Facility, Georgetown, DE			
Truckload move	3.7 hours	4.4 hours	\$886
Distribution Facility, Maspeth, NY			
Totals	5.3 hours	6.2 hours	\$1,466

3.4.5 Lessons Learned

The experience of this case study showed that it was feasible to measure the end-to-end performance of the supply chain using NPMRDS data. This approach requires stringing together the roadway segments that make up the representative supply chain route, extracting the appropriate data from the NPMRDS data set, and then calculating the cumulative distance, speed, travel time and travel-time reliability.

Use of the NPMRDS has advantages for MPO, state DOT and FHWA analysts. It provides nationwide coverage of all National Highway Systems roadways and intermodal connectors,

making it possible to evaluate the performance of most truck routes without tracking individual trucks or identifying specific shippers and receivers. The data are based on real trips, not modeled trips; the analysis is repeatable; and because the data are reported in increments across all hours of the day and all days of the year, it is possible to analyze daily, weekly and seasonal variations in supply chain performance. Moreover, having longitudinal data makes it possible to differentiate delays caused by endemic congestion from delays caused by severe weather and construction.

When the NPMRDS data are evaluated using a vehicle trajectory analysis, it is also possible to test the impact of different truck dispatch times on travel time and travel-time reliability. Many shippers and motor carriers carefully tailor their operations to avoid peak-period congestion, dispatching their trucks so that most travel is accomplished during the less-congested, mid-day, evening and overnight-hours rather than during heavily congested morning and evening peak hours. This is an important analysis capability for assessing supply chain performance because a route that is highly congested during the day may serve supply chains well during off-peak times.

The use of the NPMRDS data flagged several other issues that should be addressed by further research. First, it was very time-consuming to link the individual route segments together to define a specific truck route. FHWA should consider developing software that will automate this task, which would greatly reduce the time and effort involved in setting up a supply chain analysis, especially one that involves long routes that span several states. Automation would also assist the process of updating routes as supply chains are rerouted in response to changes in economic, logistics and infrastructure conditions.

Second, while there were good data on truck travel speeds and times on high-volume Interstates and major highways within metropolitan regions, data on truck travel speeds and times over state routes and less-traveled arterials, especially in rural areas, were sparse. The case study analysis used data from the first tranches of information supplied to the NPMRDS. It is anticipated that data set will become more robust as missing data points are identified and filled in. In the interim (and for roads that carry very low volumes of trucks), automobile data can be used as a proxy if it is factored to account for the difference between average passenger and average truck travel speeds. This refinement was not done for the case study, but guidance of appropriate sample sizes and adjustment factors should be developed and provided to practitioners.

Another subject for further research is the connection between the multi-state leg of the supply chain and the urban “last mile” distribution of shipments, in this case, poultry products moving from the retail distribution centers in New York to local retail stores, restaurants and institutions. Such analysis, which was not within the scope of this effort, could offer information to assess the relative effects of the performance of the producer’s distribution network and the local urban delivery network on the availability of product on store shelves. Analysis of these last-mile trips is complicated by the fact that the destinations are many and disparate, truck volumes between each origin and destination pair are low and data on the performance of local arterials and city streets, related specifically to freight, are not readily available.

3.5 Agriculture Industry Case Study

This case study measured a soybean export chain from a farm in Illinois to a Louisiana river port for reshipment by ocean-going ship to customers in Asia. The case study was chosen because there is interest in understanding how to increase the U.S. share of the global market for soybeans.

3.5.1 Industry

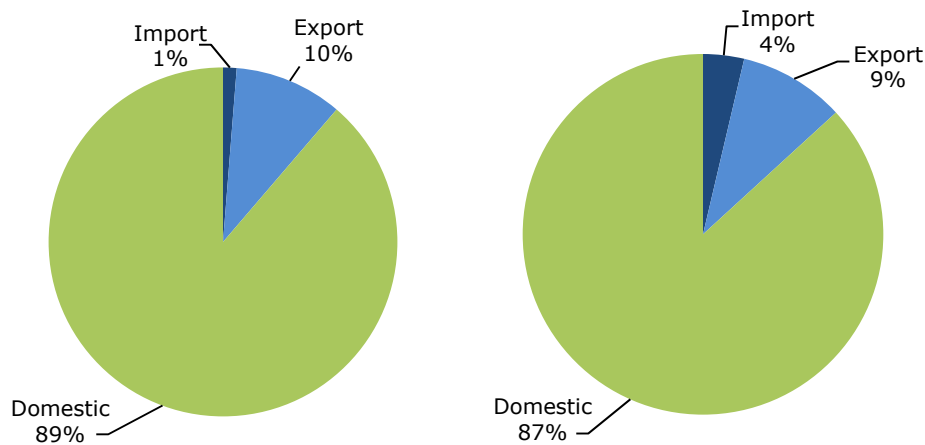
The agriculture industry employed 789,000 people and contributed \$192 billion to the nation's GDP in 2013.⁶ An estimated 2.5 billion tons of agricultural products were transported on the nation's freight transportation network in 2012.⁷ Ninety percent of those shipments (by tonnage) were domestic moves. International imports and exports represented one percent and ten percent of processed agriculture products, respectively.

Total agricultural tonnage is projected to grow by 71 percent to 4.2 billion tons in 2040. Import tonnage will grow significantly, accounting for four percent of total tonnage in 2040. Export tonnage will account for nine percent of agricultural tonnage in 2040, with export tonnage increasing from 246 million tons to 400 million tons, a 63 percent increase. Figure 3.8 shows the relative shares of domestic, imported and exported U.S. agricultural shipments by tonnage in 2012 and 2040.

⁶ U.S. Bureau of Economic Analysis, "Table 6.4D. Full-Time and Part-Time Employees by Industry," <http://www.bea.gov/iTable/iTable.cfm?ReqID=9&step=1#reqid=9&step=3&isuri=1&903=193> (accessed June 12, 2015); U.S. Bureau of Economic Analysis, "Value Added by Industry," <http://www.bea.gov/iTable/iTable.cfm?ReqID=51&step=1#reqid=51&step=51&isuri=1&5114=a&5102=1> (accessed June 12, 2015).

⁷ U.S. Department of Transportation, "Freight Analysis Framework Data Tabulation Tool," <http://faf.ornl.gov/fafweb/Extraction0.aspx> (accessed June 12, 2015).

Figure 3.8 Domestic, Imported and Exported U.S. Agriculture Shipments by Tonnage
Percentages in 2012 (left) and 2040 (right)



Source: U.S. Department of Transportation, “Freight Analysis Framework Data Tabulation Tool,” <http://faf.ornl.gov/fafweb/Extraction0.aspx> (accessed June 12, 2015).

The United States is today a net exporter of grain crops and meat products. Corn, soybeans and wheat are the top three grain crops grown in the United States by value, generating \$63.9 billion, \$37.6 billion and \$14.6 billion in cash receipts in 2011, respectively.⁸

The United States is the world’s largest soybean producer. Soybeans are the primary source of high-protein feed in the world and are also used for biofuel, vegetable oil and other food products. The acreage planted to soybeans is second only that of corn.

Until 2012-2013, the United States was also the world’s largest soybean exporter; it is now second to Brazil.⁹ In 2013, 3.3 billion bushels of soybeans were produced in the U.S., 1.4 billion or 44 percent of which were exported. Soybeans and soybean products represented 21 percent of U.S. agricultural exports in 2013. China was the destination for more than 60 percent of soybeans exported from the U.S. that year.¹⁰

Most U.S. soybeans are grown in the Upper Midwest and the Corn Belt. The U.S. Department of Agriculture (USDA) estimates that 60 percent of soybean exports are moved through Mississippi Gulf ports. Nationally, in 2013, about 50 percent of soybean export tonnage moved

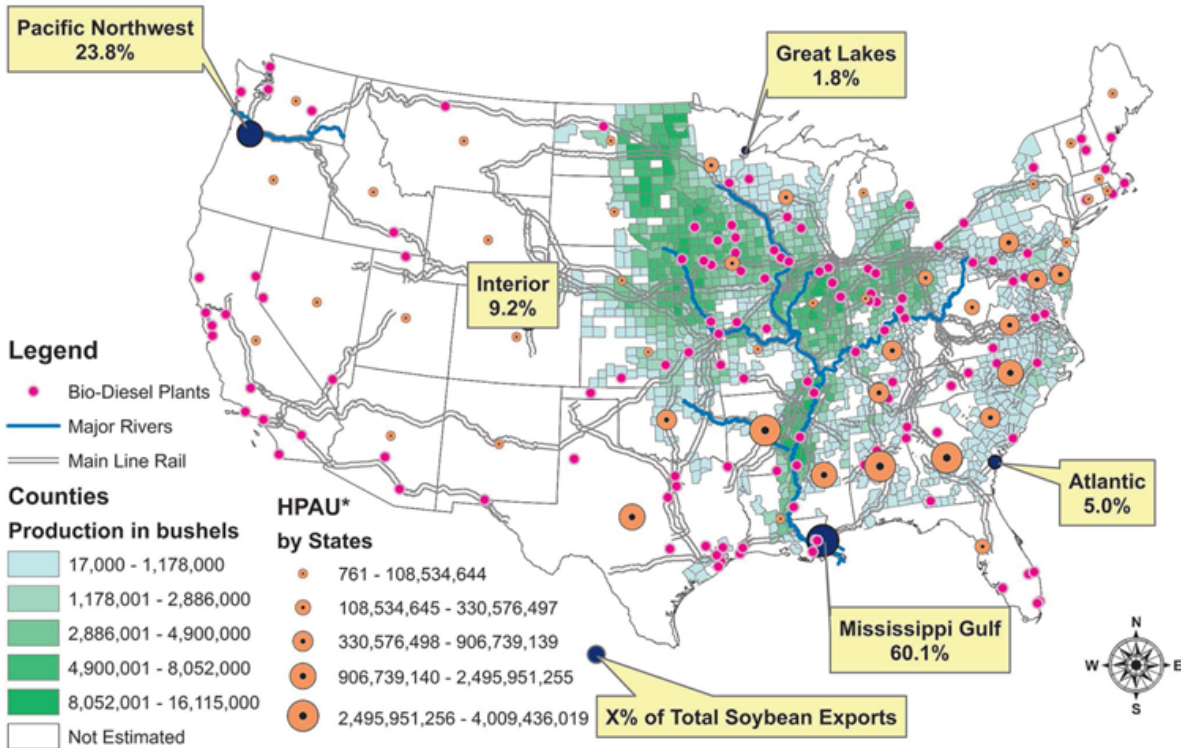
⁸ U.S. Environmental Protection Agency, “Major Crops Grown in the United States,” <http://www.epa.gov/oecaagct/ag101/cropmajor.html> (accessed June 12, 2015).

⁹ The information in this section was adapted from, Marina R. Denicoff, Marvin Prater and Pierre Bahizi, Soybean Transportation Profile. U.S. Department of Agriculture, Agricultural Marketing Service, October 2014. Web <http://dx.doi.org/10.9752/TS203.10-2014>.

¹⁰ Minnesota Department of Agriculture, “Why the Export Market is Important for U.S. Soybeans,” 2014, <https://www.mda.state.mn.us/food/business/~media/Files/food/business/economics/exports-soybeans.ashx> (accessed June 12, 2015).

by barge, 30 percent by rail and the balance by truck. Figure 3.9 shows the distribution of soybean production, uses and exports.

Figure 3.9 Soybean Production, Use and Export, 2013
Agriculture Case Study



3.5.2 Representative Supply Chain

The case study looked at the movement of soybeans from a farm about 35 miles east of Peoria, Illinois, to a barge loading facility on the Illinois River at Peoria, and from there down the Illinois and Mississippi Rivers to Reserve, Louisiana, where the soybeans are transferred to ocean-going ships for export. The general route is shown in the schematic map in Figure 3.10. The map insets provide detail on the routing in the vicinity of Peoria, Illinois, and Reserve, Louisiana.

This path is only broadly representative of shipments by barge from the Midwest to the Gulf. There are about 74 million acres of land in soybean production within thousands of farms across the United States, hundreds of barge loading facilities along the Mississippi and its tributaries and dozens of Southern Louisiana Ports with barge-to-ship transfer facilities. Experts familiar with the soybean industry said that measures available for this path would likely be available for other truck-to-barge-to-port moves.

The decision to export through the Mississippi Gulf ports is driven by three key factors: distance from the grower to a major waterway, ocean-shipping rates and market prices. For growers within 50 to 100 miles of a major waterway, it is usually cost-effective to truck the soybeans to the river and then barge them to the Gulf. Growers located farther from the major rivers are more likely to use rail. However, the higher the cost of ocean-shipping from a Mississippi Gulf port, the more likely it is that the grower will export through a Pacific Northwest port. Shipment by barge is less expensive than shipment by rail, but the barge costs must be low enough to offset higher ocean-shipping costs through the Mississippi Gulf ports.

Figure 3.10 Soybean Export Supply Chain
Agriculture Case Study





3.5.3 Data Sources and Analysis Methods

The truck travel time between El Paso, Illinois, and Peoria, Illinois, was estimated using Google Maps. Google Maps was tested as source of data for estimating travel time because the travel distances involved were relatively short and Google Maps provides information for local roads that are off the National Highway System network covered by the NPMRDS database and the use of Google Maps data does not require custom analysis of ATRI truck trip data.

Google calculates travel times based on distance and posted speed limits. (The ADM/ Growmark Peoria Terminal Wharf Port Facility was used as the truck destination and barge-loading location for the case study, but a grower in region might use any of the number of similar loading facilities on the Illinois River above and below Peoria. Most growers within cost-effective reach of the Mississippi River have a choice of several loading facilities.)

On Interstate highways and in many urban areas, Google offers travel time estimates that are adjusted to reflect current and historical speeds, thereby better capturing delays caused by

congestion and roadway incidents. Where this information is available, a comparison of peak and off-peak travel times estimates can be used to approximate 95th percentile travel times. However, no peak/off-peak or historical data were available for the route between the El Paso and Peoria.

To estimate travel-time reliability, a travel-time multiplier, which was developed by the Texas Transportation Institute (TTI) and published in their Urban Mobility Report, was used.¹¹ TTI reports that the 95th percentile travel time in small metropolitan area (areas of less than 500,000 population) nationwide is typically 11 percent more than free-flow travel time.¹² To account for potential delays due to traffic in the Peoria area, an index multiplier of 1.11 was applied to the Google travel time.

Truck cost data were obtained from Chainalytics and adjusted to represent a short-distance, domestic, for-hire truckload move.

Barge travel time from Peoria, Illinois, to Reserve, Louisiana, was estimated using National Automatic (vessel) Identification System (NAIS) data collected by the U.S. Coast Guard and provided by the U.S. Army Corps of Engineers (USACE).¹³ The NAIS is a tracking system used to identify and locate vessels. (Vessels fitted with NAIS transceivers can also be tracked by NAIS base stations located along coastlines and waterways.)

The USACE has been tracking ship and barge travel paths and times along the Illinois River, the Mississippi River and other waterways to measure delays caused by lock operations, obstructed channels, river traffic and other events. For the case study, the USACE provided a sample of travel times for 120 tug trips from Peoria, Illinois, down the Illinois River and the Mississippi River to Reserve, Louisiana. The observations covered a period of 18 months between mid-June 2012 and early-January 2014. The travel-time data were cleaned and averaged and 95th-percentile travel times were calculated.

¹¹ Texas Transportation Institute, “2012 Urban Mobility Report,” <http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobility-report-2012.pdf> (accessed June 12, 2015).

¹² Texas Transportation Institute, “2012 Urban Mobility Report,” <http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobility-report-2012.pdf> (accessed June 12, 2015).

¹³ Correspondence and data provided by Dr. Kenneth Ned Mitchell, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (Research), Navigation Systems Research Program, 3909 Halls Ferry Road (CEERD-HN-C), Vicksburg, MS 39180-6199.

Barge costs were approximated using USDA and industry data. Barge rates fluctuate substantially with seasonal demand and river conditions. Nominal rates are quoted as a percentage of tariffs.¹⁴ For the case study period, the nominal or tariff rate for barge traffic moving south on the Lower Illinois River averaged \$20 per ton.¹⁵ Actual spot-market rates would have been lower, typically by as much as 20 percent. Barge operators who are owned by or under contract to major growers and food processors would also likely have seen even lower rates. The study used a discounted rate of \$15 per ton as a best estimate.¹⁶ The data sources are summarized in Table 3.11.

Table 3.11 Soybean Export Supply Chain Measures
Agriculture Case Study

Links and Nodes	Source	Notes
Farm in vicinity of El Paso, IL		
Truck move	Google travel time data TTI 95% travel time index small urban areas Chainalytics truck rates	
Peoria Terminal Wharf Port Facility		
Barge move	U.S. Army Corps of Engineers National Automatic Identification System (NAIS) data USDA barge tariff rates and publicly available spot-market quotes	NAIS observations are sparse, but improving; custom analysis required, but could be automated Contract barge rates not readily available
Loading Facility, Reserve, LA		

¹⁴ Inland Waterway tariffs were originally derived from Bulk Grain and Grain Products Freight Tariff No. 7, which was issued by the Waterways Freight Bureau (WFB) of the Interstate Commerce Commission (ICC). In 1976, the United States Department of Justice entered into an agreement with the ICC to drop Tariff No. 7. The WFB no longer exists and the ICC has become the Surface Transportation Board of the United States Department of Transportation; however, the barge industry continues to use the tariffs as benchmarks as rate units. <http://www.ams.usda.gov/AMSV1.0/getfile?dDocName=STELPRDC5084399>.

¹⁵ See U.S. Department of Agriculture data available in spreadsheet format at <https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CB4QFjAAahUKEwjigPHhyoPHAhVHjw0KHSr0DVI&url=http%3A%2F%2Fwww.ams.usda.gov%2FAMSV1.0%2Fgetfile%3FdDocName%3DSTELPRDC5084402&ei=RXq6VaLKM8eeNqrot5AF&usg=AFQjCNHsnRENQyc7A5VxOOUZS6hYhE7Htg>.

¹⁶ In the summer 2015, tariff rates were being quoted at \$17-\$18 per ton before negotiation and adjustments for volume. See for example <http://www.terraliverservice.com/barge-rate/calculator>.

3.5.4 Performance

Table 3.12 shows the travel time, travel-time reliability and cost estimates for the domestic transportation legs of the soybean export chain. The truck move required about 50 minutes, and the barge travel time averaged just over eight days. The 95th-percentile travel time was about double for both modes, with most of the overall variation accounted for by the barge travel time.

The cost of the truck trip was estimated at \$205 and the barge move at \$15 per ton. Costs are presented on per trip and per ton basis. Total cost would vary with the volume of the shipment and contract terms negotiated for both the truck and barge moves. A typical truckload is 17 to 20 tons. Using Waterborne Commerce Statistics, the Corps of Engineers reports that barge shipments from Peoria average 1,580 tons.

Table 3.12 Soybean Export Supply Chain Performance
Agriculture Case Study

Links and Nodes	Transit Time/ Dwell Time (Days, hours)	Reliability (95% travel time)	Cost (2013\$)
Farm in vicinity of El Paso, IL			
Truck move	0.8 hours	1.7 hours*	\$205 per trip
Peoria Terminal Wharf Port Facility			
Barge move	8.2 days	14.5 days*	\$15 per ton
Loading Facility, Reserve, LA			
Totals	9.0 days	14.6 days	-

3.5.5 Lessons Learned

This case study anticipated two challenges: finding data on barge travel times and obtaining realistic cost data.

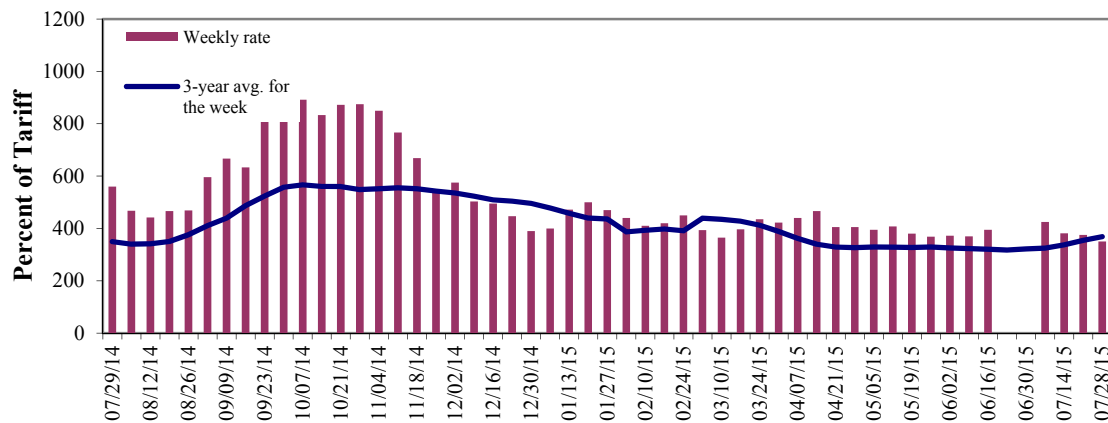
The USACE's vessel NAIS data solved the first challenge, providing a reasonable snapshot of barge travel times from Illinois to Louisiana. The USACE is expanding the number of NAIS base stations along the major inland waterways and accumulating a database of travel patterns and times analogous to the FHWA's National Performance Management Research Data Set (NPMRDS), which captures truck travel speeds and travel times along the National Highway System. The USACE's data collection program is operated today as a research program, but with sufficient and stable funding could be expanded to provide ongoing travel time data for representative pairs of inland and intra-coastal waterway ports.

The case study did not adjust the barge travel times to account for seasonality. Most soybean export shipments occur over the summer and fall. With an expanded sample of tug trips, a

more detailed analysis could control for and estimate seasonal and annual variation in travel times.

The case study was able to approximate the cost of the truck and barge moves. Data on general costs trends are available; as an example, Figure 3.11 shows the USDA's chart of tariff (nominal) rates from mid-2014 through mid-2015. If more precise costs estimates are desired, then data must be collected directly from shippers and their carriers. This could be done through an industry association that collates individual trip data, strips it of identifiers and then reports it for public use. FHWA's agreement with ATRI for the reporting of truck travel times is one model for this approach.

Figure 3.11 Weekly Barge Rates for Illinois River
2014-2015



Notes: Rate = percent of 1976 tariff benchmark index (1976 = 100 percent); 24-week moving average of the 3-year average.

Source: U.S. Department of Agriculture, Agriculture Marketing Service, Transportation & Marketing Programs. "Barge Rates 2004 to Present (Figure 8)."

The case study reported cost data per truckload and per barge-ton. However, most growers would contract to ship hundreds if not thousands of tons at a time. This would require multiple truck trips (at 17 to 20 tons per truckload) and perhaps multiple barge loads (at 1,580 to 1,600 tons per barge). The volume of the shipment (and whether the grower was an independent or company grower) would directly affect supply chain costs. The case study did not calculate total costs for a typical grower, although this could be done based on USDA and state-specific data on farm production by region and county. Finally, the case study did not include the time and cost for transshipping the soybeans from truck-to-barge and barge-to-ship or the cost of ocean shipping to Asia. Studies of total shipping costs are available, but are not published regularly enough to measure supply chain performance annually.

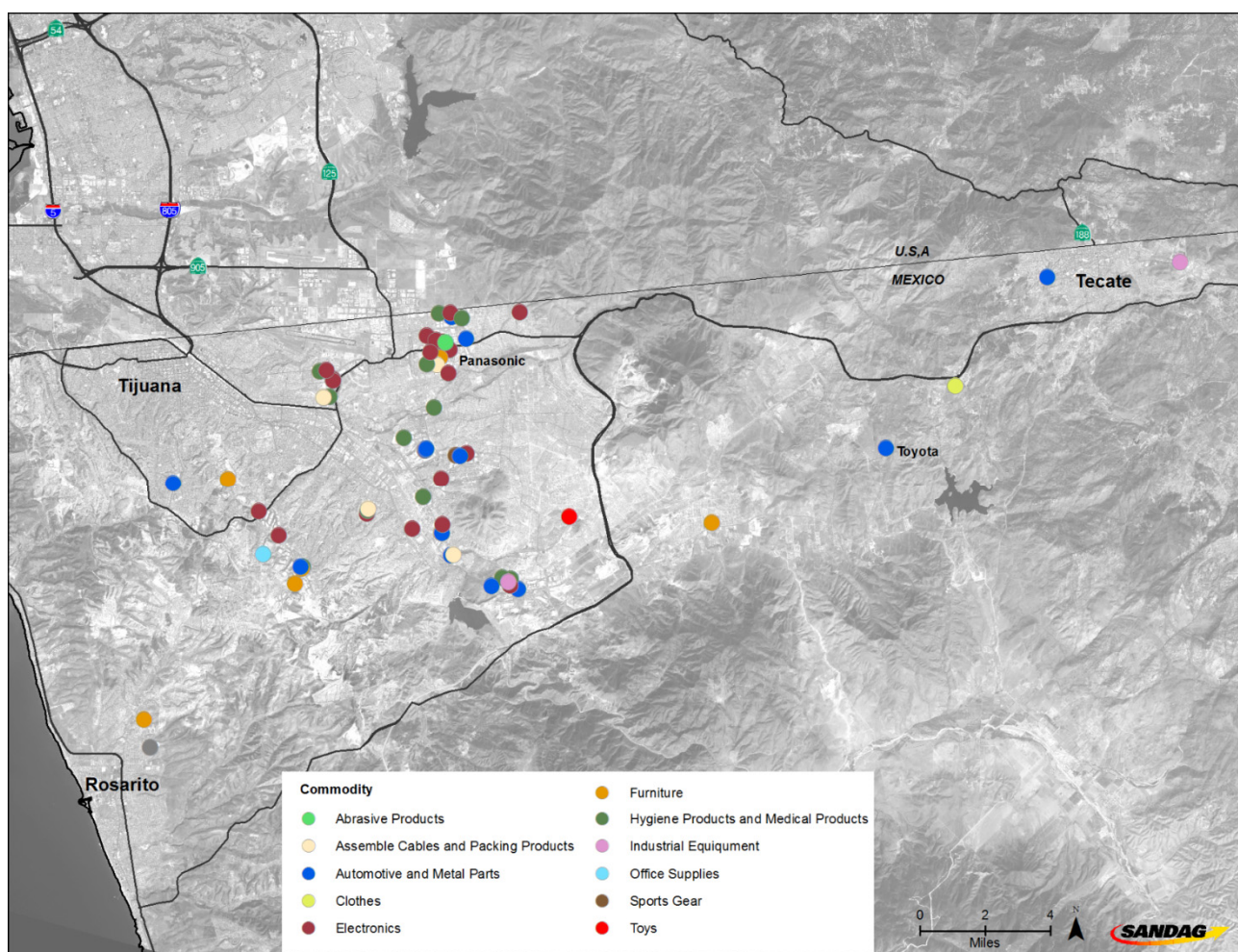
3.6 Electronics Industry Case Study

The final case study traced a Panasonic supply chain moving electronic parts and finished products between manufacturing and assembly facilities in San Diego, California, and Tijuana, Mexico.

3.6.1 Industry

The electronics industry is one of a dozen industries in the San Diego and Tijuana area that operate research and development, manufacturing, assembly or wholesaling operations on both sides of the U.S.-Mexico border. Figure 3.12 shows the approximate locations of maquiladora plants serving industries in the San Diego area. Timely, reliable and cost-effective truck freight service among these facilities is a critical to the productivity and profitability of these industries.

Figure 3.12 Location of San Diego/Tijuana Maquiladora Plants by Product (Commodity)



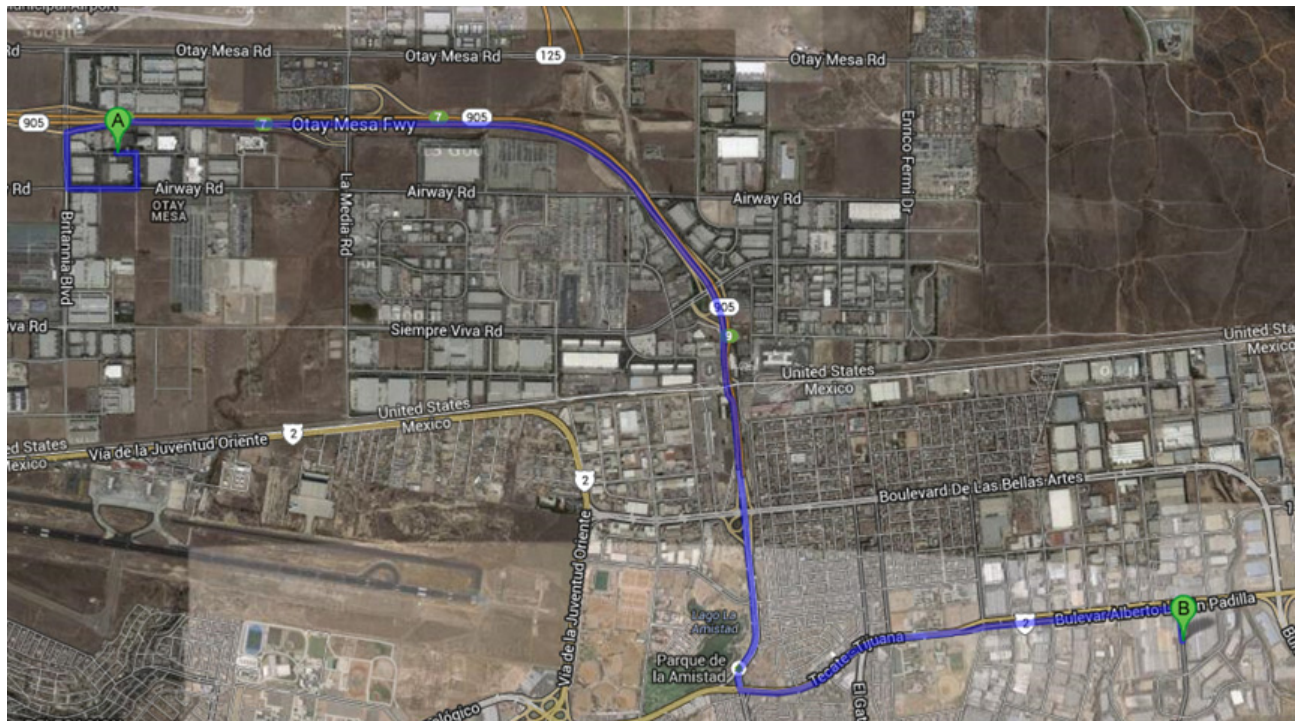
Source: San Diego Association of Governments.

3.6.2 Representative Supply Chain

This case study explores the supply chain performance measures available for shipment of electronic components and products between Panasonic's facilities in San Diego and Tijuana. The location of the two facilities and the truck route between them are shown in Figure 3.13.

Trucks leaving Panasonic's San Diego facility travel east and then south on the Otay Mesa Freeway (California Route 905 East) to the U.S./Mexico crossing at Otay Mesa. After clearing the customs and immigration inspections, the trucks follow Boulevard Garita de Otay, Boulevard de los Aztecas Sur and finally Bulevar Alberto Limón Padilla/Carretera Federal 2 to Panasonic's Tijuana facility.

Figure 3.13 Electronics Supply Chain
Panasonic Case Study



Source: Cambridge Systematics and Google Maps.

3.6.3 Data Sources and Analysis Methods

Truck travel times were obtained using Google Maps travel time estimates. Separate estimates were made for the leg from Panasonic San Diego to the Otay Mesa border crossing and for the leg between the border crossing and Panasonic Tijuana.

The 95th percentile for truck travel-time reliability was approximated by using a sample of Google Maps travel-time estimates during peak- and off-peak periods and the Texas Transportation Institute's travel-time reliability index for medium-to large urban areas.

Border crossing times and variability were obtained from a report entitled *Measuring Cross-Border Travel Times for Freight: Otay Mesa International Border Crossing*, prepared for the Federal Highway Administration by Delcan Corporation.¹⁷ The report was the most definitive study of truck travel at the Otay Mesa crossing available at the time of the case study.

The trucking costs were estimated using Chainalytics data. The costs are based on dry-van truckload costs for the San Diego region.

Table 3.13 Electronic Supply Chain Measures
Panasonic Case Study

Links and Nodes	Sources	Notes
Panasonic San Diego Facility		
Truckload move	Google travel time data	
Otay Mesa International Border Crossing	FHWA Cross-Border Travel Time Study*	Queuing and crossing time available from carriers and ATRI on case-by-case basis; no consistent national database
Truckload move	Google travel time data	
Panasonic Tijuana Facility		

3.6.4 Performance

Table 3.14 lists the estimated travel time, travel-time reliability and costs for the supply chain. The trip is approximately 6.5 miles in length and without traffic and border-crossing inspections would take about 12 minutes at posted driving speeds, with about six minutes of travel time on either side of the border. However, high volumes of traffic and inspections can extend the trip time significantly. The 95th-percentile travel time was estimated at about 30 minutes for each leg, and the Delcan study reported an average dwell time at the international border-crossing of 1.1 hours for trucks crossing into the United States.

Total travel for the 6.5-mile trip was estimated at 1.3 hours and the 95th-percentile travel time at 3.7 hours. Delcan reported considerable variability in the dwell time at the inspection facilities depending on the commodity being carried by the truck and the clearance status of the driver, motor carrier and shipper. The cost was estimated at \$730 per truckload shipment. Shippers, such as Panasonic, compensate by adding buffer time in their scheduling of trips, shipping during off-peak periods and participating in known-shipper and motor carrier pre-clearance programs.

¹⁷ Belella, Tirumalachetty, DiStefano and Hou. *Measuring Cross-Border Travel Times for Freight: Otay Mesa International Border Crossing: Final Report* (FHWA-HOP-10-051). Prepared for Federal Highway Administration, Office of Freight Management and Operations, Washington, DC by Delcan Corporation, Vienna, VA, September 2010. <http://ops.fhwa.dot.gov/publications/fhwahop10051/fhwahop10051.pdf>.

Table 3.14 Electronic Supply Chain Performance
Panasonic Case Study

Links and Nodes	Transit Time/ Dwell Time (Hours)	Reliability (95% travel time)	Cost (2013\$)
Panasonic San Diego Facility			
Truckload move	0.1 hours (6 mins.)	0.5 hours	\$288
Otay Mesa International Border Crossing	1.1 hours*	2.7 hours*	
Truckload move	0.1 hours (6 mins.)	0.5 hours	\$442
Panasonic Tijuana Facility			
Totals	1.3 hours	3.7 hours*	\$730**

* Estimated using data from *Measuring Cross-Border Travel Times for Freight: Otay Mesa International Border Crossing*, (Final Report), prepared by Delcan for FHWA, September 2010.

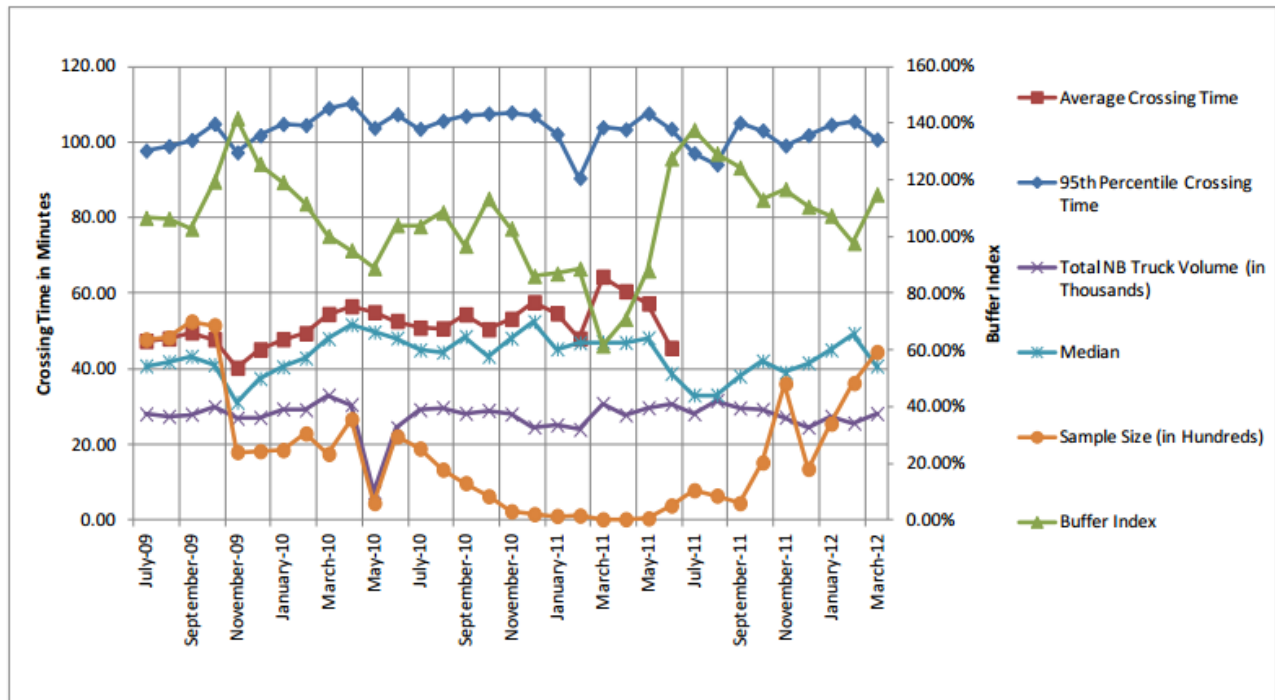
** Preliminary (high) estimate.

3.6.5 Lessons Learned

This case study reinforced the general findings of the automotive case study that data on truck travel time and travel-time reliability to and from the international border crossings are available, but that data on dwell time at the border crossings are not yet produced and published regularly.

FHWA has commissioned a number of studies of truck crossing times at other border stations. The findings show that—as at Otay Mesa—there is considerable variability in dwell time. As an example, Figure 3.14 charts the crossing-time statistics for the Bridge of the Americas port of entry serving El Paso, Texas, and Juarez, Mexico. The Bridge of the Americas study tracked the movement of trucks by reading the radio-identification (RFID) transponders on the trucks as the trucks passed roadside RFID-reader stations located up- and down-stream of the border-crossing facility. The average and median crossing times ranged between 40 and 60 minutes, while the 95th percentile times centered around 100 minutes. The study reported that truck volume, the number of customs primary inspection booths manned and open, the time of day and the number incidents or accidents at the facility accounted for much of the variability.

Figure 3.14 Average Truck Crossing Times, Bridge of the Americas Port of Entry, El Paso, Texas/Juarez, Mexico, 2009-2012



Source: Rajbhandari, Villa, Tate, Samant, Ruback, and Kang, Measuring Border Delay and Crossing Times at the U.S. – Mexico Border Final Report on Automated Crossing and Wait Time Measurement (FHWA-HOP-12-049). Prepared for FHWA Office of Operations by Texas Transportation Institute (College Station, TX) and Battelle Memorial Institute (Columbus, OH). <http://ops.fhwa.dot.gov/publications/fhwahop12049/fhwahop12049.pdf>.

4.0 Conclusions

4.1 It is Feasible and Practical to Measure the Performance of Representative Supply Chains

The study was able to map supply chains and assemble data on performance for five case study supply chains, demonstrating that it is feasible and practical to measure the high-level performance of representative supply chains.

4.2 The Most Accessible Measures of Supply Chain Performance are Travel Time, Travel-Time Reliability and Cost.

Travel time, travel-time reliability and cost measures are common across supply chains and can be scaled up or down for national, multi-state and metropolitan use. “Some assembly is required,” but the data on travel time, travel-time reliability and cost are available and rapidly becoming more accessible and more affordable.

Safety data are available, but not readily accessible. Freight shippers, receivers, carriers and their insurers routinely assess supply chain risk, but the assessments and supporting data are not usually available to the public and can be subjective.

The next sections provide more detail on the findings and conclusions about the data and their sources.

4.2.1 *Travel Time and Travel-Time Reliability*

Travel time and travel-time reliability data are available from an array of public and private sources, but most data require purchase or custom processing.

- **Truck travel time and travel-time reliability data**

- **NPMRDS.** Data on truck travel times are available from the FHWA’s NPMRDS, which is a repository of historical and monthly vehicle probe data. It provides a nationwide database of average roadway travel speed and times by five-minute increment for use by states and MPOs. Freight data are compiled by ATRI from satellite GPS truck position records shared by motor carriers and aggregated to protect confidentiality. Passenger vehicle data are compiled by HERE North America, LLC (formerly known as Nokia/NAVTEQ) from a number of sources including mobile phones, vehicles and portable navigation devices. The NPMRDS covers the entire National Highway System (NHS) and reports travel time by road segments, which are of variable length and are identified by traffic message channel (TMC) location reference codes. Segment distances are defined, and road numbers and names, latitude/longitude and direction are provided. Times are reported in seconds and computed at five minute intervals,

24 hours daily for every day of the year. (More information is available at http://www.ops.fhwa.dot.gov/freight/freight_analysis/perform_meas/index.htm).

It is computationally intensive to calculate origin-destination transit times and reliability from the NPMRDS. Highway segment data must be assembled into routes, and the travel speed along the routes is affected by temporal factors such as peak hour exposure. The sheer volume of data can present processing challenges as well. The models and computer power this study employed to overcome such difficulties can be duplicated; however, standard tools could be developed to automate the process and the associated statistical analyses.

- ATRI. The strong quality of ATRI's data and its coverage of the NHS help explain its selection for the NPMRDS. Nevertheless, there are analyses ATRI can conduct that cannot be performed from the Federal data set because ATRI is able to work from micro-data under stringent confidentiality and usage agreements with its suppliers. The micro-data follow the paths of individual trucks; therefore, the routes selected are known, the time of day and seasonal variables are fully reflected and the hours of service effects are visible. Public agencies may purchase analyses from ATRI tailored to their needs, as this and other studies have done. This entails custom analysis by ATRI requiring time and expense, but may be efficiently repeatable for performance tracking purposes because the computer queries can be stored and reapplied to fresh data.
- Vehicle Probe Data Providers. A consortium of the I-95 Corridor Coalition agencies purchase vehicle probe data (VPP) from INRIX, HERE and TomTom. There are other business vendors offering mobile source data of similar form. VPP vendors, such as INRIX and HERE, can distinguish travel by commercial vehicles and continue to develop sources to segregate freight traffic from other commercial types. Data are offered for route segments much as the NPMRDS provides, although it is conceivable that VPP vendors could utilize source signatures to trace actual vehicle paths as ATRI does.
- The Texas Transportation Institute (TTI) and INRIX. TTI incorporates INRIX data in its annual and publicly available Urban Mobility Report, which measures roadway congestion and freight delay for a large number of cities of varying size. TTI estimates travel-time reliability through a Planning Time Index, which provides a buffer factor. The travel time needed to arrive at a destination with 95 percent reliability can be calculated by multiplying the free-flow traffic time by the Planning Time Index (buffer) factor.
- Google Maps. Google and other widely available mapping software vendors offer estimated travel times for specified routes. Originally based on posted speeds, mapping software increasingly reflects historical average travel times and utilizes crowd-sourced information to predict travel speeds based on current conditions. Averages can be combined with TTI buffer factors to produce approximations of transit time and reliability. This is a back-of-the-envelope method that does not isolate truck traffic from automobile traffic and may be too general for many supply chain

performance-tracking applications. Its advantages are its very low cost and improving basis in empirical observation.

- **Rail travel time and travel-time reliability data**

- TransCore is a commercial vendor that collects rail performance data through its services in inventory tracking and freight management. Its coverage is limited to major intermodal lanes, for which it reports line-haul transit and terminal dwell times along with calculations of reliability derived from them. Coverage excludes some and perhaps all traffic with Mexico. The cost and the full scope of TransCore data need to be clarified. For example, the company is a large player in RFID technology but this study did not determine whether RFID sources contribute to its data. A larger data purchase would have permitted a more detailed assessment of the scope of TransCore's data sources, but the data sample provided by TransCore free of charge was sufficient to show feasibility, and budget discussions seemed to indicate that acquisition costs would be manageable, at least for a Federal procurement.
- RSI Logistics is a commercial supplier that captures transit time and variability for rail carload traffic as part of its business in managing and tracking railcars, great numbers of which are owned or leased by shippers. Terminal dwell time presumably would be included, since railcars spend significant amounts of time in yards. The company does not track rail intermodal activity. The full scope and cost of services from this vendor were not determined because carload shipping was not part of the supply chain case studies for this report. However, carload traffic—from single cars up through unit trains—is the largest class of rail activity and this company does appear to be a viable resource for data on carload moves.
- Railinc is a wholly owned subsidiary of the Association of American Railroads (AAR), on whose behalf it provides a range of customer and other services including equipment and shipment tracking and tracing. Railinc has the capability of supplying comprehensive data on rail travel time and reliability, but it is not a commercial vendor and procuring data from this source would require the agreement of AAR membership. Because other data sources were able to satisfy the needs of this study, an agreement with AAR and Railinc was not explored. It is worth noting, however, that Transport Canada, operating under Canadian regulatory statutes, was able to negotiate and obtain data on rail moves from the Canadian Class I railroads for Transport Canada's Freight Fluidity program. If the U.S. DOT were to negotiate a similar agreement with the U.S. Class I railroads, Railinc would be the likely supplier.

- **Barge travel time and travel-time reliability data**

- NAIS. Waterway and port operations data are available from the U.S. Army Corps of Engineers and port authorities. The National Automatic (vessel) Identification System (NAIS) is a high-quality, public source of travel time on inland and coastal waterways collected by the U.S. Coast Guard and made available through the USACE. Capturing GPS-based vessel locations and identities for navigation management purposes, its

coverage of U.S. waterways is substantial and expanding. Custom analysis is required and was performed for this study by the USACE. However, tools could be developed to automate route and vessel definition and the generation of statistical analyses.

- **Port dwell time and dwell time reliability data**

- Port dwell time can be viewed from several perspectives. For the Retail case study, NAIS data were used to measure the turnaround time for container ships arriving at and departing port terminals. ATRI believes it is capable of capturing truck turnaround time at marine terminals by geo-fencing the location and observing truck arrival and departure times. For ports at which ATRI's participating carriers have sufficient volume of activity, this seems a promising approach. However, from the shipment performance perspective, the critical metric is the elapsed time from ship arrival to shipment exit from the port, which can exceed both of the other measures. The only systematic source for this information would appear to be individual port terminal operators. Transport Canada's Freight Fluidity program captures Canadian port data, and the Port Performance Freight Statistics Program established in the Fixing America's Surface Transportation (FAST) Act could require many U.S. port authorities to collect data on container dwell times within ports. At this writing, NAIS and perhaps ATRI can offer part of the dwell-time picture, with the rest dependent on individual operators or regulatory changes.

4.2.2 Cost

Cost data can be purchased from private suppliers. In almost all cases, the cost data provided by shippers, receivers and freight carriers are aggregated by a third party so that confidential shipper and carrier information is protected.

- **Truck cost data**

- Chainalytics is a benchmarking consortium of Fortune 100-size shippers who share confidential information about freight shipping rates. Data are extensively cleaned and aggregated by a third party manager so that no participant's rates are visible to others, but each can check its charges against a representation of the market price. This is a high quality, repeatable, primary source for freight cost information, covering truckload movements in dry vans, reefers and flatbeds. It encompasses long- and short-haul lanes within the U.S. and for U.S.-NAFTA shipping, defined by postal codes. The database does not include bulk or less-than-truckload carriage and no private or dedicated fleet costs are covered, although the truckload data can be used as proxy for many private and dedicated fleet operations. Chainalytics functions as a service for a consortium of businesses; the assembly and production of data for sale is not their current business model, but one they are willing to explore and which may be cost effective at the Federal level. While issues of confidentiality are largely obviated by the consortium's built-in protections, the membership would need to agree to any arrangement and may be sensitive to the quantity of data to be shared. The cost to

procure data and any attendant provisions and limitations will need to be negotiated with the supplier.

- **Rail cost data**

- [Chainalytics](#) also tracks cost information for rail intermodal shipments, with the same coverage and quality as for truckload activity. It does not capture rail carload shipments.
- The [STB Rail Carload Waybill Sample](#) (CWS) reports railroad revenue (shipper cost) data for all sampled shipments and is used for regulatory purposes by the U.S. DOT's Surface Transportation Board (STB). The revenue data are masked but the figures for carload traffic are used as benchmarks by shippers and can be adopted as a representative fallback source for shipment cost information. The CWS covers NAFTA waybill traffic moving in the United States and among the United States, Canada and Mexico. It captures long- and short-haul rail moves, but it does not cover local shipments made on short line railroads. The CWS is available to U.S. DOT and to states from the STB.

- **Barge cost data**

- The [U.S. Department of Agriculture \(USDA\) Agricultural Marketing Service](#) reports weekly barge shipping rates as a percentage (index) of the 1976 tariff benchmark rate. Private sector brokers provide current rate quotes based on the index. However, actual spot market rates and the rates charged by barge operators owned by or under contract to major growers are not publicly available because there are a limited number of carriers operating along major waterways. Nevertheless, industry experts suggest that it may be possible to obtain rate information from barge operator associations if the data were stripped of individual company and client identifiers. The USACE Planning Center of Expertise for Inland Navigation ([PCXIN](#)) analyzes barge transportation economics and could be an additional source.
- Freight payment clearinghouses, such as [Parsons \(Cass\)](#), may capture some barge rate data. There is a charge for access and custom processing, which is necessary to satisfy confidentiality restrictions. Clearinghouses are also sources for cost data in other modes as well, but coverage is a function of the participating companies' customer bases, which are not uniform across industries and geographies and can change over time, so that analyses are not necessarily repeatable.

4.2.3 Safety

Safety data are available, but not readily accessible. Freight shippers, receivers, carriers and their insurers routinely assess supply chain risk, but the assessments and supporting data are not usually available to the public and can be subjective.

- FARS data is the most accurate and readily accessible data on transportation-related fatalities. NHTSA and its state and local partners are improving the accuracy of accident location data, but it can be time-consuming to verify the location of some crashes. The larger impediment is apportioning incidents to specific supply chains. In many cases, the number of fatalities will be too small to calculate a statistically reliable safety performance measure for any one supply chain.
- State DOTs maintain records of fatalities, injuries and property damage on state and local roads, but the data are usually reported by class of roadway or by type and severity of accident, rather than by highway corridor or roadway segment. The safety data can be allocated by location (e.g., by corridor), but this requires considerable computational work, and the crash or incident data must then be apportioned to a specific supply chain. Again, the number of incidents may be too small to calculate a statistically reliable safety performance measure.

4.2.4 Risk

Risks affecting product integrity—loss, damage and theft, as well as incorrect item counts—are routinely monitored by freight shippers, receivers, carriers and their insurers, but their data generally are not made public and may not be compiled outside their organizations. Theft is the exception because it is a matter for law enforcement, yet systematic statistics have not been available due to inadequate identification and reporting, and fragmented, local jurisdiction. Under PATRIOT Act provisions, the FBI began an initiative to capture data, although reports through April 2015 reflect participation by just seven states.¹⁸ While security risks from terrorism are recognized by industry and monitored by the Department of Homeland Security, tracking of such risks is a confidential matter with little public reporting.

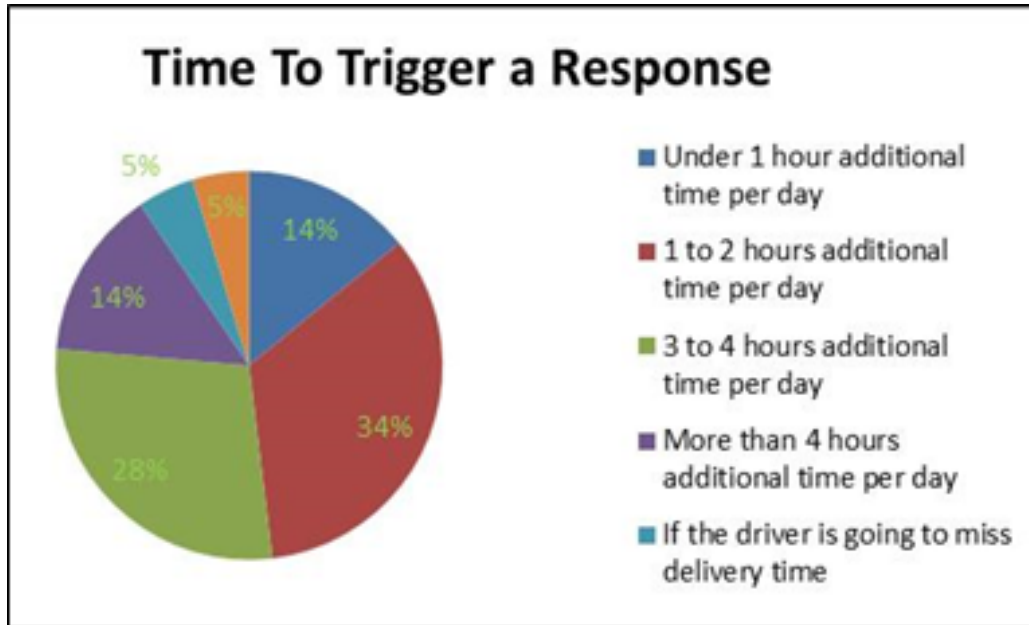
Risks of other types are evaluated for specific supply chains by participating shippers and carriers, but assessments are not usually made available to the public and can be subjective. The case studies and discussions with participating shippers and carriers suggested five categories of risk are considered in assessing supply chain performance. The first relates to short-term logistics planning, and the remaining four to longer-term location considerations.

- *Operational risk.* This category encompasses immediate challenges to daily supply chain performance brought about by traffic congestion, weather, work zones, customs hold-ups, cultural events, truck shortages and other local circumstances that delay shipments. Shippers and carriers actively manage their operations to minimize this risk, normally over a two- to three-day horizon that reflects the practical limit of forecast information and allows time to make adjustments by shipping early, using expedited delivery services or rerouting. Management is done by tracking and benchmarking shipment performance by route, carrier and time of day, and by monitoring weather, road and other short-term conditions. Early awareness and information quality and completeness are crucial. Supply chain sensitivity to operational risk can be seen in the accompanying chart, which indicates how quickly an intervention response is triggered by shipment delay. According to a

¹⁸ Uniform Crime Reporting Program, Cargo Theft Update, Federal Bureau of Investigation, April 2015

survey of major supply chain managers, half the companies take action within just two hours—and this action is in addition to the routine performance buffering already built into freight schedules to allow for variable travel speeds.¹⁹

Figure 4.1 Operational Risk Sensitivity



Source: NCHRP 08-99 “Methodology for Estimating the Value of Travel Time Reliability for Truck Freight System Users,” draft Interim Report, Transportation Research Board, 2015.

The impact of traffic congestion and other local conditions is partially captured in NPMRDS data, which report the variation in automobile and truck travel speed in five-minute increments. It is technically feasible to capture variation by hour, day, week and month, but this requires extensive data analysis. There is considerable public and private research in this area, especially among state DOTs, MPOs and private sector traffic information services, so the quality and availability of congestion data are likely to improve rapidly.

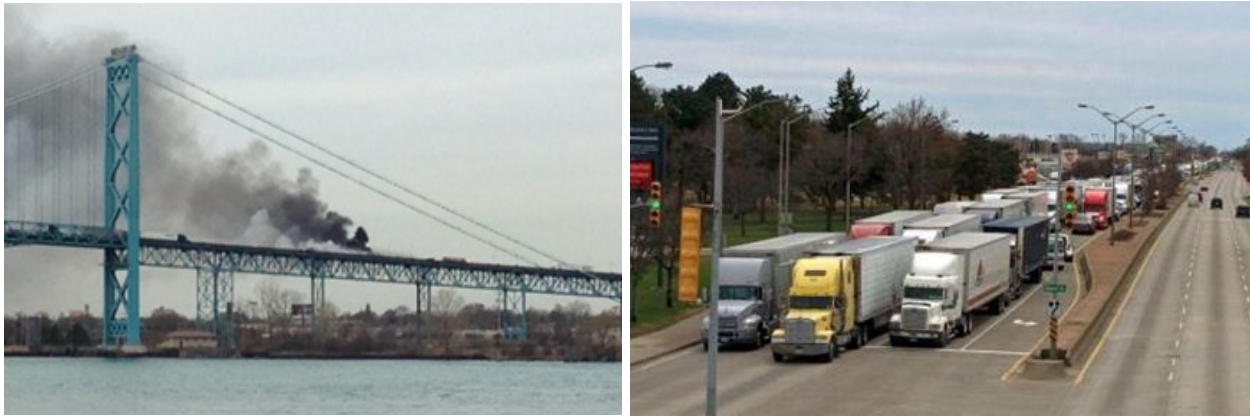
- Institutional risk.** This category covers risk to supply chain performance from uncertainties in the implementation of improvements, brought about by delayed action by Federal, state and local agencies. A prime example is the prolonged wait times to obtain permitting approval for capacity expansion. This can cause a project to miss its window of market opportunity and cause users to tolerate inefficient and expensive operating conditions for extended periods. An important corollary effect is that prolonged approval can deter the investment of private funds in projects that might otherwise warrant them, because investment returns are delayed too long to compete for private capital. Projects may not proceed at all, or the burden on public funds may become unnecessarily large. Other examples of institutional risks include public infrastructure investments that are too small,

¹⁹ NCHRP 08-99 “Methodology for Estimating the Value of Travel Time Reliability for Truck Freight System Users,” draft Interim Report, Transportation Research Board, 2015.

slow or stymied because of inadequate funds or political opposition and operational improvements that are similarly retarded due to insufficient funding, staffing or conflicting agency priorities.

- *Disruption risk.* This category describes infrequent but possibly serious supply chain disruptions, such as those caused by major storms, tornadoes, earthquakes, infrastructure failure, labor disputes, political actions and wars. While specific events can be difficult to predict, recognizing exposure to elevated risks of various types is possible at least at a general level. Disruption risk is a growing concern in supply chain management, especially as severe weather events have risen in frequency and could presage a “new normal.”
- *Acceleration risk.* This category encompasses conditions that may grow much worse rapidly. The typical example is phase transition or state change in traffic flow, where a roadway incident turns slow moving traffic into gridlock. Other examples include loss of energy supply, such as the New York gasoline shortages after Superstorm Sandy, which exacerbated and prolonged the harm done by the storm, and the West Coast port slowdown of late 2014, where the effects of a labor action were greatly magnified because throughput was already hampered by other causes.
- *Deterioration risk.* This category covers conditions that gradually grow worse, causing performance to decline over time. Worsening congestion on roadways is the obvious example, imposing steadily lower reliability and higher buffering costs. A different example is drought, whose ill effects are worse when they are prolonged, whether month to month or over a number of years.

An incident affecting the automotive supply chain described in the case study offers an illustration of some of these risks. The incident was a truck fire on the Ambassador Bridge between Windsor, Ontario, and Detroit, Michigan, in the spring of 2015. The fire caused traffic on the bridge to be halted for several hours. Viewed narrowly, this was an operational risk with no advance warning. Some trucks could divert almost 100 miles north to the Blue Water Bridge, but others were simply obliged to wait. At several hours, the delay would have triggered alarm bells for all of the automotive manufacturing traffic crossing the bridge; moreover, all truck drivers bound for Spring Hill, Tennessee, would exceed their hours-of-service (HOS) limits before making delivery. Viewed more broadly, the incident reflected two further risks. First, the approach route to the bridge in Windsor is on local roads with many stoplights and heavy volume, so the incident caused traffic conditions to accelerate into gridlock. Second, the effect of the incident could have been diminished by added capacity in the form of a second, parallel bridge, but plans for such a bridge have been slowed for years by a number of institutional battles. Both situations amplified the consequences of the fire.

Figure 4.2 Fire and Gridlock Affecting Automotive Supply Chain

Source: CBC News.

Operational risks are a cost of doing business; they are competitively harmful but normally are managed and resolved. However, an operational problem graduates into a location risk if it becomes chronic. The four risks associated with location conditions—disruption, acceleration, deterioration and institutional factors—are considered by supply chain managers in their site selection decisions. If the risk is tolerable, managers accept the consequences; if it is not, the company takes steps to mitigate it (such as adding extra capacity) or it takes its business elsewhere. Both alternatives are costly to the local economy—either the company absorbs extra expenses and is less competitive, or its jobs go to a different community. Moreover, siting decisions are subject to medium-term adjustment—jobs and production can be moved to another location without closing a facility, suppliers in a vulnerable location can be cut off, or a tenant in a leased facility can vacate without selling the building or constructing another.

Location risks are challenging to measure. Traffic deterioration can be tracked through time-series examination of corridor level-of-service, or through continuous sources like the TTI Mobility Report. Traffic acceleration can be detected from travel-time distributions in reliability data. Disruption tends to be assessed subjectively by supply chain managers, although analysis of infrastructure conditions or climate projections can introduce quantified elements. Institutional risks are widespread and affected by political considerations. The manifold nature of risk suggests that the more practical approach to measurement would be to routinely poll shippers and carriers on their qualitative experience with supply chain routes and facilities of key interest.

4.3 Supply Chain Performance Measurement Could Have Significant Benefits

Case study participants anticipated significant benefits from systematically measuring supply chain performance for key industries. The applications most frequently cited by public sector agencies were:

- Identifying freight bottlenecks and the businesses most affected by them as part of conditions and performance reporting;
- More effectively managing operations within and across jurisdictions by recognizing the contributions of individual improvements to total end-to-end performance;
- Targeting investments strategically—and conversely, fending off projects that do not have a significant economic payoff—as part of planning and programming;
- Identifying critical supply chain routes and alternative or redundant paths for disaster and emergency recovery planning and operations;
- More directly linking transportation improvements to supply chain improvements affecting specific industries and associated jobs and economic growth, making it easier to explain the benefits of investing in freight transportation improvements to legislators and the public; and
- Better competing for scarce program dollars by being able to make a more compelling case for investment in freight transportation improvement projects.

The application most frequently cited by private sector companies was using supply chain performance information for competitive benchmarking. Transport Canada has already developed and applied similar measures to assess the performance of the Canadian supply chains linking Canada's West Coast ports to Toronto and Montreal and is now developing measures for the routes serving its East Coast import and export routes.²⁰ At a recent Transportation Research Board workshop, Transport Canada officials reported that their Fluidity Indicator is being used by shippers and carriers to benchmark the performance of their individual supply chains.

A second kind of application should be anticipated as the adoption of state and local freight advisory councils proceeds around the country. Councils create a mechanism by which industry can urge improvements to address performance deficiencies, and indeed coordinate the way they do this in jurisdictions across their supply chains. Concerted action of this sort does not seem evident today, but could arise as private engagement in public planning evolves.

²⁰ See Transport Canada, *Gateways and Corridors, Section 11.2 Supply Chain Performance Monitoring*, <https://www.tc.gc.ca/eng/policy/anre-menu-3023.htm>. See also, Louis-Paul Tardiff (Transport Canada), Fluidity Overview and Implementation: The Canadian Experience, *Developing Freight Fluidity Performance Measures Supply Chain Perspective on Freight System Performance: Summary of a Workshop* in Transportation Research Circular E-C187, Transportation Research Board, May 2014.

5.0 Recommendations

Two sets of recommendations are provided—one general, the other programmatic. The recommendations are based on the findings and conclusions of the case studies, discussions with members the national Advisory Committee on Supply Chain Competitiveness, and the advice of the study sponsors and technical advisory committee. The general recommendations are consistent with the recommendations forwarded to the Secretary of Commerce in September 2014 by the Advisory Committee on Supply Chain Competitiveness.²¹

5.1 General Recommendations

Use supply chain performance measures to inform freight transportation policy and target strategic investments in the freight transportation system.

The nation's ability to compete in the global marketplace depends on the ability to move freight through supply chains reliably and cost-effectively. But today, highway interchanges serving critical supply chains are major bottlenecks; ports, border crossings and intermodal terminals are operating over capacity; and access roads to terminals and distribution centers are deteriorating. These bottlenecks—and the delays they cause—slow down freight movement, raise the cost of moving goods through our supply chains and reduce the ability of shippers and carriers to deliver goods reliably, quickly and on schedule to global and domestic customers. The results are less competitive industries and lost economic opportunity.

A more systematic effort to look at the performance of supply chains can complement and inform Federal, state and local freight transportation policy and investment decisions and result in more effective and competitive supply chains. Accordingly, FHWA, state DOTs and MPOs should consider routinely monitoring and evaluating the general performance of representative supply chains serving major industries, especially those driving global export earnings.

Performance trends over time should be used as an indicator of supply chain competitiveness. Where there is deterioration in service, FHWA, state DOTs and MPOs should look at the performance of the major links and nodes along the supply chain to identify critical bottlenecks and economic impacts and then work with the affected shippers, receivers and carriers to fashion corrective policies and target improvements.

Use travel time, travel-time reliability and cost as the key measures of supply chain performance.

Data on travel time, travel-time reliability and cost are available and rapidly becoming more accessible and more affordable. These measures are common across supply chains and can be scaled up or down for national, multi-state and metropolitan use. Safety and risk should be considered, but the data and methods for generating valid and reliable safety and risk

²¹ See “Committee Approved Letter to the Secretary – Freight Policy,” at http://trade.gov/td/services/oscpb/supplychain/acsc documents/10-11Sep2014/2014-09-11%20SEC-LTR_ACSCC%20FP%20Rec%20-%20Approved.pdf.

measurements for representative supply chains are not yet available. Accordingly, initial measurement of supply chain performance should focus on travel time, travel-time reliability and cost as the most accessible and informative measures.

Provide standardized analytical methods and tools to cost-effectively measure end-to-end supply chain performance—by single mode or across multiple modes—and identify critical bottlenecks for improvement.

There are multiple data sources and methods for measuring supply chain performance and more will emerge as practitioners examine supply chains. FHWA should consider supporting research and developing guidance on the most valid and reliable data sources and methods. This will help accelerate the application of supply chain performance measurement to public sector transportation planning and investment and ensure consistency across regions. This is particularly important because most supply chains and the markets that they serve span multiple states and metropolitan areas. Standardized analytical methods and tools will be important in ensuring that state DOTs and MPOs have compatible measures of performance along corridors serving and crossing their regions. Cumulative performance, totaled end-to-end across this span, is the decisive outcome from the viewpoint of markets, and consistent evaluation of the weak links is crucial for management of the end result.

Apply supply chain performance measures at the industry-, metropolitan-, state and multijurisdictional-, national- and North American-levels.

The case studies focused—by design—on the domestic portions of supply chains spanning several states. However, the same data and methods can be applied at the metropolitan level and at the North American/NAFTA levels.

Applying performance measures to the portions of supply chains in metropolitan areas will be especially important. Metropolitan areas are the economic centers and engines for economic growth in the 21st Century, and as such they are the origin and destination points of many critical supply chains. But metropolitan areas are also the most congested areas and the areas of the freight transportation network for which there are relatively little readily accessible freight data.

Applying performance measures at the North American/NAFTA level will be equally important. Transport Canada has already developed and applied supply chain performance measures as part of its Freight Fluidity program. The program assesses the performance of the supply chains linking Canada's west coast ports to Toronto and Montreal. It is now developing measures for the routes serving its east coast import and export routes. In February 2014, at the North American Leaders' Summit, the North American Heads of State committed to the development of a North American transportation plan, beginning with a North American freight plan. Accordingly, coordination and collaboration among the United States, Canada and Mexico on measuring supply chain performance would contribute measurably to the advancement and realization of that freight plan.

Disseminate supply chain performance information routinely to supply chain stakeholders.

Information on supply chain performance has the potential to benefit a wide range of freight stakeholders, not just public sector agencies. Transport Canada officials, for example, reported that their Fluidity Indicator is being used by transportation agencies to identify freight system bottlenecks for improvement, but also is being used by shippers and carriers to benchmark the performance of their individual supply chains.

Advances in technology and communications have catalyzed new businesses and services aimed at improving the ability of automobile drivers to plan and optimize their individual trips through the highway network. Better information on supply chain performance has the potential to stimulate new private-sector services and tools to plan and optimize freight trips through the freight transportation network.

5.2 Programmatic Recommendations

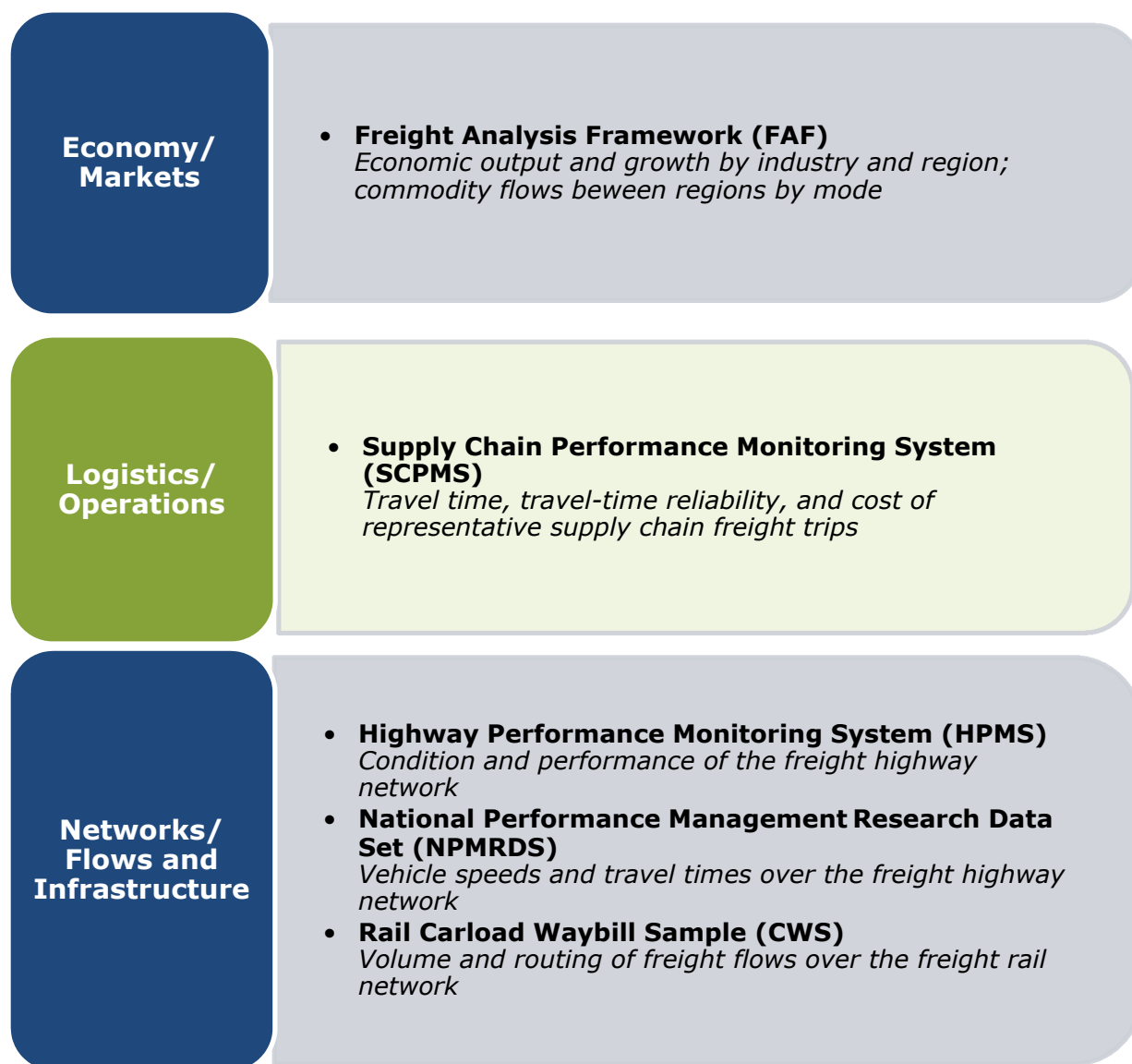
To advance the implementation of the general recommendations, the following are recommended programmatic actions:

Establish a national supply-chain performance-measurement initiative.

The objective of the initiative should be to build out the middle of the three levels of information necessary for an effective Freight Performance Monitoring System. The three levels, illustrated in Figure 5.1, are: information about the economy and the demand for freight transportation; information about supply chains—the paths along which freight shipments move—and the end-to-end trip performance; and, information about the condition and performance of the highway, rail and other networks and facilities that carry the freight.

The U.S. DOT and FHWA have successfully developed information about the economy and freight demand. The Freight Analysis Framework (FAF) describes and forecasts economic output by region and industry and simulates the resultant commodity flows over the highway and rail networks. The U.S. DOT and FHWA have also successfully developed information on the condition and performance of the highway network. The Highway Performance Monitoring System (HPMS) provides information on truck volumes and pavement conditions by roadway segment. The new National Performance Management Research Data Set (NPMRDS) provides information about travel speeds and travel times over the same roadway segments. And the Rail Carload Waybill Sample (CWS) provides data on the types of commodities and their tonnage hauled over the major rail lines.

The missing element is a sustained program to describe and measure the performance of supply chains—to understand how well the highway, rail and other networks support the timely and cost-effective completion of freight trips and whether those trips satisfy the needs of business and industry to compete and grow in national and global markets. The programmatic recommendations are intended to advance the creation of a sustained supply chain performance measurement program.

Figure 5.1 Freight Performance Monitoring System (FPMS)**Establish the initiative as a cooperative public-private enterprise.**

Supply chains span multiple industries and political jurisdictions. To be successful, the Supply Chain Performance Monitoring System initiative must be championed and advanced cooperatively by the three parties with the greatest interest in and potential to benefit from supply chain performance measurement information:

- Public sector transportation agencies, including the U.S. DOT, state DOTs and transportation authorities, MPOs and local transportation authorities;
- Public sector economic development agencies, including the U.S. Department of Commerce (Commerce) and state and local economic development agencies; and

- Private sector, including major shippers, trade associations and carrier associations.

The Federal government, through the U.S. DOT and the Department of Commerce, should take lead responsibility to catalyze the initiative and provide a central point for integrating and disseminating supply chain performance information. The focus of private sector participation should be at the state and local level, ensuring that supply chain information is accurate and effectively incorporated into state and MPO decisions about regulating freight transportation and investing in freight system improvements.

The Department of Commerce, working closely with state economic development agencies, should be charged with defining the most critical industries, trading partners and commodities for initial supply chain mapping. The U.S. DOT and its state DOT partners should be charged with the parallel and coordinated responsibility of mapping out and documenting the initial set of supply chains identified by Commerce and its partners. The initial set should provide sufficient industry and geographic coverage that state DOTs and MPOs can expand upon them and develop more detail at the state and local levels.

Direct research at improving the state of knowledge and the state of practice.

Research should address the following topics:

- Representative “market basket” of supply chains. For policy and planning purposes, it is not necessary to look at every industry and supply chain. Supply chains differ significantly across industries, but they tend to be relatively similar within industries. Moreover, when firms within the same industry are located in the same general area, they are likely to use the same freight transportation systems and see similar performance. FHWA, multistate coalitions, state DOTs and MPOs should be able make considerable progress in understanding the strengths and weaknesses of the freight transportation system in their region by looking at supply chains serving their key industries. But how much is enough? Guidance is needed to better define how to cost-effectively select cases for evaluation.
- Appropriate level of data granularity. The public sector does not need the hour-by-hour and day-by-day performance measurement that is required by freight shippers and carriers. Monthly, quarterly or annual performance information may suffice, but that choice will depend on the industry and the issues at stake. Likewise, the public sector does not need to know the exact path and travel time of every truck, container or rail movement. Transit and dwell times by major link and node or even overall travel times may suffice, but again will depend on the industry and issues. What level of granularity is appropriate for different industries, supply chains and geographies and cost-effective for FHWA, state DOTs and MPOs? Their needs will differ and those needs must be determined.
- Urban freight stages. Information and guidelines are needed to assess the performance of urban freight moves—the pick-ups, transfers and deliveries that are the first and last miles in many supply chains. It would be helpful, for example, to have probability-based estimates of travel time and travel-time reliability in a Quick Response Supply Chain

Performance Manual that could be used to estimate the impact of truck pick-up and delivery operations in different urban areas on overall supply chain performance.

Reliability measures in the form of buffer metrics also can double as cost measures in urban environments. This is because buffering is added time, and the magnitude of buffering has a direct effect on the amount of work that truck fleets can accomplish in a day. Drivers, equipment and fuel are the principal components of trucking cost and all three—including fuel—are influenced by the operating conditions. Buffering is an indicator of the productivity of these conditions: the smaller the buffer, the more deliveries a driver, a truck and a tank of fuel can complete each day, and the lower the cost per delivery.

- Correlating supply chains with freight traffic volumes. Methods are needed to match performance data for supply chain links and nodes with truck-, container- and rail-volume data for those same links and nodes as reported in FAF, HPMS and the Carload Waybill Sample. Is the local traffic truly local or one interdependent stage in something bigger? Do the travel times for a specific industry supply chain apply to five percent or fifty percent of the trucks on a specific roadway? A closely related issue is the need for guidelines on assessing the statistical reliability of truck travel-time data on low-volume roads where speed sampling is infrequent.
- Dwell times at ports and border crossings. There is considerable variation in the dwell times for different carriers and commodities moving through customs and security clearance at ports and land-border crossings. It would be useful to have factors that could be applied to average dwell times to adjust for the level of carrier and commodity security clearance. Dwell times also have different elements and available windows of information on activity. At seaports, the Army Corps of Engineers' NAIS data can capture the turnaround time for ships at dock, and mobile tracking data can capture turnaround for trucks entering and leaving port facilities. However, the time shipments spend from dockside arrival to landside exit is the most important supply chain metric, but is known accurately only to marine terminal operators and to individual shippers about their own goods.
- Barge travel time and cost data for inland and intra-coastal waterways. The Army Corps of Engineers through the U.S. Coast Guard is collecting data on barge and ship travel times. Many of the analytical techniques developed to analyze roadway traffic flows can be adapted to analyze waterway traffic flows, but funding is needed to make the data available.
- Safety performance measures. Data on transportation-related fatalities are available from the National Highway Traffic Safety Administration's Fatality Analysis Reporting System (FARS). Most state DOTs and MPOs collect detailed data on injuries and property damage for crashes within their jurisdiction. The quality of crash-location data varies, but is improving with the application of GPS technology. However, most safety data are aggregated and reported by class of road, type of incident or jurisdiction. Cost-effective methods are needed to allocate incidents to freight links and nodes, and then apportion them in statistically defensible ways to representative supply chains.

- Risk measures. Risk measures can inform public awareness and planning for freight resiliency, redundancy of services and government responsiveness. Theft is the chief type of product integrity risk that raises a public concern; the availability and standardization of cargo theft data should improve as implementation of the FBI's Uniform Crime Reporting Program continues. The five additional categories of risk—operational, institutional disruption, acceleration and deterioration—vary in character and measurability. Operational risks are relatively routine and measurement for some could be organized and analyzed from existing data sources, such as customs clearance time and the effect of work zones on travel time buffers. Similarly, deterioration and acceleration risks can be portrayed from existing data on declining traffic conditions and the frequency of gridlock. While disruption risks are harder to pinpoint, data on bridge conditions are pertinent to the odds of infrastructure failure, and increasing examination of climate change should make the risk from severe weather events somewhat clearer. Assessment of institutional risks is perhaps the most subjective, yet data on permit speed has been and can be compiled at the Federal and more local levels, and as requirements are instituted to make permitting more rapid, compliance statistics should accompany them. Finally, both as a pragmatic place to start and as a high-level view of conditions, a qualitative annual poll could be conducted with shippers and carriers covering a range of risk factors and the key locations where risks are rising and falling.

Provide policy direction, funding eligibility and competitive grant opportunities to encourage states, MPOs and coalitions of states to undertake pooled projects to map out supply chains common to a region, in particular those that cross jurisdictional boundaries.

While the concept of mapping and measuring the performance of representative supply chains is straightforward, the complexity of the U.S. economy and geographic extent of the freight transportation mean that hundreds of supply chains may need to be mapped to build a meaningful atlas of supply chains. The FHWA and Commerce should provide policy direction, funding eligibility and competitive grant opportunities (such as those in the recent FAST Act) to encourage states, MPOs, and coalitions of state (in cases where supply chains span many jurisdictional boundaries) to undertake pooled projects to map out supply chains within their region.

The objective should be to rapidly expand the number of supply chain case studies, thereby building a knowledge base of supply chain patterns and issues across industry sectors and geographies. Corridor coalitions are particularly well suited to this purpose, first because existing groups such as the I-95 Corridor Coalition, the Institute for Trade and Transportation Studies (ITTS) and the Mid-America Freight Coalition have established research programs; second because they are cost-effective—they can leverage the skills and contributions of multiple states, consultants and vendors and do so over a number of years; and third because their geographic bounds allow a better approximation of economic megaregions and other market areas than the jurisdictional boundaries of states and MPOs.

Policy direction and funding mechanisms likewise are needed to address the implications of end-to-end performance measurement for operations management. If nationally important

supply chains are facing declining reliability and rising costs, who is responsible for ascertaining the causes and their public components and then ensuring a public response? Under current programs, U.S. DOT would use the supply chain program to identify and diagnose performance issues, but would leave it to states, MPOs and others to take action. Under a more proactive policy approach, U.S. DOT could adopt the role of a systems integrator for national performance and call for action to be taken where it is warranted. This could be done, for example, in published guidance for state freight plans and freight elements in MPO plans, by requiring that corrections for identified supply chain bottlenecks be included; in solicitations for competitive grants, by calling for solutions to identified supply chain performance deficiencies and prioritizing a portion of awards to applicants that effectively provide them; and in information dissemination to industry, whose mechanism for follow-through would include state Freight Advisory Councils and freight outreach by MPOs. Operations management is another place where corridor coalitions could take on a heightened role, by acting as regional coordinators for supply chain issues.

Develop model data acquisition contracts that MPOs, state DOTs and multi-state/regional coalitions can use to purchase data from private sector suppliers, and encourage joint purchasing programs to take advantage of economies of scale in data purchases and development of analytical tools

There is substantial precedent and experience among states, multistate coalitions and the Federal government in purchasing and using private sector data without compromising proprietary and business confidential information. The I-95 Corridor Coalition's Vehicle Probe Data program and the FHWA's FAF and NPMRDS databases are good recent examples of successful data acquisition programs. Effective and well-thought-out model contracts will be especially important for obtaining railroad and port data. Leveraging development of shared analytic tools provides a way to optimize agencies' ability to effectively utilize this data. Examples of this include the I-95 CC's Integrated Corridor Analysis Tool and Vehicle Probe Project Suite, which were developed to analyze historical vehicle probe data for operations and performance measures.

Produce an on-line guide and on-line seminars for transportation and economic development professionals that describe available data sources, analysis methods and applications.

FHWA has a successful record of producing planning guides and webinars that help practitioners fulfill their duties and researchers understand and advance the state of the art. Meanwhile, new sources of data and data combinations seem to be arising in a steady stream. Building on such capabilities and responding to changing opportunities, FHWA—coordinating with Commerce—should establish an on-line guide supported by webinars and regular updates, to orient, inform, refresh and stimulate the development and utilization of fluidity data.

Pilot a benchmarking program that provides ongoing information about the performance of representative supply chains to the public and private sector shippers and carriers.

Tracking trends in performance greatly enlarges the value from observations of fluidity by showing where conditions are improving or not, and where actions have been effective or not. Similarly, the differences in performance between comparable areas help to diagnose the challenges to be addressed, and highlight competitive advantages. FHWA and related agencies should institute an ongoing benchmarking program to enable both kinds of benefit. The program should monitor the performance of nationally important supply chains, disseminate this information to public and private users and ideally provide some interpretative context (for example, by noting the influence of weather events or labor actions).