National Center for Intermodal Transportation for Economic Competitiveness

Final Report 522

Development of Performance Measurement for Freight Transportation

by

Peter Kelle, Ph.D.
Louisiana State University

Mingzhou Jin, Ph.D.
University of Tennessee

NCITEC
National Center for Intermodal Transportation for Economic Competitiveness

Supported by:

MISSISSIPPI STATE UNIVERSITY | LSU LOUISIANA STATE UNIVERSITY | DOTD LOUISIANA DEPARTMENT OF TRANSPORTATION & DEVELOPMENT | LOUISIANA TRANSPORTATION RESEARCH CENTER

4101 Gourrier Avenue | Baton Rouge, Louisiana 70808 | (225) 767-9131 | www.ltrc.lsu.edu

TECHNICAL REPORT STANDARD PAGE

1. Report No.
FHWA/LA.14/522

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Development of Performance Measurement for Freight Transportation

5. Report Date
September 2014

6. Performing Organization Code
LTRC Project Number: 13-3SS
State Project Number: 30000762

7. Author(s)
Peter Kelle and Mingzhou Jin

8. Performing Organization Report No.

9. Performing Organization Name and Address
Department of Information Systems and Decision Sciences, Louisiana State University, Baton Rouge, LA 70803
Industrial and Systems Engineering, University of Tennessee at Knoxville, Knoxville, TN 37996

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Center for Intermodal Transportation for Economic Competitiveness (NCITEC)
Mississippi State University
260 McCain
Miss. State, MS 39762

Louisiana Department of Transportation and Development
P.O. Box 94245
Baton Rouge, LA 70804-9245

13. Type of Report and Period Covered
Final Report
July 2012 – December 2013

14. Sponsoring Agency Code

15. Supplementary Notes
Conducted in Cooperation with the U.S. Department of Transportation, Research and Innovative Technology Administration (RITA), Federal Highway Administration

16. Abstract
In this project, the researchers built a set of performance measures that are unified, user-oriented, scalable, systematic, effective, and calculable for intermodal freight management and developed methodologies to calculate and use the measures.
The following measures for freight transportation systems are suggested to address the needs of transportation users.

1. *Mobility:* Reducing transportation time and delay is a major concern of most transportation users.
2. *Safety*: The objectives related to transportation safety and security includes improving traffic safety, i.e., reducing traffic accident rates, injuries, fatalities, and risks. They also include increasing traffic security and reducing crime rates, improving accident detection and response, and increasing public and homeland security.
3. *Environmental Stewardship*: The objectives include reducing the amount of transportation-related pollutants, promoting the community livability near major transportation infrastructures, and decreasing energy consumption.
4. *Direct Cost Efficiency*: The objectives include developing cost-efficient transportation systems that have low cost/benefit ratios and high sustainability.
5. *Economic Growth*: The objectives include promoting local or regional economic growth and increasing local or regional employment opportunities.

There are two major outcomes from this project:

- An intermodal performance measurement system for freight management, including metrics definition, calculation procedure, and methodologies of data collection.
- A case study that demonstrates how to apply the proposed performance measurement system to evaluate the Louisiana intermodal network for freight management.

17. Key Words
Freight, multimodal, measurement, planning

18. Distribution Statement
Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.

19. Security Classif. (of this report)

20. Security Classif. (of this page)

21. No. of Pages
78

22. Price

Project Review Committee

Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

LTRC Administrator/ Manager

Kirk M. Zeringue, P.E.

Special Studies Research Manager

Members

Joe Accardo

Sharon Balfour

Brandon Buckner

Dennis Decker

Dean Goodell

Phil Jones

Directorate Implementation Sponsor

Dennis Decker

DOTD Assistant Secretary, Office of Multimodal Planning

Development of Performance Measurement for Freight Transportation

by

PI: Peter Kelle, Ph.D., Professor
Ourso Family Distinguished Professor of Business Analysis
Department of Information Systems and Decision Sciences
3195 Patrick F. Taylor Hall, Baton Rouge, LA 70803
qmkell@lsu.edu, (225) 578-2509

Co-PI: Mingzhou Jin, Ph.D., Associate Professor and Associate Department Head
Industrial and Information Engineering
University of Tennessee at Knoxville
405 East Stadium Hall, Knoxville, TN 37996
jin@utk.edu, (865) 974-9992

LTRC Project No 13-3SS
State Project No. 30000762

conducted for

Louisiana Department of Transportation and Development
Louisiana Transportation Research Center
National Center for Intermodal Transportation for Economic Competitiveness (NCITEC)

September 2014

ABSTRACT

The Intermodal Surface Transportation Efficiency Act (ISTEA) and the Transportation Equity Act for the 21st Century (TEA-21) require all states to establish performance measures for freight movement. All administrations in the U.S. Department of Transportation (USDOT) report the performance for their transportation systems in terms of different measures. In this project, the researchers built a set of performance measures that are unified, user-oriented, scalable, systematic, effective, and calculable for intermodal freight management and develop methodologies to calculate and use the measures.

The following measures for freight transportation systems are suggested to address the needs of transportation users.

- *Mobility:* Reducing transportation time and delay is a major concern of most transportation users.
- *Safety*: Improving traffic safety, i.e., reducing traffic accident rates, injuries, fatalities, and risks. They also include increasing traffic security and reducing crime rates, improving accident detection and response, and increasing public and homeland security.
- *Environmental Stewardship*: Reducing the amount of transportation-related pollutants, promoting the community livability near major transportation infrastructures, and decreasing energy consumption.
- *Direct Cost Efficiency*: Developing cost-efficient transportation systems that have low cost/benefit ratios and high sustainability.
- *Economic Growth*: Promoting local or regional economic growth and increasing local or regional employment opportunities.

There are two major outcomes from this project:

- An intermodal performance measurement system for freight management, including metrics definition, calculation procedure, and methodologies of data collection.
- A case study that demonstrates how to apply the proposed performance measurement system to evaluate the Louisiana intermodal network for freight management.

ACKNOWLEDGMENTS

The authors are thankful for the support and direction of the Project Review Committee. Their suggestions, criticisms, and the data they supplied were very valuable for improving the results.

IMPLEMENTATION STATEMENT

The authors suggest performance measures that can be annually updated with reasonable effort of the administration without any major new investment in data gathering and software development. The data used is publicly available on the Internet or maintained by DOTD. The software used, TransCAD, is also available for DOTD. The implementation of the measurement system requires further steps for measuring reliability, which is not included in the scope of this project but is planned for another LTRC project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

With increased emphasis on intermodal transportation development, the issue of how to evaluate an intermodal system has been receiving intensive attention since the enactments of the Intermodal Surface Transportation Efficiency Act (ISTEA) and the Transportation Equity Act for the 21st Century (TEA-21). All administrations in the U.S. Department of Transportation (USDOT) report the performance for their transportation systems in terms of different measures. The Federal Highway Administration (FHWA) uses truck travel times in freight-significant corridors. The Maritime Administration uses port and waterway performance measures (e.g., port throughputs, shipping, and port availability), and the U.S. Class I railroads use three measures: cars on line, train speed, and terminal dwell hours. However, *all these measures are defined for different modes and thus none of them can be used to measure a freight network that often involves multiple modes*. The ISTEA requires all states to implement a performance-based planning process, and the new Moving Ahead for Progress in the 21st Century Act (MAP-21), which has been passed by U.S. Senate and is pending in the U.S. House, requests the national freight network to “incorporate concepts of performance, and accountability into the operation and maintenance of the national freight network.” The Act specifically requires the USDOT and all states to “establish performance measures for freight movement.” Once established, all states are expected to use those performance measures to select freight management projects for federal funding and demonstrate the benefits of improvement investments. Some states, such as Minnesota, Oregon, Florida, and California, have already enacted some performance measures for intermodal transportation, but not specifically for freight management.

OBJECTIVE

The objectives of this project were to build a set of performance measures that are unified, user-oriented, scalable, systematic, effective, and calculable for intermodal freight management, and to develop methodologies to calculate and use the measures. The measures needed to be able to evaluate an arbitrary freight network and to fairly compare intermodal designs with different sizes and modes. An intermodal freight management performance measurement system should meet the following criteria:

- It should be *applicable* to all modes and their combinations for evaluating a freight network.
- It should be based on *user needs*. The users include all stakeholders of freight networks, such as shippers, transportation service providers, federal and state DOTs, and local communities.
- It should be s*calable* to compare systems of different sizes.
- It should be *effective* and s*ystematic*. A good performance measure system should include a limited number of measures that are the most significant and effective from the system viewpoint and should be as quantitative as possible to make objective comparison between different designs.
- It should be *calculable*. An indicator of performance is applicable only when it can be calculated based on data that are collectible.

A well-established performance measurement system is fundamental to and has a significant impact on freight network planning and improvement, especially on project selection and prioritization and on demonstrating the benefits of investment. The performance measures help to compare intermodal designs and improvement projects and select ones with best benefit-to-cost ratios. The project directly responds to the objective of National Center for Intermodal Transportation for Economic Competitiveness (NCITEC): "to improve intermodal connectivity, enhanced operational integration, capacity enhancement, safety, and reduction of congestion in the nation's transportation system." The proposed efforts are closely related to the research topics listed by the NCITEC, such as "modeling of intermodal transportation, development and evaluation of innovative technologies designed to enhance intermodal economic competitiveness, and improvement of intermodal transportation economics and system resilience."

SCOPE

Once established, state DOTs are expected to use those performance measures to evaluate their freight networks and select freight management projects for federal funding and demonstrate the benefits of improvement investments. That limits suggestions to only measures that can be annually updated with reasonable effort of the administration without any major new investment in data gathering and software development.

METHODOLOGY

Methodology Summary

Four tasks have been conducted with detailed methodology descriptions to achieve the project objectives.

Task 1: Summarization of existing intermodal freight transportation measures

Many performance measures in the literature are defined only for a single mode. An earlier literature review of general intermodal transportation has been done in the Co-PI's previous project of "Intermodal Transportation System Performance Assessment Model and Decision Tool" funded by the NCIT and presented in the paper "Transportation Performance Measurement System with a Case Study in Mississippi" in 2006. The review has been updated with recent publications and practices and focuses on freight management for three major surface transportation modes: highways, railways, and waterways, though the aviation freight movement is also considered.

Task 2: Identification of performance measures using systems engineering approaches

Systems engineering approaches were applied to identify indicators of performance common to all three major surface transportation modes and their connections regarding freight flows. The major stakeholders for freight transportation systems were identified along with their needs. They are shippers, transportation service providers, federal and state DOTs, and local communities. This task identified the following metrics on the basis of the literature and DOT practice.

- Mobility: average travel time per mile based on geographic distances not on traveling distances;
- Reliability: dependable levels of transportation service;
- Safety: fatality, injury, and property damage rates per ton-mile;
- Environmental Impacts: energy consumption and emission per ton-mile;
- Direct Cost Efficiency: vehicle operating costs and transportation facility costs including initial investment and maintenance costs; and
- Economic and Employment Impacts: impacts on the regional economy and employment.

Task 3: Procedure development for calculation, data collection, and application

The calculation procedures have been developed for all identified performance metrics, and the data sources for supporting the calculation will be located. This task also developed the procedure to use the proposed performance measurement system to make project selection decisions, including the judgment of acceptable and unacceptable performance. The following freight demand data and intermodal network data are involved in the calculation.

- *Freight Analysis Framework Version 3*: With data from the 2007 Commodity Flow Survey and additional sources the Freight Analysis Framework version 3 (FAF^3) provides estimates for tonnage and value, by commodity type, mode, origin, and destination for 2007, 2009, and forecasts through 2040.

- *ORNL Intermodal Surface Network*: The team has obtained the intermodal transportation network data from the Oak Ridge National Lab (ORNL) through collaboration in previous projects.

Other data sources include the *fatality analysis reporting system* (FARS) maintained by the National Center for Statistics and Analysis (NCSA) and the USDOT; *Railroad Accident/Incident Reporting System* maintained by the Federal Railroad Administration; the *U.S. Waterway Data* managed by the U.S. Corps of Engineers; *Ports & Waterways Safety Assessment* used by U.S. Coast Guard; *U.S. Emissions Inventory Report* and *Access to Air Pollution Data* distributed by the U.S. Environmental Protection Agency; a survey on the construction cost in other states conducted by the Washington DOT; *Highway & Motorway Fact Book* published by Public Purpose; *National Transportation Statistics* published by Bureau of Transportation Statistics (BTS); and *Complete Economic and Demographic Data Source*. Additional data sources, if necessary, will be located.

Task 4: Case Study, demonstration, and technology transfer

A case study has been conducted to evaluate the freight network of the state of Louisiana to demonstrate the application of the proposed performance measure system. TransCAD was used to conduct traffic assignment and display the study results.

Summarization of Existing Intermodal Freight Transportation Measures

The past decade has witnessed a considerable growth of intermodal freight transportation. The Moving Ahead for Progress in the 21st Century Act (MAP-21) requests the national freight network to "incorporate concepts of performance…and accountability into the operation and maintenance of the national freight network" and requires the U.S. Department of Transportation (USDOT) and all states to “establish performance measures for freight movement” *[1]*. Congress, USDOT, and state DOTS will increase their interest in measuring freight system performance in order to effectively enhance freight efficiency, safety, and convenience. A great deal of research has been conducted and good practices exist in the area of performance measures for freight transportation, which is summarized in this review. This review will provide a better understanding of existing freight transportation performance metrics and may aid transportation agencies in better developing their measurement system and evaluating their freight system.

Measures Used by Federal Agencies

USDOT reports performance measures annually for evaluating the national transportation system, for both freight and passenger transportation *[2]*. Their 2011 report listed the following six major comprehensive objectives.

- Safety;
- Reduced congestion;
- Global connectivity;
- Environmental stewardship;
- Security, preparedness, and response; and
- Organizational excellence.

The report provides a general description of these six performance objectives. Detailed goals are further identified under each objective. However, those detailed quantitative measures are mainly defined for single modes rather than from an intermodal viewpoint.

The following ten measures (SA1-SA10) are used for the safety objective.

SA1. Passenger vehicle occupant highway fatality rate per 100 million passenger vehicle miles traveled (VMT);

SA2. Large truck and bus fatality rate per 100 million VMT;

SA3. Motorcyclist fatality rate per 100,000 motorcycle registrations;

SA4. Non-occupant fatality rate per 100 million VMT;

SA5. Number of commercial air carrier fatalities per 100 million persons onboard;

SA6. Fatal accidents per 100,000 flight hours in general aviation;

SA7. Rail-related accidents and incidents per million train miles;

SA8. Transit fatalities per 100 million passenger-miles traveled;

SA9. Number of natural gas and hazardous liquid pipeline incidents with death or major injury; and

SA10. Number of hazardous materials transportation incidents with death or major injury.

Obviously, each of these ten measures is defined for one mode and there is no way to evaluate the safety of a system with multiple modes or compare two systems with different modes. Their definitions even show different units so that it is impossible to compare safety among modes. For example, the rail safety (SA7 above) is defined based on distance traveled (per million train miles) while the airway safety is defined by 100 million persons onboard and 100,000 flight hours in general aviation. At the same time the pipeline system safety does not consider transportation volume and travel distance at all.

For the reduced congestion objective, seven measures (CO1 through CO7) are used.

CO1. Percentage of travel on the National Highway System (NHS) meeting pavement performance standards for "good" rated ride;

CO2. Percentage of deck area on NHS bridges rated deficient;

CO3. Percentage of total annual urban area travel occurring in congested conditions;

CO4. Average percent change in transit boardings per transit market (150 largest transit agencies);

CO5. Percent of transit bus fleets compliant with the Americans with Disabilities Act (ADA);

CO6. Percent of key transit rail stations compliant with the ADA; and

CO7. Percent of all flights arriving within 15 minutes of schedule at the 35 Operational Evolution Partnership airports due to National Airspace System (NAS) related delays.

All the seven congestion reduction measures are very specific and the improvement of each can help to mitigate congestion in the nation's transportation network. However, a system-wide measure is still lacking, especially for systems with more than one mode. The modes of railway and waterway are not included, though they play a significant role in congestion reduction by mitigating freight traffic from highways.

There are multiple measures for each objective of environmental stewardship (ES), security (SE), and organizational excellence (OE):

ES1. Number of areas in conformity lapse;

ES2. Number of hazardous liquid pipeline spills with environmental consequences;

ES3. Number of Exemplary Human Environmental Initiatives undertaken;

ES4. Median time in months to complete environmental impact statements for DOT funded infrastructure projects;

SE1. Percentage of Department of Defense (DoD)-required shipping capacity complete with crews available within mobilization timelines;

SE2. Percentage of DoD-designated commercial ports available for military use within DoD established readiness timelines;

SE3. Percentage of DOT personnel with emergency management responsibilities who are prepared to respond to disasters and emergencies;

SE4. Percentage of DOT agencies meeting annual response requirements;

OE1. Percentage of major federally funded transportation infrastructure projects with less than a 2 percent annual growth in the project completion milestone as reported in the finance plan;

OE2. Percentage of finance plan cost estimated for major federally funded transportation infrastructure projects with less than a 2 percent annual growth in project completion cost;

OE3. For major DOT aviation systems, percentage of cost goals established in the acquisitions project baselines that are met; and

OE4. For major DOT aviation systems, percentage of scheduled milestones established in acquisition project baselines that are met.

Many of the above measures, if not all, are used to measure some activities in a single mode. In addition to the USDOT annual performance report, each USDOT Administration also reports its mode-specific performance regularly.

The Maritime Administration reported port performance measures in 2003 and reported their performance to Congress in 2008 and 2009 *[3, 4]*. The 2009 report followed the structure of the USDOT report but only listed their efforts in the four areas of

- Reduced congestion;
- Global connectivity;
- Environmental stewardship; and
- Security, preparedness, and response.

The Federal Railroad Administration (FRA) reports rail service metrics and performance of intercity passenger train operations under the following categories *[5]*.

- Financial Performance
  - Short-term avoidable operating costs;
  - Fully allocated operating cost covered by passenger-related revenue;
  - Long-term avoidable operating loss;
  - Adjusted loss per passenger- mile;
  - Passenger-miles per train-mile;
- On-Time Performance (OTP)
  - Change in effective speed from FY 2008 baseline (miles per hour, Mph);
  - Endpoint OTP;

    - All-stations OTP;
- Train Delays
    - Off-NEC[1] host responsible delays per 10,000 train-miles;
    - Off-NEC Amtrak responsible delays per 10,000 train-mile;
    - On-NEC total host and Amtrak responsible delays per 10,000 train-miles;
- Other Service Quality
    - Customer satisfaction indicator scores;
    - Service interruptions per 10,000 train-miles due to equipment-related problems;
    - Complaints received;
- Public Benefits
    - Connectivity measure; and
    - Availability of other modes;

Because freight railroads are private in the United States, FRA does not report performance of freight rail. The seven U.S. Class I railroads report three measures online at *www.railroadpm.org*. They are

- Cars on line;
- Train speed (mph); and
- Terminal dwell hours.

However, William Vantuono pointed out that the railroads actually use different ways to calculate those measures and it is difficult to compare them on a railroad-by-railroad basis *[6]*.

The FHWA uses truck travel times in freight-significant corridors to measure the performance of their freight transportation system *[7]*. The times are calculated based on collected operating speeds for trucks at any given place and given time along twenty-five interstate highways. In addition, FHWA also reports border delay and crossing times for freight *[8]*.

Based on the report of "Federal Transit Administration (FTA) Has Opportunities to Improve Performance Accountability" from the U.S. Government Accountability Office in 2010, FTA does not, in general, analyze fully or use the performance data it collects from transit agencies to evaluate the effectiveness of its transit grant programs *[9]*. MAP-21 requires FTA to define objective standards for measuring:

1 NEC stands for Northeast Corridor

- Safety for all modes of public transportation, and
- Condition of capital assets.

Furthermore, FTA, along with FHWA, is also required by MAP-21 to develop a performance-based planning process *[10]*.

The Federal Aviation Administration (FAA) lists the following performance metrics and their targets for 2018 in their strategic plan regarding safety, workplace, aviation access, sustainability, and global collaboration *[11]*.

- Reduce the commercial air carrier fatalities per 100 million persons on board by 24 percent over a nine-year period (2010-2018). No more than 6.2 in 2018.
- Reduce the general aviation fatal accident rate to no more than 1 fatal accident per 100,000 flight hours by 2018.
- Maintain the rate of serious runway incursions at or below 20 per 1000 events.
- Reduce risks in flight by limiting the rate of the most serious losses of standard separation to 20 or fewer for every thousand (.02) losses of standard separation within NAS.
- Implement 40 percent of mitigating strategies for the top 5 airport risk areas.
- Ensure no cyber security event significantly degrades or disables a mission-critical FAA system.
- No fatalities, serious injuries, or significant property damage to the uninvolved public during licensed or permitted space launch and reentry activities.
- The FAA is rated in the top 25 percent of places to work in the federal government by employees.
- Achieve a 90 percent success rate in the areas of financial management and human resources management.
- Optimize airspace and Performance Based Navigation (PBN) procedures to improve efficiency an average of 10 percent across core airports by 2018.
- Increase throughput at core airports by 12 percent to reduce delays by 27 percent using a 2009 operations baseline.
- Improve flight predictability by reducing variances in flying time between core airports based on a 2012 baseline.
- Improve throughput at core airports during adverse weather by 14 percent by 2018.
- Maintain 90 percent of major system investments within 10 percent variance of current baseline total budget at completion.
- Ensure Localizer Performance (LP) procedures are available at 5,218 runways in the NAS by 2018.

- Achieve a 5 percent reduction in average taxi-time at Core airports, identified by the Future Airport.
- Capacity Task 3 for surface traffic management.
- Reduce the U.S. population exposed to significant aircraft noise around airports to less than 300,000 persons.
- A replacement fuel for leaded aviation gasoline is available by 2018 that is usable by most general aviation aircraft.
- Improve National Aviation Services (NAS) energy efficiency (fuel burned per miles flown) by at least 2 percent annually.
- Aviation emissions contribute 50 percent less to significant health impacts and are on a trajectory for carbon neutral growth using a 2005 baseline.
- One billion gallons of renewable jet fuel is used by aviation by 2018.
- World-wide fatal aviation accident rate declines 10 percent compared to 2010.
- 40 percent of all commercial aircraft from the top 25 aviation states are using fully interoperable NextGen technologies and capabilities by 2018.
- States representing 85 percent of international activity are taking actions to contribute to the 2 percent global annual fuel efficiency improvement goal of International Civil Aviation Organization (ICAO) by 2018.

Although numerous performance measures are used by USDOT agencies, as summarized above, there is no systematic measurement system to evaluate intermodal transportation alternatives. Most existing measures can be applied only to a single mode. The administration structure of USDOT partially causes the problem. Different administrations, mainly organized based on modes, develop their own performance metrics specifically for their focuses. For instance, the safety in airborne transportation is usually measured by the number of accidents per takeoff. It is not comparable with the highway accident rate, which is often defined as the number of casualties per million passenger miles. G. Scott Rutherford pointed out the measures defined for highway (or any single mode) cannot lead to multimodal solutions *[12]*. It is noted that different administrations are also at different sophistication levels of defining and using performance metrics. Some of them have better defined metrics and clear goals for those metrics, perhaps because their system is more centralized so that data collection is relatively easier. Please also note that many of the summarized performance metrics listed above are only applicable to passenger transportation rather than freight transportation, though they may provide insights on how to define quality performance metrics for freight transportation.

Measures Used by State DOTs

Several state DOTs are very active in performance measurement, such as Missouri DOT (MoDOT), Minnesota DOT (MnDOT), and North Carolina DOT (NCDOT). However, they define and track their performance with very different metrics and even the detail levels of those metrics significantly vary from each other.

MoDOT is using a comprehensive tool called *Tracker* to measure how they deliver services and products to customers and update most metrics quarterly *[13]*. Those measures cover many aspects of MoDOT performance and are grouped into the following 19 categories:

1) Uninterrupted Traffic Flow;
2) Smooth and Unrestricted Roads and Bridges;
3) Safe Transportation System;
4) Roadway Visibility;
5) Outstanding Customer Service;
6) Partner with Others to Deliver Transportation Services;
7) Advance Economic Development;
8) Innovative Transportation Solutions;
9) Fat Projects That Are of Great Value;
10) Environmentally Responsible;
11) Great Workplace, Great Employees;
12) Efficient Movement of Goods;
13) Easily Accessible Modal Choices;
14) Customer Involvement in Transportation Decision Making;
15) Accommodating Roadsides;
16) Best Value for Every Dollar Spent;
17) Advocate for Transportation Issues;
18) Proactive Transportation Information; and
19) MoDOT's Bolder Five-Year Direction

For each category, there are from several to a dozen of metrics. Table 1 lists metrics in categories related to freight transportation. The relevance to freight performance is rated by H (High), M (Medium), L (Low), and I (Irrelevant). Many of the metrics are updated quarterly. The large number of measures requires a significant amount of efforts of collecting and analyzing data to calculate the measure, evaluating system performance, and making recommendations.

Table 1
Performance metrics used by MoDOT

Metrics	Unit/Calculation	Relevant to Freight *
	Uninterrupted Traffic Flow	
Average travel times on selected freeway sections	10-mile travel time (minutes) =10 miles/ Average Speed ×Free flow speed	H
Average rate of travel on signalized routes	High: speeds at 80 percent of the speed limit; medium: 50 to 79 percent; low: less than 50 percent.	H
Average time to clear traffic incident	Minutes	M
Traffic impact closures on major interstate routes	Total closure minutes for events with an actual or expected duration of one hour or more closure at selected mile markers at major highways	H
Work zone (WZ) impacts to traveling public	Number of WZ with major and moderate impact. An impact is defined as the additional time added to the public's normal travel: Minor: less than 10 minutes, moderate: 10 to 14 minutes, and major: 15 minutes or greater.	H
Time to meet winter storm event performance objectives	Average time (hours) involved in road clearance during winter weather on continuous and non-continuous operations routes.	H
	Smooth and Unrestricted Roads and Bridges	
Percent of major highways in good condition	On high-speed routes (speed limits greater than 50 mph), the International Roughness Index (IRI) is used to measure good conditions. For lower-speed routes (mostly urban areas) where smoothness is less critical, a condition rating is used in combination with the smoothness component.	H
Percent of minor highways in good condition	Smoothness is evaluated using the IRI. Pavements below the prescribed threshold are considered good. A condition rating of visual distress is also evaluated and if those criteria are met, the roadway is considered good.	H
Percent of vehicle miles traveled on major highways in good condition	An annual measure based on VMT estimation on major highways.	H
Percent of bridges in good condition	A bridge is considered "good" if it is not either "structurally deficient" or "functionally obsolete" as defined using FHWA criteria.	H
Percent of major bridges in good condition	A major bridge is defined as any structure with a length greater than 1,000 feet.	H
	Safe Transportation System	
Number of fatalities and disabling injuries	The total number within one year based on crash data.	H
Number of impaired driver-related fatalities and disabling injuries	The total number within one year based on crash data.	H
Percent of safety belt/passenger vehicle restraint use	The percentage is calculated based on a statewide survey is conducted at 460 pre-selected locations in 20 counties in Each June using a formula approved by the National Highway Traffic Safety Administration	M
Number of bicycle and pedestrian fatalities and disabling injuries	The total number within one year based on crash data.	L
Number of motorcycle fatalities and disabling injuries	The total number within one year based on crash data.	L
Number of commercial motor vehicle crashes resulting in fatalities and injuries	The total number within one year based on crash data.	H
Number of fatalities and injuries in work zones	The total number within one year based on crash data.	M
Number of highway-rail crossing fatalities and collisions	The total number within one year based on crash data.	H
	Advance Economic Development	
Economic return from transportation investment	Annual number of jobs created from transportation investment and economic return of 20 years (in dollars) from each dollar of transportation investment. Both are calculated based on a model from the Regional Economic Modeling, Inc. (REMI).	H
Job creation by government sector industries	The multiplier for transportation employment indicates how many additional jobs every new transportation job will create throughout the State's economy. This multiplier is compared to other government sector industries.	H
Number of jobs and businesses in freight industry	The number of jobs and businesses that are classified within the freight transportation industry.	H
	Environmentally Responsible	
Percent of projects completed without environmental violation	If a violation is noted, it can result in a Letter of Warning or a Notice of Violation.	H
Number of tons of recycled material	Annual tons of recycled/waste materials used in roadway projects, including timber, steel/aluminum, concrete and hot mix asphalt and Annual tons of waste material recycled by MoDOT.	M
Gallons of fuel consumed and miles per gallon	Annual gallons (in million) of gasoline & E85, diesel, and biodiesel consumed and statewide average miles per gallon, including cars, pickups, light duty trucks, heavy duty trucks and extra heavy duty trucks.	H
Pedestrian and ADA transition plan improvements	Investment (in dollars) in pedestrian facilities based on contract awards, percentage of investment completed toward the estimated $153.2 million of work needed to achieve accessibility for right of way, and percentage of investment completed toward the estimated $1.9 million of work needed to achieve accessibility for building facilities.	M

Table 1
Performance metrics used by MoDOT (continued)

Metrics	Unit/Calculation	Relevant to Freight *
Efficient Movement of Goods		
Freight tonnage by mode	A freight tonnage estimator tool is used to provide twice a year tonnage estimates for these primary rail and motor carriers. Freight data for aviation and waterways is a combination a direct survey of airports, public ports and waterborne commerce data and trend analysis for private ports	H
Commercial motor carrier contributions to the state road fund	Dollars in millions of commercial motor carrier contributions to the state road fund, calculated based on statewide financial account system, SAM II.	H
Missouri and Mississippi River waterborne freight tonnage	Tonnage in millions of quarterly waterborne freight on the Missouri and Mississippi rivers including sand and gravel based on data from Waterborne Commerce Statistics Center.	H
Best Value for Every Dollar Spent		
Number of full-time equivalencies expended	Quarterly full-time equivalencies including the regular hours worked or on paid leave of temporary and salaried employees, as well as overtime worked (minus any hours that are fixed during the workweek).	L
Number of lost workdays	Quarterly number of lost workday because of work-related injury occurred during this year or prior to this year. The data is from Riskmaster.	M
Total and rate of MoDOT recordable incidents	Annual number of recordable injuries, in total and as a rate of injuries per 100 workers. The injury data is from Riskmaster.	M
Number of claims and amount paid for general liability	Number of claims and amount paid for general liability in each quarter based on data from Riskmaster.	L
Percent of vendor invoices paid on time	Percent of payments with a check issued within 31 days of invoice date in each fiscal year.	L
Distribution of expenditures	Distribution of annual expenditures among construction, maintenance, multimodal, and other areas (administration, FFIS, highway safety, and motor carrier).	L
Accuracy of state and federal revenue projections	Percent variance of DOT's state (quarterly) and federal (annually) revenue projections from actual ones.	L
Number of excess properties conveyed and gross revenue generated from them	Number of excess parcels conveyed in each quarter, number of excess parcels in inventory, and the gross revenue (dollars in millions) from excess properties conveyed. The data are from the realty asset inventory system	L
Cost per lane mile and total number of lane miles for highway construction improvements	The costs associated with the equipment, labor and fringe benefits and materials necessary to construct each of the types of projects (seal coat, minor road resurfacing, major road resurfacing, interstate resurfacing, new two-lane highway construction, and new four-lane highway construction) based on historical prices received from contractors.	M
Average bridge costs	Average bridge replacement cost per square-foot of bridge based on bid historical data.	M
Off roadway unit costs	Average annual cost per acre mowed and treated, total cost to manage roadside vegetation, and snow removal cost per lane mile.	L

Table 2
MnDOT performance measurement system

Category	Measure with Definition	Relevant to Freight
Traveler Safety	Total traffic fatalities and serious injuries	H
Infrastructure	Percent of bridges whose conditions are good or satisfactory	H
	Percent of bridges whose conditions are poor (structurally deficient or functionally deficient)	H
	Percent of state highway miles in poor pavement condition	H
	Percent of state principal arterials miles in poor pavement condition	H
	Percent of state principal arterials miles in good pavement condition	H
Maintenance	Frequency of achieving bare lane within target hours, all storms and routes	H
	Percent of bridge safety inspections that were inspected within the required time period	H
	Customer satisfaction with state highway maintenance from 1 to 10 based on a survey	H
National and Global Connections	Airline annual available seat miles on scheduled commercial flights	I
	Annual tonnage of shipments to and from MN Great Lakes & river ports	H
	Annual tonnage of shipments on Minnesota Railroads: from, to and through Minnesota	H
Statewide Connection	Percent of major interregional routes can be driven within 2 mph of the corridor target speed	H
	Percent of Minnesota population within 30 minute drive time of an airport with paved and lighted runway	H
Twin Cities Mobility	Percent of miles below 45 mph in AM or PM peak	M
	Average clearance time for metro urban freeway incidents	H
	Annual rail and express bus transit ridership	I
MN Metro and Regional Mobility	Annual Greater Minnesota bus service hours	I
Community Development and Transportation	Percent of state highway intersections with Accessible Pedestrian Signals	L
	Percent of commuter trips with bicycle commuting, walking and public transit in major metropolitan areas	I
Energy and the Environment	Annual billions of gallons sold in Minnesota	H

MnDOT reports its performance in their annual Minnesota Performance Report with a score card *[14]*. Their metrics are summarized in Table 2 and part of the score card is displayed in

Figure 1. NCDOT has a relative aggregate performance measurement system and uses dashboard to display NCDOT's performance *[15]*. Their measures are summarized in Table 3 and a screen snapshot of their dashboard is displayed in Figure 2.

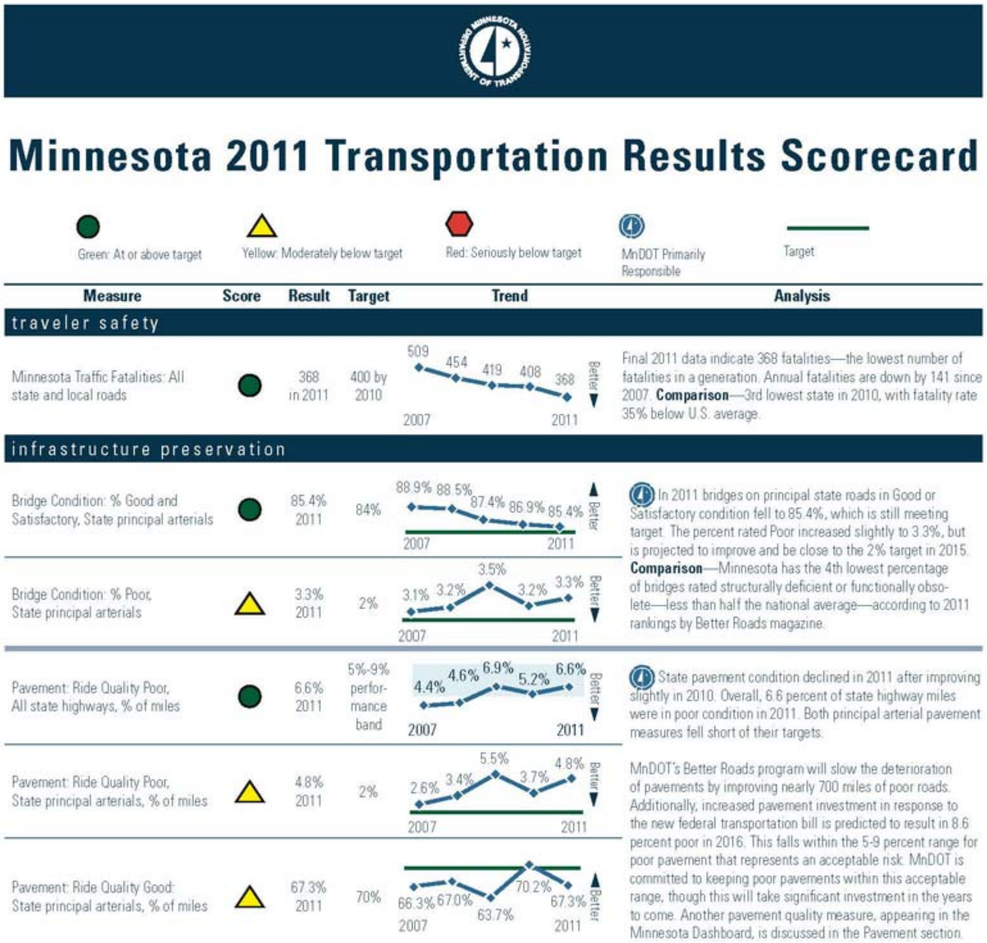

Figure 1
Part of the MnDOT scorecard

Table 3
Performance metrics used by NCDOT

Measure	Definition	Relevant to Freight
Fatality Rate	Total number of statewide fatalities on NC roads per 100 million vehicle	H
Incident Duration	Average time it takes to clear a major accident (i.e. one that causes significant or unusual delays) from a North Carolina highway	H
Infrastructure Health	Bridge health index: Percent of bridges in good condition. A bridge is considered to be in good condition if the Level of Service (LOS) for the Deck, Sub-Structure and Super Structure are all greater than or equal to 6 (on a 1 to 9 scale)	H
	Pavement condition rating: Percent of lane miles in good condition. A good condition for pavement is defined as a Pavement Condition Rating (PCR) value of 80 or higher (on a 0 to 100 scale).	H
	Roadside feature condition score: a weighted value score that represents the physical condition of all highway features and elements, excluding pavement and bridges, which are captured by the two previous metrics described above	H
Delivery Rate	Percent of plans completed and bids opened on time	M
	Percent of right of way plans completed on time	M
	Percent of construction projects completed on schedule	M
	Percent of construction projects completed on budget	M
	Environmental compliance index: Average scores on a 10 point scale of all construction projects, including contract construction, road maintenance, and bridge maintenance projects based on their compliance with the Sedimentation and Pollution Control Act.	M
Employee Engagement	Employee emotional and rational commitment indices derived from the employee engagement survey	I
	Employee discretionary effort index derived from the employee engagement survey	I
	Intent to stay index derived from the employee engagement survey	I

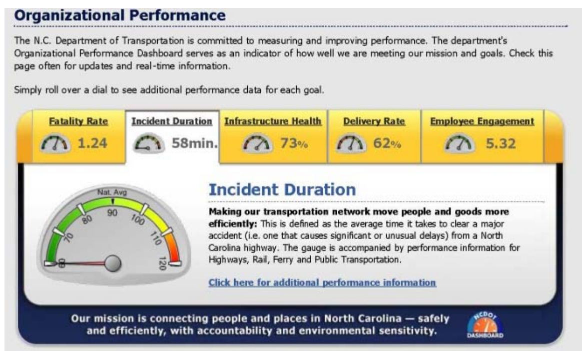

Figure 2
NCDOT performance dashboard

In addition to state DOT performance for agency-wide performance measurement, a research projected supported by MnDOT has also developed a specific system for the freight transportation by assessing the freight performance in 19 aspects: network and infrastructure, safety or damage, access, capacity, travel time, reliability, market share, modal share, modal costs, freight productivity, freight security, shipment rates, pricing, agency cost, carrier cost, shipper cost, externalities and community cost, transportation indices, and external factors *[16]*. The cost of calculating and maintaining so many metrics for freight transportation systems seems prohibitive.

According to the Performance Measurement Library of Washington State Department of Transportation, almost every state uses strategic planning in one form or another, but all DOTs use performance measurements at various programmatic levels *[17]*.

Measures Discussed in the Literature

Hagler Bailly Services, Inc. groups transportation performance measures into eight main categories: mobility and accessibility, reliability, safety and security, environmental impact, cost effectiveness, infrastructure conditions, economic impact, and industry productivity *[18]*. This section summarizes performance measures in the literature following these eight categories.

Michael D. Meyer defines mobility as the ability to transport goods and people in an efficient way and measures mobility by average origin-destination travel time per trip while Bertini et al. and Shaw consider average speed as mobility *[19-21]*. The Albany metropolitan area uses both speed and trip length *[19]*. Colorado's performance measurement system defines Passenger (Freight) Mobility Coefficient as PMT (FTMT) × Average Speed/1,000,000, where PMT (FTMT) stands for passenger (freight ton) miles traveled *[22]*. Passenger Mobility Index and Freight Mobility Index are also used in *[20, 22]*. The Passenger Mobility Index is (PMT/VMT) × Average Speed, where VMT stands for vehicle miles traveled. Similarly, the Freight Mobility Index is FTMT/(Truck VMT) × Average Speed. A mobility index can be used to compare different modes, but it favors public transportation because of its large loading efficiency. The American Transportation Research Institute (ATRI) explores methods for measuring freight performance on highways and concludes that positioning data from trucks can provide average travel rates and its standard deviation along major U.S. freight corridors *[23]*. The system is called the National Corridors Analysis and Speed Tool (N-CAST) *[24]*. Schrank and Lomax evaluated eighty-five U.S. urban areas with the Travel Time Index (TTI) and the delay per traveler *[25]*. The TTI is the ratio of peak period travel time to free-flow travel time.

Accessibility is another major concern in the literature to measure the performanc of a transportation system. Bertini and El-Geneidy consider the amount of goods and the number of people that are able to access a transportation system *[26]*. The percentage of urban population within *X* miles of transit is commonly used to evaluate the accessibility of transit service *[22, 27, 28]*. The percentage of employment sites within *Y* miles of major highways is another similar factor used for the San Francisco Bay Area to evaluate its accessibility or connectivity *[27]*. The accessibility measures are major factors influencing the average total travel time. The researchers believe accessibility should be a second-tier measure because the mobility index has covered accessibility.

VMT, PMT, and their ratio of PMT/VMT are often used to represent capacity of transportation systems *[20, 22]*. For freight transportation analysis, truck vehicle miles traveled, truck freight ton miles traveled, and truck freight ton miles traveled/truck vehicle miles traveled are used as capacity measures *[22]*. Vehicle hours traveled and passenger hours traveled are sometimes considered for passenger transportation capacity *[20, 21]*. Passenger hours traveled can be calculated by using VMT and the Average Vehicle Occupancy (AVO). BRW Inc. also uses truck freight Ton Miles Traveled (TMT) to represent capacity *[22]*. In fact, all the above capacity definitions are actually throughput. Capacity should be defined as *maximal throughput* though higher throughput under a given capacity may cause lower travel speed. Because higher capacity usually means higher mobility for given traffic demand, capacity is a factor that influences mobility rather than a system-level measure.

Transportation reliability is usually measured by delays caused by unusual events or incidents, such as accident delays, intersection delays, intermodal terminal delays, or other lost time. There are several measures for delays, such as transfer time between modes, delays per ton mile, lost time or delay time, congested highway miles divided by total highway miles and annual delay per traveler *[18, 20, 22, 29, 30]*. Travel time reliability is proposed by the Washington DOT to determine the best available tools and methods for collecting travel time data on a real-time basis *[31]*. BRW Inc. uses the level of congestion to measure reliability *[22]*. On-time percentage and frequency of service are considered a major measure of transportation system reliability, especially for transit systems *[32]*. N-CAST uses the standard deviation of vehicle speeds to measure reliability as part of the mobility performance for trucks *[24]*. The shortcoming of using the standard deviation is hard to compare systems with different average speeds.

Safety in highway transportation is commonly measured by fatalities and injuries per 100 million VMT, while the measure for airborne transportation is fatal aviation accidents per 100,000 departures *[2]*. Maritime safety is determined by the number of recreational boating fatalities per year, the number of calls for help received by the Coast Guard, and the percent of all mariners in imminent danger who are rescued *[4]*. A common safety measure for railroads is train accidents per million train-miles and rail-related fatalities per million train-miles. Transit transportation safety is measured by transit fatalities or injured people per 100 million passenger-miles traveled *[2]*. All the above safety measures are defined for a single mode, and no existing measure can be used to evaluate and compare the safety of systems having multiple transportation modes.

In the long run, the sustainability of a transportation system is affected by its impact on the environment *[33]*. Several state DOTs use tons (in millions) of mobile source emissions from on-road vehicles as one major measure *[33]*. MoDOT uses gallons of fuel consumed of Gasoline&E88, diesel, and biodiesel and average miles per gallon while MnDOT uses annual billions of gallons sold in Minnesota *[13, 14]*. Some studies define environment-related measures based on emission types. For example, the USDOT uses metric tons (in millions) of carbon-equivalent emissions or greenhouse gas emissions from transportation sources. FHWA calculates total emissions per vehicle mile. A significant amount of pollution results from waterborne and pipeline transportation, and the gallons spilled per ton mile can be used to measure environmental impact *[34]*. The U.S. Environment Protection Agency (USEPA) determines transportation impacts on the environment based on criteria of pollutants *[35]*.

The cost of highway freight per ton mile is identified by Hagler Bailly Services, Hickling Lewis Brod, Inc., and the Florida DOT to measure the direct freight operation cost *[18, 36, 37]*. Labor cost and fuel consumption cost are two major drivers of the total operation cost. Truck technology and drivers' wages are used by both Hagler Bailly Services, Inc. and the Florida DOT as system-level measures *[18, 37]*. Dollars per vehicle hour are used to represent long-term cost efficiency by Hagler Bailly Services, Inc. without considering the loading factor for freight transportation or vehicle occupancy for passenger transportation *[18]*. Transportation facility maintenance also incurs direct cost.

The number of bridges and the number of deficient bridges per 100 miles are used by BRW Inc. to measure highway infrastructure condition *[22]*. The lane-miles of highway requiring rehabilitation are used by the California DOT to denote the infrastructure condition *[38]*. The Michigan DOT uses the percentage of miles of state trunk lines with a surface condition classified as good and the number of bridges rated as good along with MoDOT and MnDOT, as discussed before *[39]*. Similar concepts may be applied for other modes. For example, the percentage and total length of different grade of railroad infrastructure are used to evaluate railway infrastructure *[39]*.

Regarding economic impact, the number of direct and indirect jobs created by transportation construction and operation is considered one economic impact measure (e.g., *[13, 40, 41]*). Contribution of investment to GDP growth is another measure *[36]*. The state of Florida uses revenue per ton mile by mode to measure economic development *[37]*. This benefit is indirect monetary benefit of a transportation system and is related to mobility. The value of the freight that is moved from, to, and within a region is used by the St. Louis Region MPO as economic performance measures *[41]*. In fact, the value that a freight transportation system carries is mainly decided by freight transportation needs and has little relationship with transportation performance.

"Industry productivity" refers to the efficiency of the transportation industry instead of transportation systems in the literature. Brenda Thompson uses vehicle miles per capita, passenger trips per capita, revenue hours per employee, and passenger trips per employee to evaluate industry productivity *[42]*. The FHWA measures transportation industry productivity by empty/loaded ratio for truck moves, annual miles per truck, and average length of haul by vehicle *[43]*.

The National Cooperative Freight Research Program Report 10 of *Performance Measures for Freight Transportation* is a recent report discussing freight performance measurement *[44]*. The report has the following major findings:

- A reporting framework for freight transportation is possible.
- The impediments to creating a Freight System Report Card are numerous and there is no entity and no budget to develop a Freight System Report Card.
- A coalition of interested parties will need to coalesce around the concept of producing a Freight System Report Card.

The report describes the performance of the U.S. freight transportation system following a framework called a Freight System Report Card. The framework includes 29 performance measures in 6 categories: freight demand, freight efficiency, freight system condition, freight environmental impacts, freight safety, and the adequacy of investment in the freight system.

Freight Demand. Under the category of Freight Demand measures, it indicates that influencing all other freight performance trends has been and likely will continue to be the steady growth in overall freight volumes over the long run. Intermodal movements of imports grow at a significantly faster rate than other types of movements. The Freight Analysis Framework forecast that intermodal movements of imports rise from $716 in 2002 to $3,708 billion by 2035. Both Truck Freight Volumes and Rail Freight Volumes are increasing. The trend for Inland Water Freight is mixed, depending on the kind of submarkets (domestic, border crossings, and sea movements). Containerized Imports/Exports are steadily growing.

Freight Efficiency. Under the category of Freight Efficiency measures, the American Transportation Research Institute (ATRI) calculates average speeds over time for a strategic set of U.S. interstate corridors with significant levels of truck activity. In addition to average truck travel speeds or a comparison of the percentage of segments with average truck speeds than free-flow, the ATRI system can measure the travel-time reliability of corridors and specific segments. Reliability refers to the predictability of travel speeds or travel times. The ATRI/FHWA Freight Performance Measure system features a database that contains historical truck position data for most of the last decade and is updated monthly. The system can analyze trends in severe highway bottlenecks. The rankings are based on a measure called the total freight congestion value, which is an index that uses truck delay and relative volume information within bottlenecks as inputs. Train speed measures the line-haul movement between terminals. The average speed is calculated by dividing train-miles by total hours operated, excluding yard and local trains, passenger trains, maintenance-of-way trains, and terminal time.

Freight System Condition. Freight System Condition indicators include the National Highway System (NHS) Bridge Structural Deficiencies and NHS Pavement Conditions. The primary considerations in classifying structural deficiencies are the bridge component condition ratings for the deck, superstructure, and substructure. These structural deficiencies are considered separately from “functional obsolescence,” which measures geometric issues such as width, approach curvature, or other issues that may reflect current design standards and not the structural integrity of the bridge.

Freight Environmental. Under the category of Freight Environmental measures, air quality planners assign estimated volumes of pollutants, typically measured in tons or metric tons, to specific sources of emissions. Emissions included as performance measures for the freight transportation system include: particular matter, oxides of nitrogen, volatile organic compounds, ozone, and greenhouse gas emissions.

Freight Safety. Freight Safety Measures include Truck Injury and Fatal Crash Rates, Highway-Rail at-grade incidents. A highway-rail at-grade crash is any impact between a rail user and a highway user at a crossing site, regardless of severity.

Freight Investment. Freight Investment Measures include Investment to Sustain NHS, Rail Industry Cost of Capital, Estimated Capital to Sustain Rail Market Share, and Investment to Sustain Inland Waterway System. NCFRP Report 10 is a new, detailed, and objective research of performance measures for freight transportation, but does not emphasize intermodalism. It describes the facts of performance on each mode and lacks system-level performance measures for intermodal transportation though the national freight network is highly intermodal.

Discussions on the Literature Review

Performance measures are used to evaluate how well a system can satisfy its users/customers. Transportation engineers, state DOTs, MPOs, and other practitioners are not freight transportation users, though they design, build, operate, and manage freight transportation systems. However, most existing transportation measures, as shown in the above reviews, are developed from the perspective of decision-makers instead of transportation users. Furthermore, current transportation measures have many overlaps and oversights. For instance, accessibility of intermodal facilities and connectivity between modes are usually listed along with mobility, which is usually defined by the average travel time per trip.

However, the former two factors influence mobility rather than measures at the system-level. A good intermodal transportation performance measurement system should meet the following criteria:

- It should be *applicable* for all modes and their combinations.
- It should be based on *user needs*. Transportation systems are built for their users rather than others.
- It should be s*calable* to compare systems of different sizes.
- It should be *scientific* and s*ystematic*. A good performance measure system should be a hierarchy with system and subsystem measures. At the system level, there should be no overlaps or oversights.
- It should be as *quantitative* as possible. Though it is difficult to quantify all performance measures, such as comfortability, quantitative measures can help scientifically compare alternatives.
- It should be *cost-effective*. The cost of collecting data, calculating measures, evaluating a freight transportation system, and facilitating decision-making should be considered in the measure selection.

Well-defined freight transportation performance measures can be used for decision-making in various contexts such as policy analysis, resource allocation and programming, tradeoff analysis, corridor and project-level analysis, system operation, and ongoing monitoring and evaluation *[45]*. For example, MnDOT spent more than two years aligning customer needs, outcomes, strategic objectives, targets, and measures for investment decision-making. The San Diego Metropolitan Transit Development Board uses performance measures to guide its most critical decisions on deployment service *[46]*.

Identified Transportation Needs and Objectives

Transportation Users and Stakeholders and Their Needs

Based on the principles of Systems Engineering, performance of any system should be measured by how the system can meet its stakeholder and user needs. Freight transportation users include all agencies and participants with various purposes, preferences and requirements. The freight transportation stakeholders and users include:

- *Investors* include transportation investors, who are sometimes government agencies. Their major concerns would be how to develop a cost-effective system and how to get the investment return as soon as possible.

- *Industries* include both shippers and carriers. Their major concerns are to transport their goods in a quick, safe, cheap, reliable, profitable, and efficient manner.

- *Society users*' (or the public's) major concerns include environment impacts, economic growth, and community development related to freight transportation systems.

The following transportation objectives and metrics are based on the author's earlier paper with significant modifications *[47]*.

Transportation Objectives

Performance measures should be developed in response to goals *[45]*. The following objectives for freight transportation systems are identified to address the needs of transportation users.

1) Mobility and Reliability: Reducing transportation time and delay is a major concern of most transportation users.
2) Safety: The objectives related to transportation safety and security include improving traffic safety, i.e., reducing traffic accident rates, injuries, fatalities and risks. They also include increasing traffic security and reducing crime rates, improving accident detection and response, and increasing public security and homeland security.
3) Environmental Stewardship: The objectives include reducing the amount of transportation-related pollutants, promoting the community livability near major transportation infrastructures, and decreasing energy consumption.
4) Direct Cost Efficiency: The objectives include developing cost-efficient transportation systems that have low cost/benefit ratios and high sustainability.
5) Economic Growth: The objectives include promoting local or regional economic growth and increasing local or regional employment opportunities.

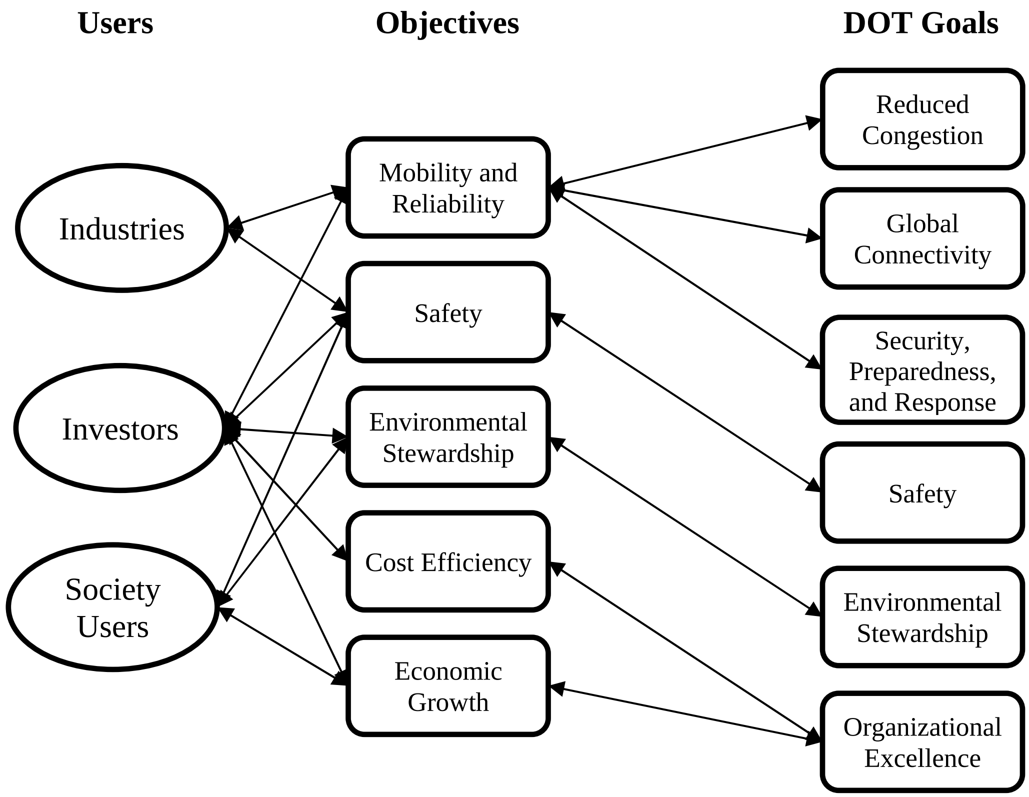

Figure 3
Mapping between identified objectives and US DOT goals

These five objectives are aligned to the six goals identified by USDOT and users, as shown in Figure 3. Performance metrics will be defined to measure these five objectives in a quantitative fashion. The relationships will be further discussed in the next subsection where the detailed definitions of all metrics are given.

Proposed Intermodal Transportation Performance Measurement System

Any system should be evaluated based on how it could meet the needs of its stakeholders and users. In this report, freight transportation needs is defined based on *ton miles required (TMR),* where the miles are the *geographic* distance, the length of a straight line connecting the origin and destination of a trip, instead of the actual travel distance, which depends on the selected route. For a customer who wants to move her goods from Point A to Point B, her transportation need is measured by the geographic distance between the two points. In other words, the customer wishes to minimize the total transportation time rather than the average speed. Figure 4 shows two possible designs for meeting freight transportation needs between Points A and B. Design 2 is a highway with higher speed limit but a longer travel distance. Transportation needs should be the same for users who need to move 1 ton from A to B no matter which route is selected. Design 1 may have better mobility, whose definition will be given later, for users because of less travel time resulting from a shorter travel distance while meeting the same transportation need measured by geographic distance. In this report, almost all performance metrics will be defined based on needs measured by TMR. This discussion on transportation needs measured by TMR is also justified by the study on a logistics network of a major automotive maker *[48]*. The automaker pays their transportation providers based on the geographic distance between the plant and its dealers rather than actual distance traveled by trucks. In fact, they do not care which routes transportation service providers choose. Their major concern is how to ship their finished vehicles from their plants to their dealers quickly, safely and cost-effectively.

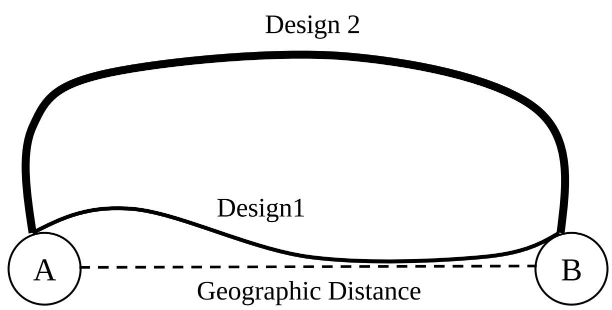

Figure 4
Geographic distance between origin and destination

Mobility and Reliability

Mobility (*M*) is defined as the average travel time per mile required, where unit distance is geographic distance rather than travel distance. Mobility is the ability to transport goods in an efficient way *[19]*. For a freight transportation system, mobility M can be obtained by the following statistics.

$$M = \frac{\sum_{(i,j,n)\in R} p_{i,j,n} T_{i,j,n}}{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}} \tag{1}$$

One trip is characterized by a triplet (i,j,n), where i is the origin, j is the destination, and n is the index of the trips with the same OD of (i,j). R is the set of all trips in the system, $l_{i,j}$ is the *geographic* mileage from i to j, $p_{i,j,n}$ is tons involved in trip (i,j,n), and $T_{i,j,n}$is the total travel time of trip (i,j,n), which includes the time in all modes and the time for transfer between modes and access to a transportation facility. For instance, if a trip (i,j,n) involves both trucks and railways, $T_{i,j,n}$ includes time waiting for a truck to pick up, time on highways, transfer time from the truck to a rail train, the dwelling time on rail yards, the travel time on rails, the waiting time in rail yard for a delivery truck, and trucking time. In other words, $T_{i,j,n}$ is the total time from the moment when the freight is ready to ship to the moment when it is delivered. With the total transportation demand in the denominator, the mobility measure is normalized and can be used to compare systems of different sizes. M defined (3.1) is related to average speed, which is used to measure freight mobility on interstate highways in N-CAST but M is more intermodal and more related to user needs *[24]*.

<u>Reliability (R)</u> is the dependable levels of transportation service and is defined as the coefficient of total variation of travel time per mile required, as expressed by equation (2).

$$R = \frac{\sqrt{\frac{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j} \left(\frac{T_{i,j,n}}{l_{i,j}} - M\right)^2}{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}}}}{M} \tag{2}$$

Smaller R means total travel times for a trip can be more easily predicted and may help to avoid or reduce delays with effective counter measures. Even if a trip takes much time, delays (being late) can be well avoided by departing earlier when the travel time has low variability. Though big incidents such as the September 11th terrorist attack or Hurricane Katrina do not happen often, they have a large impact on reliability because of their large resulting variance. In addition to the enhanced transportation security and safety, providing more transportation alternatives and having redundant capacity may alleviate transportation impacts of disasters and improve the overall reliability (sometimes called "resilience") of a transportation system. The definition of reliability is consistent to the reliability definition used in N-CAST by ATRI, which uses standard deviation of speed at interstate highways *[24]*. This report proposes to use the coefficient of variation to make this measure more scalable for all modes. Part of the total variance is predicable (e.g. recurrent congestion), while the remaining is not difficult to forecast. Therefore, another reliability measure R_u is defined as the coefficient of unpredicted variation of travel time per mile required.

$$R_u = \frac{\sqrt{\frac{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j} \left(\frac{T_{i,j,n} - f_{i,j,n}}{l_{i,j}}\right)^2}{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}}}}{M} \tag{3}$$

Here, $f_{i,j,n}$ is the expected travel time for trip (i, j, n), which is calculated with all known information such as the time when the trip happens. R_u is the main reason for delays or inconvenience. In traditional transportation engineering, a common performance measure is delay that includes recurring delays and nonrecurring delays. Recurring delays happen regularly and are predictable. The researchers believe reliability R and R_u defined above are more scientific and can cover all delays. With M, the mobility, as the denominator, reliability R and R_u are also scalable and can be used to compare freight transportation systems with different sizes and features. *Reliability (R)* is the dependable level of transportation service and is defined as the coefficient of total variation of travel time per mile required. Part of the total variance is predicable (e.g. recurrent congestion), while the remaining is difficult to forecast. Therefore, another reliability measure, R_u, is defined as the coefficient of unpredicted variation of travel time per mile required. Both R and R_u will be estimated based on simulation. Because of the complexity of the simulation, it will not be in the scope of this project but will be conducted in the follow-on project of *Intermodal Freight Transportation Simulation*. The simulation will utilize the same data used in the calculation of mobility including the freight transportation network data and OD data. The traffic assignment results will be implemented in the simulation models. In addition to assumed variability of the time at each node and at each link, the non-recurrent accident data at different transportation mode will be created randomly in the system in order to calculate R_u.

Safety

Safety is evaluated by two metrics: *Fatality Rate (S_F)* is the number of fatalities per TMR and *Injury Rate (S_I)* is the number of injuries per TMR in the state of Louisiana.

Fatality Rate (S_F) is the number of fatalities per TMR that can be estimated by equation (4).

$$S_F = \frac{\sum_{(i,j,n)\in R} F_{i,j,n}}{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}}. \tag{4}$$

$F_{i,j,n}$ is the fatalities in trip (i, j, n), and $\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}$ is the total TMR for freight transportation. In practice, most state DOTs maintain crash databases and $\sum_{(i,j,n)\in R} F_{i,j,n}$ is available for a given period.

Injury Rate (S_I) is the number of injuries per TMR that can be estimated by equation (5).

$$S_I = \frac{\sum_{(i,j,n)\in R} I_{i,j,n}}{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}}. \quad (5)$$

$I_{i,j,n}$ is the number of injuries in trip (i, j, n). Similar to $\sum_{(i,j,n)\in R} F_{i,j,n}$, most state DOTs have crash databases and $\sum_{(i,j,n)\in R} I_{i,j,n}$ is available for a given period. Different transportation modes have different accident outcomes. An airplane crash may result in more fatalities than injuries, as opposed to a highway truck accident. Safety also has a large impact on delay. Jeffery Lindley estimated that over 60 percent of the congestion delay experienced on urban freeways is caused by incidents rather than recurring congestion *[49]*. In the measure system developed by the researchers for this project, this effect is included in reliability. In the literature, accident detection and response efficiency are common safety measures, but they have been covered by mobility and reliability. Therefore, the safety measures in this report do not consider congestion caused by accidents.

Environmental Stewardship

The main environment impact measures are energy consumption and transportation-related pollutants released.

Energy Consumption Rate (*EC*) is the average unsustainable energy consumption (Gallon of Gasoline) per TMR. The value of *EC* can be estimated by equation (6).

$$EC = \frac{\sum_{(i,j,n)\in R} E_{i,j,n}}{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}}. \quad (6)$$

$E_{i,j,n}$ is the total *unsustainable* energy consumed by n^{th} trip from origin i to destination j. Unsustainable energy such as natural gas, oil, and coal cannot be renewed and has a larger negative impact on the environment than renewable energy, such as solar energy, wind power, biofuel, and hydrogen. The energy consumption is defined from the perspective of environment impact rather than operation cost, which will be included in the cost effectiveness. Fuel is only a part of energy consumed in the freight transportation. A significant amount of energy is used to produce and maintain vehicles. It is called embodied energy and also should be included in $E_{i,j,n}$. $\sum_{(i,j,n)\in R} E_{i,j,n}$ is available or could be calculated without knowing the details of each trip. The fuel consumption efficiency significantly varies among different transportation modes. A freight system that can favor fuel-efficient modes such as waterways and railways may improve its EC. The recent progress in vehicle fuel efficiency (e.g., electric cars, hybrid vehicles, and more efficient engine designs) is also expected to lower EC. In addition to huge energy consumption, the transportation system is also a big contributor to the air pollutants. In many databases, energy consumption is measured by British Thermal Unit (Btu) no matter which type of energy is consumed.

However, in order to make the public understand this measure better, Btu is converted into gallons (US) of automotive gasoline with the rate of a gallon $=\ 124{,}884$ Btu.

Pollutant Released Rate (P) is the tons of emissions from transportation systems per TMR and is defined by equation (7).

$$P = \frac{\sum_{(i,j,n)\in R} PO_{i,j,n}}{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}}. \quad (7)$$

$PO_{i,j,n}$ is the tons of mobile pollutants emissions caused by trip (i, j, n). Only the total pollutants are considered a system-level measure.

Direct Cost Efficiency

This measure considers the direct cost of a transportation system rather than a comprehensive cost model that includes external costs such as environment impacts. The direct cost includes vehicle operation cost and transportation facility costs for construction, operation, maintenance and disposal.

Operational Cost (C): Operational cost mainly covers labor, fuel consumption, vehicle insurance, vehicle maintenance, vehicle depreciation costs, and facility cost per TMR. This general cost index considers the life-cycle cost for vehicle operation and varies for different modes. Different components of transportation modes should be considered for each segment of a trip in an intermodal transportation system. The operational cost (C) can be obtained by equation (8).

$$C = \frac{\sum_{(i,j,n)\in R}\left(LC_{i,j,n} + GC_{i,j,n} + VI_{i,j,n} + VM_{i,j,n} + VA_{i,j,n}\right) + +FC}{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}}. \quad (8)$$

Here $LC_{i,j,n}$ is the labor cost, $GC_{i,j,n}$ is the fuel consumption cost, $VI_{i,j,n}$ is the vehicle insurance cost, $VM_{i,j,n}$ is the vehicle maintenance cost, $VA_{i,j,n}$ is the associated vehicle depreciation cost in trip (i, j, n), and FC is the cost of the transportation facility in the freight transportation during the estimation period (e.g., annual equilibrium cost).

Labor, fuel consumption, vehicle insurance, vehicle maintenance, vehicle depreciation, facility cost, and other costs are involved in vehicle operations. Some of them are variable costs (also called out-of-pocket expenses) that depend on vehicle usage, such as fuel, oil, and tire wear, while others are fixed costs that are unrelated to how many vehicles are utilized. Petroleum costs are major contributors to vehicle operation costs, and they depend on the transportation modes, gas prices, vehicle speed, and vehicle loads. Vehicle insurance costs, vehicle maintenance costs, and other overhead are well-studied in the literature. Insurance costs are usually higher for new or large-sized vehicles. Maintenance costs are, in general, higher for older vehicles and depend on the surface and geometric condition of highway systems. Please note that the costs of $\sum_{(i,j,n)\in R}\left(LC_{i,j,n} + GC_{i,j,n} + VI_{i,j,n} + VM_{i,j,n} + VA_{i,j,n}\right)$ are out of the control of State DOTs. We suggest using the revised operational cost efficiency measures C' as in equation (9).

$$C' = \frac{FC}{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}}. \quad (9)$$

Economic Growth and Employment Improvement

Because of the high investment involved in transportation design, construction, operation and maintenance, local governments are aggressively seeking financial support for transportation projects to improve their local business sales and employment. It is widely believed that the business sales and local economy can be significantly increased due to transportation investment, including initial capital investment and operating and maintenance investment. The transportation industry contributed 9.7 percent in 2011 to the U.S. GDP according to the National Transportation Statistics *[50]*. However, the economic growth stimulated by transportation projects is also influenced by the economic conditions of a specific region. It is very difficult to isolate the portion of increase actually related to transportation investment. In some sense, the economic benefits of freight network improvement is partially covered by mobility and reliability. This study proposes to only consider *Regional Employment Improvement* (J), the number of job years created by a one million-dollar investment. Employment opportunities provided by freight transportation investment can be obtained for specific projects or for a specific region.

Regional Employment Improvement (J) is the number of job year opportunities created by a one million-dollar transportation investment. Transportation-related construction and maintenance can create a large number of jobs. Some of the jobs may last many years, while others are available only for a relatively short time. Therefore, the employment improvement should be measured by job years as in equation (10).

$$J = \frac{TJ}{TI}. \quad (10)$$

Here, TJ is the total created job years due to the freight transportation system. These measures are developed from the perspective of government agencies or society rather than from the freight industries. Thus, they are defined based on investments rather than TMR.

Developed Procedure for Calculation, Data Collection, and Application

This Section presents a general discussion on how the proposed performance measures in the previous section can be obtained. The calculation procedures have been developed and discussed next for all identified performance metrics and the data sources are also listed for supporting the calculation. If there are no existing data sources, the methodologies to collect data are recommended.

Procedures to Calculate Mobility and Reliability

Mobility of a freight transportation system defined by equation (1) can be calculated either based on the collected data or through the analytical estimation. The field data based method collects the sample data of the OD demand including tonnage, survey the mode and route choice of each OD demand, collect the actual speeds from fields at each segment of each mode, collect transfer times between modes or at connection within a mode, and calculate M based on collect data. There are two major shortcomings for calculating M based on the collected data: (1) high cost and (2) lack of capability to evaluate a new design or a freight system improvement initiative with lack of data. The approach based on the estimation and analytics has the following four major steps.

1. Collect, estimate, or predict the traffic demand for the system, including through traffic and passenger traffic. The forecasting includes trip generations.
2. Conduct traffic assignment including mode choices and route choices based on the various rules based on travel time – flow (or speed – flow) models, which may be established based on historical data.
3. Calculate the total time of each freight trip based on analytical models or simulation models.
4. Calculate the mobility metric of M.

This project plans to use the above four-step approach to calculate M in the case study for evaluating the Louisianan freight transportation system. A more detailed description of the evaluation procedure includes the following steps:

1. Document the transportation network in the study area, either using FAF[3] network or ORNL intermodal network database.

2. Obtain within-region, flow-in, flow-out, and through-region OD data from FAF3 by modes through disaggregation. FAF^3 only has OD demand data between 131 FAF traffic analysis zones based on Commodity Flow Survey 2007 and has forecasts through 2040.
3. Calculate the TMR for the network, the denominator of equation (1). Demand by modes in FAF^3 of each OD pair that may affect Louisiana network routed by the shortest time. Three modes are considered: highway, railway, and waterway. For flow-in, flow-out, and through traffic, the out-of- state traffic is aggregated at access points of the state boundaries. Together with the within traffic demand, the TMR are calculated based on geographic distances, which is $\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}$.
4. Assign OD data on the transportation network to obtain the traffic volume on each segment with different transportation modes. All traffic is further routed based on the shortest-time path by mode in TransCAD. The highway speeds will be considered at free flow speeds. The railway travel time for each OD trip depends on the speed at links and the dwell time at major classification yards. The waterway travel time is calculated based on the speed of 20 miles per hour and the average waiting time at locks. There are no locks or dams at the lower Mississippi river. Calculate travel time on each segment and calculate total ton-hours carried on the networks of each region, the nominator of equation (1).
5. Calculate the mobility based on the total ton-hours divided by total ton-mile required.

$$M = \frac{\sum_{(i,j,n)\in R} p_{i,j,n} T_{i,j,n}}{\sum_{(i,j,n)\in R} p_{i,j,n} l_{i,j}}.$$

Different from studies by Amiy Varma, Robert Bertini, and the San Fransisco Metropolitan Transportation Commission, this study does not include *accessibility* as a systematic performance measure because it is covered by mobility M, which is defined by *the total time* from an origin to a destination per mile required *[16, 26, 27]*. Unlike other studies by Robert Bertini, Terrel Shaw, and BRW, Inc., this report does not consider *capacity* a performance measure, since it is not any users' need and is a design parameter that can influence both mobility and reliability, which is defined as follows *[20, 21, 22]*. With the same demand measure TMR, higher capacity often leads to better mobility.

Both reliability metrics R and R_u defined by equations (2) and (3) are difficult to calculate because of the complexity and large scale of a freight transportation system and the stochastic feature of disruptions. The data in N-CAST may help to derive useful information for calculating R and R_u *[24]*. Simulation, either macro-level or micro-level, could be used to collect statistics to facilitate the calculations of R and R_u. However, the computational time involved in simulation for calculating reliability could be a great change because of a large number of disruption scenarios. In order to have dependable R and R_u, the simulations needs to either run for a very long period or have numerous runs. Some research is necessary to speed up simulation for the purpose of calculating reliability metrics.

The intermodal transportation network from the Oak Ridge National Lab (ORNL) is available at http://cta.ornl.gov/transnet/Intermodal_Network.html *[51]*. The traffic on each link in the network is obtained through traffic assignment based on the shortest time rule by using Freight Analysis Framework version 3 (FAF^3) Origin-Destination Data at http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/faf3/netwkdbflow/ *[52]*. With data from the 2007 Commodity Flow Survey and additional sources, FAF^3, maintained by Federal Highway Administration, provides estimates for tonnage, value, and domestic ton-miles by regions of origin and destination, commodity type, and mode for 2007 and future years. The total ton miles required (TMR) in each region can be calculated based on data from FAF^3 and any GIS system to obtain geographic distance of each OD pair. The total ton hours are calculated by the sum of the loads on the links. Alternatively, the total ton hours can be obtained by the sum of ton hours of each individual trip, but a costly large transportation survey is required to obtain ton hours of each trip. Therefore, this study will estimate the total travel time based on traffic assignment of OD data. The free FAF^3 data have relatively low resolution. The commercial OD data of IHS Global Insight Transearch data have much higher resolution but are much more costly. In addition, some state DOTs collect field volume data that can be used to estimate the volume *[53]*. The N-CAST database maintained by ATRI can provide the volume and speed information on interstate highways *[24]*. The database also provides the network information of the interstate network and is expected to be expanded to cover the NHS network. Among all of the above steps, calculating total TMR is critical, not only for M but also for other metrics.

In a future project, reliability metrics of R and R_u will be estimated based on simulation. Because of the complexity of the simulation, it will not be in the scope of this project but will be conducted in the follow-on project of *Intermodal Freight Transportation Simulation*. The simulation will utilize the same data used in the calculation of mobility including the freight transportation network data and OD data. The traffic assignment results will be implemented in the simulation models. In addition to the assumed variability of the time at each node and at each link, the non-recurrent accident data of different transportation will be created randomly in the system in order to calculate R_u. The computational complexity involved in the simulation model will be carefully studied to reach a trade-off between run time and the accuracy of the statistics collected from simulation.

Procedure to Calculate Safety

Safety metrics of S_F and S_I defined by equations (4) and (5) can be calculated based on the data from various databases for individual modes. The number of fatalities is available from the Fatality Analysis Reporting System (FARS) in the web-based encyclopedia maintained by the National Highway Safety Administration (NHTSA) *[54]*. The FARS contains data on all crashes that occur on public roadways, including fatalities, involved vehicle types, and injuries. A more relevant database to freight is the Trucks Involved in Fatal Accidents Codebook 2009 by Joracci et al. *[55]*. The Railroad Accident/Incident Reporting System (RA/IRS) maintained by the Office of Safety Analysis at the Federal Railroad Administration provides data for railway safety analysis *[56]*. The Aviation Accident Statistics from the National Transportation Safety Board *[57]* and the Aviation Safety Reporting System (ASRS) maintained by NASA have data related to aviation safety *[58]*. The Marine Casualty and Pollution Database maintained by US Coast Guard (USGC) (MCPD) can be used to calculate marine safety statistics *[59]*. An alternative source to obtain the total fatalities and injuries is the DOTD's safety database. The Safety metrics are then calculated by the ratio of the total annual fatalities (or injuries) and TMR obtained during calculating M.

Procedure to Calculate Environmental Stewardship

Energy Consumption Rate (*EC*) is the average unsustainable energy consumption (BTU) per TMR and *Pollutant Released Rate* (*P*) is the tons of emissions from transportation systems per TMR. The Transportation Energy Data Book includes the energy consumption (BTU per ton mile) for different transportation mode and vehicle types *[60]*. In addition to the TMR obtained by the procedure described in 3.1, the calculation of EC requires a conversion from the total ton-mile travelled to the total ton-mile required. The National Greenhouse Gas Emission Data distributed by the U.S. Environmental Protection Agency contains total U.S. emissions by source, economic sector and greenhouse gas *[61]*. The total emission data of each county can be obtained by a query from the Access to Air Pollution Data (AirData) website maintained by the USEPA *[62]*.

Procedure to Calculate Direct Cost Efficiency

Transportation facility costs (FC) correspond to construction and maintenance costs of transportation facilities, and construction incurs most of the expenditure. The Highway & Motorway Fact Book published by Public Purpose can give some insight on the maintenance cost and the highway construction cost *[63]*. Please note that the costs of $\sum_{(i,j,n)\in R}\left(LC_{i,j,n} + GC_{i,j,n} + VI_{i,j,n} + VM_{i,j,n} + VA_{i,j,n}\right)$ in equation (8) are out of the control of state DOTs. We suggest using the revised operational cost efficiency measures C' as in equation (9).

Calculating C' also needs TMR, which can be obtained by the procedure described above and the investment data for State DOTs.

Procedure to Calculate Economic Growth and Employment Improvement

Regional Employment Improvement (J) defined by equation (10) require both the employment opportunities provided by freight transportation projects and the total freight transportation investment in each year. Employment opportunities provided by transportation investment can be directly obtained for a specific project. Some data for employment opportunities created by transportation-related projects can be obtained from the Complete Economic and Demographic Data Source (CEDDS) *[64]*. State DOTs may also provide their investment and employment data to calculate this metric.

Summary of Measures and Data Sources

Table 4 summarizes all data and tools that could be used to calculate all proposed metrics to assess a freight network.

Table 4
Summary of metrics, tools and data sources

Performance Measures	Project-used Data	Used Tools	Other Possible Data Sources
Mobility and Reliability			
Mobility (M) (hour per mile)	FAF[3], TransCAD Network	TransCAD Excel	TRANSEARCH, Ground Counts, US Waterway Data, ORNL Intermodal Network
Reliability (R, R_u) (no unit)	Simulation to be developed		
Safety			
Fatality Rate (S_F) (fatalities per TMR)	FARS,HSRG, FRA, MCPD	Excel	
Injury Rate (S_I) (injuries per TMR)	FARS,HSRG, FRA, MCPD	Excel	
Environmental Impact			
Energy Consumption Rate (EC) (BTU per TMR)	Transportation Energy Data Book	Excel	
Transportation Pollutants (P) (tons per TMR)	US Emissions Inventory Report, Transportation Energy Data Book, AirData	Excel	
Direct Cost Efficiency			
Direct Cost Efficiency (C') ($ per TMR)	National Transportation Statistics	Excel	Highway & Motorway Fact Book, State DOTs
Economic Growth			
Employment Improvement (J) (job years per dollar investment)		Excel	State DOTs

DISCUSSION OF RESULTS

Case Study on the Louisiana Freight Network

A case study was conducted to evaluate the freight network of the state of Louisiana to demonstrate the application of the proposed performance measure system. TransCAD is used to conduct traffic assignment and display the study results.

Calculated Mobility and Reliability

For calculating the mobility for Louisiana, the following steps were used:

Step 1) The intermodal network provided by TransCAD was used to document the freight transportation network in Louisiana, including all three major surface transportation modes of highways, railroads, and waterways (see Figure 5).

Figure 5
Intermodal network in Louisiana

Step 2) To obtain within-region, flow-in, flow-out, and through-region OD data, the researchers disaggregated the FAF^3 data. FAF^3 only has OD demand data between 131 FAF traffic analysis zones based on Commodity Flow Survey 2007 and has forecasts through

2040. In Louisiana, there are only four FAF zones; New Orleans, Baton Rouge, Lake Charles, and the remainder of Louisiana. The OD data from, to, and between the four zones do not have resolution high enough to analyze the flows in the state. Therefore, a disaggregation is conducted to obtain OD data at the parish level based on their population and economic activities (measured by GDP) in the state. To reduce the complexity of the whole analysis, the researchers used the FAF zone level data for the neighboring states (i.e. Texas, Arkansas, and Mississippi) and state-level data for the remaining 44 continental states along with export and import data from FAF^3. FHWA will soon work on FAF^4 based on Commodity Flow Survey 2012 but they are expected to keep the same data resolution at the FAF zone level. Therefore, DOTD needs to do disaggregation annually. For this project, the team conducted the disaggregation in Excel but there is a need to develop a program to do it automatically because of the large workload. Table 5 is part of the disaggregated results based on FAF^3 data.

Table 5
Disaggregated OD data at the Parish level

Origin	Destination	Mode	KTons in 2011	Origin	Destination	Mode	KTons in 2011
Calcasieu	Ascension	Truck	15.11008277	Cameron	Iberville	Water	0.27729349
Calcasieu	Assumption	Truck	3.182226326	Cameron	Livingston	Water	1.084394791
Calcasieu	East Baton Rouge	Truck	60.63503236	Cameron	Pointe Coupee	Water	0.190129115
Calcasieu	East Feliciana	Truck	2.770030804	Cameron	Saint Helena	Water	0.091845348
Calcasieu	Iberville	Truck	4.57122363	Cameron	West Baton Rouge	Water	0.200665468
Calcasieu	Livingston	Truck	17.87640629	Cameron	West Feliciana	Water	0.128768394
Calcasieu	Pointe Coupee	Truck	3.134306194	Jefferson Davis	Ascension	Truck	0.811543157
Calcasieu	Saint Helena	Truck	1.514083953	Jefferson Davis	Assumption	Truck	0.170913293
Calcasieu	West Baton Rouge	Truck	3.30799951	Jefferson Davis	East Baton Rouge	Truck	3.256629784
Calcasieu	West Feliciana	Truck	2.122765749	Jefferson Davis	East Feliciana	Truck	0.1487748
Calcasieu	Ascension	Rail	0.001236946	Jefferson Davis	Iberville	Truck	0.245514556
Calcasieu	Assumption	Rail	0.000260504	Jefferson Davis	Livingston	Truck	0.960118843
Calcasieu	East Baton Rouge	Rail	0.004963723	Jefferson Davis	Pointe Coupee	Truck	0.168339564
Calcasieu	East Feliciana	Rail	0.000226761	Jefferson Davis	Saint Helena	Truck	0.081319506
Calcasieu	Iberville	Rail	0.000374211	Jefferson Davis	West Baton Rouge	Truck	0.177668409
Calcasieu	Livingston	Rail	0.001463404	Jefferson Davis	West Feliciana	Truck	0.114011025
Calcasieu	Pointe Coupee	Rail	0.000256582	Jefferson Davis	Ascension	Rail	6.64348E-05
Calcasieu	Saint Helena	Rail	0.000123946	Jefferson Davis	Assumption	Rail	1.39914E-05
Calcasieu	West Baton Rouge	Rail	0.0002708	Jefferson Davis	East Baton Rouge	Rail	0.000266595
Calcasieu	West Feliciana	Rail	0.000173774	Jefferson Davis	East Feliciana	Rail	1.2179E-05
Calcasieu	Ascension	Water	31.46724121	Jefferson Davis	Iberville	Rail	2.00984E-05
Calcasieu	Assumption	Water	6.627090328	Jefferson Davis	Livingston	Rail	7.85975E-05
Calcasieu	East Baton Rouge	Water	126.2744366	Jefferson Davis	Pointe Coupee	Rail	1.37807E-05
Calcasieu	East Feliciana	Water	5.76867968	Jefferson Davis	Saint Helena	Rail	6.657E-06
Calcasieu	Iberville	Water	9.519722609	Jefferson Davis	West Baton Rouge	Rail	1.45443E-05
Calcasieu	Livingston	Water	37.22820034	Jefferson Davis	West Feliciana	Rail	9.33321E-06
Calcasieu	Pointe Coupee	Water	6.527295086	Jefferson Davis	Ascension	Truck	0.811543157
Calcasieu	Saint Helena	Water	3.153129317	Jefferson Davis	Assumption	Truck	0.170913293
Calcasieu	West Baton Rouge	Water	6.889017094	Jefferson Davis	East Baton Rouge	Truck	3.256629784
Calcasieu	West Feliciana	Water	4.42072905	Jefferson Davis	East Feliciana	Truck	0.1487748
Cameron	Ascension	Truck	0.440131275	Jefferson Davis	Iberville	Truck	0.245514556
Cameron	Assumption	Truck	0.092692896	Jefferson Davis	Livingston	Truck	0.960118843
Cameron	East Baton Rouge	Truck	1.76619642	Jefferson Davis	Pointe Coupee	Truck	0.168339564
Cameron	East Feliciana	Truck	0.080686334	Jefferson Davis	Saint Helena	Truck	0.081319506
Cameron	Iberville	Truck	0.133152049	Jefferson Davis	West Baton Rouge	Truck	0.177668409
Cameron	Livingston	Truck	0.520709622	Jefferson Davis	West Feliciana	Truck	0.114011025
Cameron	Pointe Coupee	Truck	0.091297063	Jefferson Davis	Ascension	Rail	6.64348E-05
Cameron	Saint Helena	Truck	0.044102717	Jefferson Davis	Assumption	Rail	1.39914E-05
Cameron	West Baton Rouge	Truck	0.096356457	Jefferson Davis	East Baton Rouge	Rail	0.000266595
Cameron	West Feliciana	Truck	0.061832593	Jefferson Davis	East Feliciana	Rail	1.2179E-05
Cameron	Ascension	Rail	3.60302E-05	Jefferson Davis	Iberville	Rail	2.00984E-05
Cameron	Assumption	Rail	7.58805E-06	Jefferson Davis	Livingston	Rail	7.85975E-05

Step 3) The researchers used the following procedure to calculate the TMR for the network, the denominator of equation (21). Demand by modes in FAF^3 of each OD pair that may affect the Louisiana network is routed by the shortest time. For flow-in, flow-out, and through-traffic, the out-of-state traffic was aggregated at access points at the state boundaries. Because the focus of this study was Louisiana's freight network, it was unnecessary to worry about the traffic needs out of the state. The aggregation process also helps to reduce the computational efforts in Step 4 traffic assignment. Together with the within traffic demand, the TMR were calculated based on geographic distances, which is

$$\sum_{(i,j)\in R} p_{i,j} l_{i,j}. \qquad (11)$$

Here, (i,j) represent all OD pairs, $p_{i,j}$ are tonnage between OD pair(i,j), and $l_{i,j}$ are geographic distance from origin i to destination j. Each origin or destination could be the center of a parish or an access point of out-of-state traffic at the state border.

The geographic distance $l_{i,j}$ can be calculated based on the longitudes and latitudes of origin i and destination j following equation (12), in which $Long_i$ and Lat_i are the longitude and latitude of node i.

$$l_{i,j} = 3{,}982 \cos^{-1}(\cos(Long_i - Long_j)\cos(Lat_i)\cos(Lat_j) + \sin(Lat_i)\sin(Lat_j)). \qquad (12)$$

Based on the above calculation, we obtain the total TMR in Table 6.

Table 6
Total TMR of Louisiana based on FAF[3] in 2011

	Total TMR (Ton-Miles Required)
Highways	3.56×10^{10}
Railways	1.03×10^{10}
Waterways	2.80×10^{10}
Total	$\mathbf{6.39\times10^{10}}$

The calculated TMR will be used to calculate multiple metrics for evaluating the performance of Louisiana's freight network.

Step 4) In order to calculate the mobility, the researchers further assign OD data on the transportation network to obtain the traffic volume on each segment with different transportation modes. All traffic is routed based on the shortest-time path (the all or none rule) by mode in TransCAD. The highway and railway flows are shown in Figure 6. The highway speeds are considered at free flow speeds at each segment. The railway travel time for each OD trip depends on the speed at links and the dwell time at major classification yard. The waterway travel time is calculated based on the speed of 10 miles per hour. There are no locks or dams at the lower Mississippi river so it is unnecessary to consider the waiting time. After the traffic assignment, we obtain the total ton-hours traveled on each transportation mode, as shown in Table 7.

Figure 6
Highway and railway freight flows in Louisiana in 2011

Table 7
Ton-hours traveled in Louisiana in 2011

	Ton-Hours Traveled
Highways	6.52×10^{8}
Railways	3.15×10^{8}
Waterways	4.00×10^{9}
Total	4.97×10^{9}

Step 5) Calculate the mobility based on the total ton-hours divided by total ton-mile required. Based on the ton-hours traveled and ton-mile required, the researchers can calculate the mobility of the freight network in Louisiana in 2011 as

$$M = \frac{\text{Ton} - \text{Hours Traved}}{TMR} = \frac{4.97\times10^{9}}{6.39\times10^{10}} = \ \text{0.077 hours per geographic mile.}$$

In other words, freight can travel about 12.86 geographic miles per hour on average in the state of Louisiana in 2011. The slow speed is mainly caused by the low speed on waterways As indicated before, the reliability metrics will be calculated based on a follow-up simulation project.

Calculated Safety

In order to calculate safety metrics, the researchers collected the 2011 crash data from the Louisiana Highway Safety Research Group (HSRG). Please note that because this study focused on freight network performance, only crashes that involved freight trucks are included in Table 8, without including single unit trucks (2 or 3 axle). The 2011 crashes including single unit trucks are summarized in Table 9.

Table 8
Highway truck-involved crashes in 2011 (no single unit trucks) in Louisiana

Code	Frequency	Percent	Cumulative Frequency	Cumulative Percentage
Missing	698	5.33	698	5.33
Fatalities	55	0.42	753	5.75
Incap/Severe	59	0.45	812	6.2
Non-Incap/Mod	401	3.06	1213	9.26
Poss/Complains	1643	12.54	2856	21.8
No Injury	10245	78.2	13101	100

Table 9
Highway truck-involved crashes in 2011 (including single unit trucks) in LA

Code	Frequency	Percent	Cumulative Frequency	Cumulative Percentage
Missing	1268	5.82	1268	5.82
Fatal	74	0.34	1342	6.16
Incap/Severe	86	0.39	1428	6.55
Non-Incap/Mod	627	2.88	2055	9.43
Poss/Complains	2706	12.41	4761	21.84
No Injury	17037	78.16	21798	100

The researchers did not include single unit trucks due to the focus on freight networks. Therefore, the total fatalities and injuries on highways for freight network analysis are 55 and 2,103 in 2011.

For railroads, the 2011 fatality and injury data are available at the Safety Database of FRA and summarized in Table 10 *[56]*.

Table 10
Railroad fatalities and injuries in Louisiana in 211

Total Employee on Duty Death		0
Trespasser Deaths		4
Railway-Highway Crossing Deaths		8
Other Deaths		1
	Total Deaths	13
Total employee on Duty Injuries		10
Trespasser Injuries		84
Railway-Highway Crossing Injuries		71
Other Injuries		0
	Total Injuries	165

The Marine Casualty and Pollution database maintains a variety of files related to waterways. To isolate only Louisiana incidents, the locations of the incidents were plotted using GIS software, and incidents outside of the state were not kept. To capture the freight network performance, the included types of vessels are freight barge and freight ship. The following vessel types are not included:

- Commercial Fishing Vessel,
- Industrial Vessel,
- Mobile Offshore Drilling Unit,
- Offshore Supply Vessel,
- Passenger 6 or Fewer,
- Passenger Inspected,

- Passenger More Than 6,
- Recreational, and
- Unspecified.

There was one injury and no deaths in 2011 on Louisiana waterways when excluding the above categories.

All freight-related fatalities and injuries are listed in Table 11. Obviously, most fatalities and injuries are caused by highway freight movement. Waterways are the safest transportation mode perhaps because of its little interaction with passenger traffic. The fatality rate for railroad freight is notably high after considering its TMR, which is almost 30% of highway TMR.

Table 11
Freight-related fatalities and injuries in Louisiana in 2011

	Fatalities	Injuries
Highways	55	2,103
Railways	13	165
Waterways	0	1
Total	68	2,269

Based on Table 11, the researchers obtained the following two safety metrics for Louisiana freight network.

$$S_F = \frac{\text{Total Fatalities}}{\text{TMR}}$$

$$= \frac{\text{68 Fatalities}}{6.39\times10^{10}\ \text{Ton Miles Required}}$$

$$= \text{10.49 fatilities per 10 billion Ton Miles Required}$$

$$S_I = \frac{\text{Total Injuries}}{\text{TMR}}$$

$$= \frac{\text{2,269 Injuries}}{6.39\times10^{10}\ \text{Ton Miles Required}}$$

$$= \text{355.09 injuries per 10 billion Ton Miles Required}$$

Calculated Environmental Stewardship

Energy Consumption Rate (*EC*) is the average unsustainable energy consumption (BTU) per TMR. The BTU consumption is calculated using the Transportation Energy Data Book (Edition 32) data *[65]*; see Table 12.

Table 12
Energy consumption of freight transportation in Louisiana in 2011

	BTU per Ton-Mile Traveled	Gallons per Ton-Mile Traveled	Total Ton-Mile Traveled	Total Energy Consumed (Million Gallons)
Highways	889	0.0071	4.24×10^{10}	301.82
Railways	298	0.0024	1.26×10^{10}	30.07
Waterways	217	0.0017	4.00×10^{10}	69.50
Total			$\mathbf{9.50\times10^{10}}$	**401.39**

Based on equation (6),

$$EC = \frac{Total\ Energy\ Consumed}{TMR}$$

$$= \frac{401.39 \text{ Million Gallons}}{6.39\times10^{10} \text{ Ton Miles Required}}$$

$$= 0.0063 \text{ Gallions per Ton Mile Required}$$

In other words, one gallon of gasoline could transport one ton of freight from Point A to Point B with the distance of 159 miles in Louisiana in 2011. This efficiency can be further improved by

- Shifting more traffic to more energy-efficient transportation modes (e.g., railway or waterway), or
- Improving the freight network to reduce the travel distances.

For the performance metric of pollutant released rate P, the Access to Air Pollution Data (AirData) website maintained by the USEPA *[62]* has the total emission data of each county (parish) for each transportation mode as shown in Table 13. For highways, we only consider trucks consuming either diesel or gasoline. It is easy to see that most emissions are caused by truck movement.

Table 13
Freight transportation emission in 2011 in Louisiana

	Carbon Emissions (Tons)
Highways	8.82×10^6
Railways	1.46×10^4
Waterways	1.66×10^5
Total	9.00×10^6

Based on equation (7), the pollutant released rate P as

$$P = \frac{Total\ Carbon\ Emission\ of\ Transportation}{TMR}$$

$$= \frac{9.00 \times 10^6 \text{ Tons}}{6.39 \times 10^{10} \text{ Ton Miles Required}}$$

$$= 1.41 \times 10^{-4} \text{ tons per ton mile required.}$$

Calculated Direct Cost Efficiency

Louisiana DOTD directly invested $20 million each year for port infrastructure improvement. The total investment is currently not available to the research team. Therefore, this report does not include a measurement for direct cost efficiency.

Calculated Employment improvement

The research team only obtained the employment numbers of the Port Program from DOTD. The annual investment of the program has been approximately $20 million plus $5 million matching from the ports. When a project was not funded completely in one fiscal year (FY), only the partial jobs created/retained by the funds provided in that FY were considered. A $15,000,000 project with 30 jobs, for example, only had $5,000,000 funded in a FY. We consider only 10 jobs for the fund in that FY. The number of jobs created by the Port Program is given in Table 14.

Table 14
Employment number for the Port Program

FY	Jobs
09/10	122
10/11	145
11/12	560
12/	971
13/14	244
Total	2,042
Average	408.4

The employment improvement measure for the Port Program can be calculated based on equation (10).

$$J = \frac{TJ}{TI} = \frac{408.4}{25} = 16.336 \text{ job years per million dollars.}$$

With more data, the employment improvement measure can be calculated for the whole freight network in Louisiana.

Summary for Louisiana Freight Network Performance

The direct cost efficiency C requires more data not available to the researchers at the time of this report. All other metrics are summarized in Table 15.

Table 15
Performance of Louisiana freight network in 2011

Performance Measures	Value
Mobility (M) (hours per geographic mile)	0.0515
Reliability (R, R_u) (no unit)	To be calculated based on the simulation project
Fatality Rate (S_F) (fatalities per 10 billion TMR)	7.46
Injury Rate (S_I) (injuries per 10 billion TMR)	247.92
Energy Consumption Rate (EC) (BTU per TMR)	839
Transportation Pollutants (P) (tons per TMR)	1.41×10^{-4}
Direct Cost Efficiency (C) ($ per TMR)	More data are required
Employment Improvement (J) (job years per million dollar) (only for the Port Program)	16.336

CONCLUSIONS

The audience of this research mainly targets state DOTs, who need developed metrics for selecting freight network improvement projects and demonstrating the benefits of investment on freight management. The results could also benefit the USDOT for transportation planning and promotion of intermodal solutions and the DHS for transportation resilience and protection. The private sector, such as Class-I and short line railroads, may use the metrics to guide their investment and seek government supports. There are two major outcomes from this project:

- An intermodal performance measurement system for freight management, including metrics definition, calculation procedure, and methodologies of data collection.
- A case study that demonstrates how to apply the proposed performance measurement system to evaluate an intermodal network for freight management.

RECOMMENDATIONS

The following measures for freight transportation systems are suggested to address the needs of transportation users.

1. *Mobility:* Reducing transportation time and delay is a major concern for most transportation users.
2. *Safety*: The objectives related to transportation safety and security includes improving traffic safety, i.e., reducing traffic accident rates, injuries, fatalities, and risks. They also include increasing traffic security and reducing crime rates, improving accident detection and response, and increasing public security and homeland security.
3. *Environmental Stewardship*: The objectives include reducing the amount of transportation-related pollutants, promoting community livability near major transportation infrastructures, and decreasing energy consumption.
4. *Direct Cost Efficiency*: The objectives include developing cost-efficient transportation systems that have low cost/benefit ratios and high sustainability.
5. *Economic Growth*: The objectives include promoting local or regional economic growth and increasing local or regional employment opportunities.

It is recommended that state DOTs adopt the proposed performance measurement system to evaluate their freight transportation system. Although most measures can be calculated based on publically available data and commercially available software, state DOTs still need to provide their investment and job creation data. Once adopted, the proposed measures and calculation procedures can be used to compare the performance of freight networks across states and across years. The system can be further used to evaluate freight network projects.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AirData	Air Pollution Data
ATRI	American Transportation Research Institute
AVO	Average Vehicle Occupancy
BTS	Bureau of Transportation Statistics
CEDDS	Complete Economic and Demographic Data Source
EC	Energy Consumption Rate
FAA	Federal Aviation Administration
FAF^3	Freight Analysis Framework version 3
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FMT	Freight Ton Miles Traveled
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
FY	Fiscal Year
GDP	General Domestic Product
HSRG	Highway Safety Research Group
ICAO	International Civil Aviation Organization
ISTEA	Intermodal Surface Transportation Efficiency Act
LaDOTD	Louisiana Department of Transportation and Development
LP	Localizer Performance
LTRC	Louisiana Transportation Research Center
MAP-21	Moving Ahead for Progress in the 21st Century Act
MCPD	Marine Casualty and Pollution Database
MnDOT	Minnesota Department of Transportation
MoDOT	Missouri Department of Transportation
Mph	Miles per Hour
MPO	Metropolitan Planning Organization
NAS	National Aviation Services
N-CAST	National Corridors Analysis and Speed Tool
NCDOT	North Carolina Department of Transportation
NSFRP	National Cooperative Freight Research Program
NCITEC	National Center for Intermodal Transportation for Economic Competitiveness
NCSA	National Center for Statistics and Analysis
NEC	Northeast Corridor

NHS	National Highway System
NHTSA	National Highway Traffic Safety Administration
NTS	National Transportation Statistics
OD	Origin – Destination
ORNL	Oak Ridge National Lab
OTP	On-time Performance
PBN	Performance Based Navigation
PMT	Passenger Miles Traveled
RA/IRS	Railroad Accident/Incident Reporting System
TEA-21	Transportation Equity Act for the 21st Century
TMR	Ton Miles Required
TMT	Ton Miles Traveled
TTI	Travel Time Index
USGC	U.S. Coast Guard
USDOT	U.S. Department of Transportation
USEPA	U.S. Environmental Protection Agency
VMT	Vehicle Miles Traveled

REFERENCES

1. US House, P.L.112-141. *MAP*-21: Moving Ahead for Progress in the 21st Century (Final Version), 07/06/2012.

2. USDOT, Annual Performance Report Fiscal Year 2011, 2012.

3. Federal Maritime Administration. *Report to Congress on the Performance of Ports and the Intermodal System*, 2005.

4. Federal Maritime Administration. *Maritime Administration Annual Report to Congress Fiscal Year 2009*. Accessed at http://www.marad.dot.gov/documents/Maritime_Annual_Report_to_Congress_2009.pdf.

5. Federal Railroad Administration. *Quarterly Report on the Performance and Service Quality of Intercity Passenger Train Operations, Covering the Quarter Ended September, 2012*, 2012.

6. Vantuono, W.C. "Compare Apples to Oranges." *Railway Age*. August 1, 2005.

7. Federal Highway Administration. *Measuring Travel Time in Freight-Significant Corridors*. 2005.

8. Federal Highway Administration. *Measuring Cross-Border Travel Times for Freight El Paso-Ciudad Juarez Bridge of the Americas*. 2009.

9. US Government accountability Office. *Federal Transit Administration Has Opportunities to Improve Performance Accountability*. 2010.

10. Federal Transit Administration. *Moving Ahead for Progress in the* 21*st Century Act (MAP-21): A Summary of Public Transportation Provisions*. 2012.

11. Federal Aviation Administration. *Destination* 2025. 2012.

12. Rutherford, G.S. "Multimodal Evaluation of Passenger Transportation." Transportation Research Board, National Research Council. *NCHRP Synthesis* 201. 1994.

13. Missouri DOT. *Tracker: Measures of Departmental Performance*. January, 2013.

14. Minnesota DOT. *Annual Minnesota Transportation Performance Report* 2011. October, 2012.

15. North Carolina DOT. *Performance Dashboard Documentation*, September, 2010.

16. Varma, A. *Measurement Sources for Freight Performance Measures and Indicators,* MnDOT, 2008.

17. Washington State Department of Transportation. *Performance Measurement Library*. Accessed at http://www.wsdot.wa.gov/Accountability/Publications/Library.htm on January 8th, 2012.

18. Hagler Bailly Services, Inc. *Measuring Improvements in the Movement of Highway and Intermodal Freight*. Federal Highway Administration, 2000.

19. Meyer, M.D. "Measuring That Which Cannot be Measured (At Least According to Conventional Wisdom)." *Proceedings* 26 *of Performance Measures to Improve Transportation Systems and Agency Operations*. Transportation Research Board, 2001.

20. Bertini, R.L., Leal, M., and Lovell, D.J. *Generating Performance Measures from Portland's Archived Advanced Traffic Management System Data*. Transportation Research Board, 2002.

21. Shaw, T. *ITS Program Performance Measures: ITS Corridor Master Plans for Florida's Principal FIHS Limited-Access Corridors.* Florida Department of Transportation, 2002.

22. BRW, Inc. *CDOT Travel Demand Improvement Projects: Improvements to Mobility Performance Measure Calculations*. Colorado Department of Transportation, 2000.

23. Jones, C., Murray, D., and Short, J. *Methods of Travel Time Measurement in Freight-Significant Corridors*. Transportation Research Board, 2005.

24. American Transportation Research Institute. *FPM & N-CAST Background and Objectives*. Accessed on May 1, 2013.

25. Schrank, D. and Lomax, T. *The 2005 Urban Mobility Report*. Texas Transportation Institute, 2005.

26. Bertini, R.L. and El-Geneidy, A. *Using Archived Data to Generate Transit Performance Measures.* Transportation Research Board, 2003.

27. Metropolitan Transportation Commission. *Performance Measures Report for the 2001 Regional Transportation Plan for the San Francisco Bay Area*, 2001.

28. Dumbaugh, E. and Meyer, M.D. *Exploring the Relationship between Agency Performance Measures and Operations Investments in a Metropolitan Area.* Transportation Research Board, 2003.

29. Czerniak, R., Gasier, S., and Gerard, D. *The Use of Intermodal Performance Measures by State Departments of Transportation*. USDOT, 1996.

30. Schrank, D. and Lomax, T. *The 2005 Urban Mobility Report*. Texas Transportation Institute, 2005.

31. Washington DOT. *WSDOT's Congestion Measurement Approach: Learning from Operation Data*, 2003.

32. Cambridge Systematics. *Performance-Based Planning Manual.* NCHRP Report 8–32(2). Transportation Research Board, National Research Council, Washington D.C., 2000.

33. Ministry of Environment and Energy and National Environmental Research Institute. *Indicators and Performance Measures for Transportation, Environment, and Sustainability in North America*. Report from a German Marshall Fund Fellowship, 2000.

34. Federal Highway Administration. "Environmental Sustainability (Chapter 11)," 2010 *Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance*. 2012.

35. U.S. Environmental Protection Agency. *Fast Facts: U.S. Transportation Sector Greenhouse Gas Emissions* 1990-2010. 2012.

36. Hickling Lewis Brod, Inc. *Workshop on Productivity Performance Indicators: Report of Proceedings.* USDOT, 1998.

37. Florida Department of Transportation. *Report to Statewide Model Task Force on Freight Modeling and Forecasting Techniques*, 1998.

38. California Department of Transportation. *1998 California Transportation Plan: Statewide Goods Movement Strategy*, 1998.

39. Act 51 Transportation Funding Study Committee. *Act 51 White Paper – State Trunklines: Performance Measures*, 1999.

40. Indiana Department of Transportation. *Economic Performance Measures*: *A Technical Report from the I-69 Evansville-to-Indianapolis Study*, 2000.

41. East-West Gateway Coordinating Council (St. Louis Region MPO). *Goods Movement Issue Paper*, 1998.

42. Thompson, B. "Performance Evaluation of Florida's Public Transit Systems." *Proceedings 26 of Performance Measures to Improve Transportation Systems and Agency Operations*. Transportation Research Board, 2001.

43. Federal Highway Administration. *Examination of Transportation Industry Productivity Measures. Conference Summary Report*, 1993.

44. National Cooperative Freight Research Program, *NCFRP Report* 10: *Performance Measures for Freight Transportation*, 2012.

45. Pickell, S. and Neumann, L. "Use of Performance Measures in Transportation Decision-making." *Proceedings 26 of Performance Measures to Improve Transportation Systems and Agency Operations*. Transportation Research Board, 2001.

46. Kassoff, H. "Implementing Performance Measurement in Transportation Agencies." *Proceedings 26 of Performance Measures to Improve Transportation Systems and Agency Operations*. Transportation Research Board, 2001.

47. Wang, H. and Jin, M. "A Transportation Performance Measurement Systems with a Mississippi Case Study." *Journal of Transportation Research Forum* 45(3), 2006, 19-37.

48. Jin, M., Eksioglu, S., Eksioglu, B., and Wang, H. "Mode Selection for Automotive Distribution with Quantity Discounts," Networks and Spatial Economics, v10/1, MAR/2010, pp. 1-13.

49. Lindley, J.A. "Urban Freeway Congestion: Quantification of the Problem and Effectiveness of Potential Solution." *Journal of the Institute of Transportation Engineer* 57(1), 1987, 27–32.

50. Bureau of Transportation Statistics, National Transportation Statistics, 2013.

51. Oak Ridge National Lab (ORNL), Intermodal Transportation Network, accessed at http://cta.ornl.gov/transnet/Intermodal_Network.html on April 1, 2013.

52. Federal Highway Administration (FHWA), *FAF*^{3} *Network Database and Flow Assignment: 2007 and 2040*, accessed at http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/faf3/netwkdbflow/on April 5, 2013.

53. IHS, *Transearch*, accessed at http://www.ihs.com/products/global-insight/industry-analysis/commerce-transport/database.aspx on April 7, 2013.

54. National Highway Traffic Safety Administration (NHTSA), *Fatality Analysis Reporting System* (*FARS*), accessed at http://www.nhtsa.gov/FARS on April 5, 2013.

55. Jarossi, L., Matteson, A., and Woodrooffe, J. Trucks Involved in Fatal accidents Codebook 2009, 2011, accessed at http://deepblue.lib.umich.edu/bitstream/handle/2027.42/89937/48532_A55.pdf?sequence=1 on April 6, 2013.

56. Federal Railroad Administration, Office of Safety Analysis, *Railroad Accident/ Incident reporting System*, accessed at http://safetydata.fra.dot.gov/officeofsafety/default.aspx on April 3, 2013.

57. National Transportation Safety Board, *Aviation Accident Statistics*, accessed at http://www.ntsb.gov/data/aviation_stats.html on March 23, 2013.

58. NASA, *Aviation Safety Reporting System*, accessed at http://asrs.arc.nasa.gov/index.html on March 25, 2013.

59. US Coast Guard, *The Marine Casualty and Pollution Data*, accessed at http://www.data.gov/list/agency/23/207/catalog/tools/page/1/count/50 on March 13, 2013.

60. Davis, S. C., Diegel, S. W., and Boundy, R. G., *Transportation Energy Data Book, Edition* 31, 2012.

61. United States Environmental Protection Agency (USEPA), *National Greenhouse Gas Emissions Data*, accessed at http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html, on March 20, 2013.

62. United States Environmental Protection Agency (USEPA), *Airdata*, accessed at http://www.epa.gov/airdata/, on March 20, 2013.

63. Public Purpose, *Highway & Motorway Fact Book*, accessed at http://www.publicpurpose.com/hwy-ix.htm on April 15, 2013.

64. Woods and Pool Economics, the *Complete Economic and Demographic Data Source*, 2013.

65. Davis, S.C, Diegel, S.W., and Boundy, R.G. Transportation Energy Data Book: Edition 32. Oak Ridge National Laboratory (ORNL), 2013.