

National Center for Intermodal Transportation for Economic Competitiveness



NCITEC

Project 2013 – 32



Intermodal Optimization for Economically Viable Integration of Surface and Waterborne Freight Transport

Final Report: NCITEC Project 2013 - 32

The University of Mississippi

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INTERMODAL OPTIMIZATION FOR ECONOMICALLY VIABLE INTEGRATION OF SURFACE AND WATERBORNE FREIGHT TRANSPORT

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ABSTRACT

U.S. economy is reenergizing its domestic manufacturing infrastructure besides sustainable growth in agriculture commodities and other products destined for export. The efficient delivery of goods and services is a key factor in economically competitive markets and quality of life in the US and around the globe. The development of larger cargo ships and expansion of Panama Canal are other factors impacting the ability of major U.S. ports to serve these new container ships. The primary objectives of this project are to: (1) identify major freight transportation corridors involving shipping ports (marine and inland waterways), highway network, and rail infrastructure assets, (2) model transport demand, visualize routing scenarios, and optimize locations of integrated intermodal terminals, and (3) evaluate the economic competitiveness considering travel time efficiency, safety, disaster resiliency, emissions, and economic development opportunities.

Global supply chain and inventory management system stakeholders, such as Walmart, and freight logistics companies depend on a smooth, seamless flow of freight through interconnecting shipping ports, airports, rails, and highways. These modes operate independently in the United States with lack of adequate operational integration, except some limited to rail and road intermodal transport terminals. Key results of the project include:

- This project developed geospatial maps, optimization models, benefit/cost results of proposed modal integration simulation studies, and life cycle economic model results of economic and environmental impacts.
- Intermodal integration study showed by diverting 30% of freight trucks from the port of Gulfport to the integrated Mississippi River and I-55 corridor, lower operating cost was calculated. Comparing the base case scenario where 100% of the commodity was transported by trucks compared to intermodal integration scenario with 30% of the freight moved by barge, 18.0% saving in cost per ton-mile was calculated. Additionally, the travel time is reduced by 19.0%, which resulted in lower fuel costs and 11.7% reduction in carbon dioxide emissions.
- Computer simulations of selected port(s) and sustainability analysis are used to show the importance of the intermodal integration approach for enhancing the economic competitiveness, safety, security and disaster resilience of freight transport.
- The intermodal freight corridor case studies are used to develop a “best practice guide” for consideration by government transportation agencies, private transport operators, and other global supply chain stakeholders.

It is recommended that the developed approach of freight corridor studies be applied by transportation agencies to assess other societal benefits, which include reduction in traffic congestion and decrease in transportation related emissions of carbon dioxide and other harmful pollutants.

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Close interaction was maintained with the Mississippi Department of Transportation (MDOT) who provided geospatial databases of transportation network, highway bridges and rivers for the State of Mississippi. Thanks are due to the MDOT engineers who lectured on traffic engineering, planning and highway design topics to undergraduate and graduate students at the University of Mississippi. We are grateful to the MDOT Traffic Engineering Division who provided traffic video surveillance wall to monitor real-time statewide traffic in cooperation with the MDOT's Intelligent Transportation System section.

This report is authored by Dr. Waheed Uddin with support from project partners Dr. Patrick Sherry at University of Denver and Dr. Burak Eksioglu of Clemson University. Thanks are also due to the M.S. students Seth Cobb, Robert Richardson, Tucker Stafford, doctoral students Quang Nguyen and Zul Fahmi Mohamed Jaafar, as well as CAIT research assistants David May, Gergo Arany, Haley Sims, Elizabeth Holt, and exchange students Rulian Ferreira De Almeida from Brazil, and Javier Ramírez Jiménez and Ana Villaseñor from Mexico at the University of Mississippi for their contributions to the project.

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1. BACKGROUND AND OVERVIEW

1.1 Introduction

Overview of Multimodal Freight Transportation Infrastructure and Research Needs

This project addresses the NCITEC theme of efficient, safe, secure, and sustainable national intermodal transportation network that can be made resilient to disasters. In today’s “global economy” the global freight transportation uses multimodal approach to interconnect each country’s ports with rail, highway, and waterway transportation hubs for import/export demand of agriculture commodities, manufacturing goods, and fossil fuels. Ships, air cargo, and land transport are used as freight carriers for most import and export goods. Bulk ships and supertankers are used to transport most of the agriculture products, raw industrial materials, and fossil fuel supplies, which include coal, crude oil, and liquefied gas. Timely capital investments were made in transportation infrastructure in the 1960s-1990s (e.g., the US Interstate and national highway systems, freight rail system, airport hubs, ports and inland navigational waterways). This efficient freight transportation network in North America led to a global competitive edge for many decades. These transportation infrastructure systems are aging, not being expanded and modernized at a rate comparable to those of other global competitors (and emerging economies such as China), and competitive advantage is eroding.

The total inbound freight (604,409 million ton-miles) in 2011 from all foreign origins to the US had the following modal distribution: 58% ships, 14% pipeline, 13% rail, 13% truck, 1% air, and the rest 1% unknown (ORNL 2015). Of this inbound freight in 2011, the largest trading partner was Canada (25% freight) followed by Eastern Asia (22%), Rest-of-America (12%), Mexico (9%), and Europe (8%). The lack of freight modal integration may result in poor performance of supply chain (Maleki 2013): “inaccurate forecasts, low capacity utilization, excessive inventory, inadequate customer service, inventory turns, inventory costs, time to market, order fulfillment response, quality, customer focus and customer satisfaction.” A major freight corridor that can benefit from surface/waterway integration is Gulfport-MS/New Orleans-LA through Memphis and St-Louis to Chicago. The study also examined integrating selected segments of the candidate corridor, especially for a case study of the lower Mississippi River region (Uddin et al. 2016).

The project investigated the aspects of multimodal freight related to congestion, intermodal integration, and impacts of fuel savings and carbon dioxide emissions. The global supply chain can be seriously disrupted by natural disasters. For example the earthquake and tsunami disaster that struck Japan in March 2011 even had an effect on car manufacturing facilities in the U.S. that lasted for several months. Similarly, the 2011 mega flood of central Thailand (Infra 2011) interrupted many industrial estates around Bangkok resulting in supply shortages of clothes, electronics, and several other manufactured items to Europe and North America. This problem of disruption in the supply chain can seriously hurt local economies which depend on distribution through surface transportation modes; even if the goods are brought in from abroad as with the Federal Express aviation cargo hub at Memphis International Airport. Similarly, other global

supply chain and inventory management system stakeholders depend on a smooth seamless flow of freight through interconnecting shipping ports, airports, rails, and roads.

As reported at National Press club on July 17, 2009 and discussed in a report of the National Academies that U.S. companies collectively spend a trillion dollars a year on freight logistics (NCFRP 2012a). This is nearly 10% of the nation's gross domestic product (GDP). The NCFRP report states that considering that about 80% of the population works and lives in cities and urban areas, 65% of goods originate or terminate in cities as per US DOT RITA's statistics based on a recent Commodity Flow Survey (CFS). About 4.5 million people or 3% of total employed work force in 2008 worked in transportation and warehouse industries. The CFS survey indicates that, on average, 42 tons of freight worth \$39,000 was delivered per person in the U.S. in 2007 (NCFRP 2012b). These statistics are indicative of the importance of the lifeline supply chain to support our society and everyday life. Traffic congestion on highways significantly impacts air quality degradation, greenhouse gas emissions, and global warming. Transportation contribution increased to 31% of energy related greenhouse gas (GHG) emissions in 2013 in the U.S., compared to 37% produced by electricity power plants (EPA 2013).

All these modal networks operate within their own policy frameworks and profit motivations with little or no real operational integration. In some cases some modes on long haul routes like highway freight trucks compete with freight rail service. Financing for preserving and upgrading intermodal infrastructure for both freight and rail is being handled very differently. Unlike freight trucks, whose infrastructure is supported by state and federal tax dollars, the freight rail industry has to manage their aging infrastructure by investing capital from their own profits without public involvement. This funding shortfall is a big hurdle in modernizing rail infrastructure, such as hardening of rail bridges for enhancing flood disaster resilience and rail electrification with almost zero emissions. Transport infrastructure funding crisis is evident on all levels and for all transportation modes.

Goals

The Primary goal of this project is the enhancement of freight mobility for economically competitive markets using intermodal integration and seamless connectivity among surface transport (rail for long-haul and road for short-haul trucks), inland waterways, and marine ports. Additional goals include development of geospatial visualization maps of freight corridors and commodity flow, improvement of supply chain delivery. The economic competitiveness, safety, security and disaster resilience of freight transport and supply chain can be significantly enhanced if owners, operators, and users of all transportation modes understand the importance of operational integration of these modes.

Objectives

The objectives of this applied research project are to:

- Identify major freight transportation corridors involving shipping ports (marine and inland waterways), highway network, and rail infrastructure assets.

Research Team and Collaborators

Key Investigators and Roles:

Dr. Waheed Uddin (PI), University of Mississippi (UM) cvuddin@olemiss.edu Professor of Civil Engineering and Director, Center for Advanced Infrastructure Technology (CAIT)

Dr. Patrick Sherry (PI), University of Denver psherry@du.edu
Executive Director of National Center for Intermodal Transportation (NCIT)
Program Director, Department of Counseling Psychology,

Dr. Burak Eksioglu (PI), Associate Professor, Department of Industrial Engineering, Clemson University, South Carolina (Formerly, Associate Professor, Department of Industrial & Systems Engineering and NCITEC Director, Mississippi State University)
burak@clemson.edu

Collaborator: Dr. Kenneth Ned Mitchell, ERDC Hydraulics lab, Vicksburg, Mississippi

Other UM Researchers

Other researchers of UM CAIT team include:

Dr. Y.M. Najjar: Professor & Chair of Civil Engineering contributed to the project, 2015.

Support from the following CAIT/Civil Engineering students, 2014-2016: Three PhD students, four M.S. students, 8 UG students, 3 exchange UG students

Other collaborators or contacts been involved

- Collaborator: Maritime Information Systems, Inc., Warren, Rhode Island. This company operates a large scale Automatic Information System network to track vessel movements in all Navigable North American Waterways.
- As Intergraph Registered Research Lab, CAIT Remote Sensing and Transportation Modeling Laboratories received geospatial industry support for education and training of students in geographical information system (GIS) applications for the project research. This Intergraph software grant is a testimony of industry support to the UM researchers and a cooperative feature of this project. Since January 2014 the statewide license has been provided by MARIS through Mississippi Institution of Higher Learning (IHL).
- Dr. Burak Eksioglu, PI, Clemson (formerly with MSU) collaborated with other stakeholders.
- Dr. Patrick Sherry, DU PI, works/collaborates with freight rail and truck fleet operators. He contacted selected logistics organizations for getting rail corridor infrastructure data and stakeholder survey feedback.
- Dr. Sherry and Dr. Uddin interacted with the following organizations.
 - Mineta Transportation Institute (MTI), San Jose State University
 - BNSF Railways, California (BNSF Government Affairs)
 - Port of Oakland, California, Port of New Orleans, LA, Port of Gulfport, MS
 - Association of American Railroads (AAR)

- Dr. Uddin networked with marine transportation stakeholders at June 2014 TRB-CMTS conference (USACE, U.S. Coast guard, port authorities, container port and logistics service providers, intermodal operators, consultants).
- Dr. Uddin is an appointed member of Board of Directors of the Mississippi Transportation Institute (MTI) since March 2014 and the Gulf Region Intelligent Transportation Society from 2009 to 2012. These are important state transportation organizations in Mississippi to benefit from the key results of the NCITEC projects.

Research Methodology

The CAIT project research team (CAIT 2014) implemented the following key steps of the research methodology:

1. Create geospatial databases and spatial maps of transportation infrastructure networks for U.S. and other North American Free Trade Agreement (NAFTA) partners, Mexico and Canada. These include highways, rail lines, inland waterways, ports, and airports. Select study sites in Mississippi, across the United States, and a port site abroad.
2. Analyze commodity flow data analysis for interstate commerce, establish intermodal freight corridor case studies, and evaluate the economic viability aspects of integrating selected segments of the candidate corridors.
3. Identify major transportation corridors involving shipping ports (marine and inland river system) highway network and rail infrastructure for examples of optimization analysis considering least shipping costs.
4. Review and synthesize both surface and waterborne databases. The primary sources of surface transportation data are DOT/RITA, US Bureau of Economic Affairs, and State DOTs.
5. Collaborate with the Army Corps of Engineers ERDC that helped to access publicly available Waterborne Commerce Statistics Center (WCSC) database. Where necessary, the research team got support via the Corps’ Channel Portfolio Tool (CPT) web portal (Mitchell 2013). The Corps’ WCSC collects and collates data from several sources concerning commercial use of US waterways (Mitchell 2011).
6. Access the commercial use of Automated Information System (AIS) data from navigating vessels and use for assessing cargo shipping flow through selected navigation channels. Abroad a vessel, AIS broadcast record transmits real-time vessel response to any condition. The AIS data presents new opportunities in performance-based management of waterway infrastructure (Scully and Mitchell 2013).
7. Develop shipping flow demand models using time series models (Uddin et al. 1985) and Artificial Neural Network (ANN) methods (Najjar et al. 2002).
8. Produce the following “best practice guide” examples for consideration by government transportation agencies, private transport operators, and all other stakeholders:

- a) Environmental impacts and benefits of freight intermodal integration studies using the results of reductions in shipping costs and Carbon Dioxide (CO₂) emissions.
 - b) Disaster risk assessment and resilience studies for selected port cities.
9. Promote transportation engineering workforce development by training graduate and undergraduate students and provide research work opportunities to the students from minority and underrepresented communities.

1.2 Project Accomplishments

Key outcomes and other achievements are summarized, as follow

1. This project developed geospatial maps of the Mississippi River waterway, inland ports and interconnecting surface transportation network.
2. Additional studies included synthesis of both surface and waterborne databases and commodity flow, optimization models, benefit/cost results of proposed modal integration studies, and life cycle economic evaluation and environmental impacts.
3. The availability of the AIS data broadcast by navigating vessels is a useful addition to historical spatial-temporal waterborne transport data. These data were acquired online to evaluate cargo vessel flow through selected shipping channels. The data sets are being used in doctoral research to develop marine navigational traffic flow demand and flow models.
4. Computer simulations of selected inland port(s) and surface freight corridor(s) with life cycle cost analysis provide the benefits of the intermodal integration approach for enhancing the economic competitiveness, safety, security and disaster resilience of freight transport infrastructure.
5. The developed models of freight intermodal corridor and marine ports were used to assess other societal benefits, which include reduction in highway traffic congestion, cost avoidance of millions of gallons of fuel wastage on congested corridors, decrease in transportation related emissions of carbon dioxide and other harmful pollutants, and economic competitiveness impacts on the affected cities and counties.
6. The intermodal freight corridor case studies and disaster resilience studies of selected port cities were used to develop “best practice guide” examples for consideration by government transportation agencies and supply chain stakeholders.
7. Training of undergraduate (UG) and graduate students in transportation network analysis and development of geospatial workforce are additional benefits.
8. Engineering e-newsletter published a brief overview of this NCITEC research projects and other projects (Appendix).

The project results were presented at regional and national meetings and published, as summarized in the following section, and disseminated through web posts and other online social media.

Education and Training of Workforce Development

All graduate students and several UG students took Dr. Uddin’s “Geospatial Course” in May Intersemester 2014 and 2015, and Spring 2015. Four PhD students, two MS graduate students, and several UG students working on the NCITEC projects took a “highway pavements” course taught by Dr. Uddin during Fall 2014. The graduate students were also taught a graduate level course by Dr. Uddin in Spring 2015 about optimization analysis using linear programming and advanced time series modeling. The students of the “highway pavements” course were taught about transportation infrastructure and life cycle analysis for asset management. Three UG senior students during 2014-2016 pursued M.S. degrees under Dr. Uddin’s supervision at the University of Mississippi.

Project staff used the computer stations and backup equipment installed in the CAIT Transportation Modeling and Visualization Lab at Ole Miss Jackson Center. This laboratory has now a statewide ITS surveillance monitoring equipment in cooperation with the Mississippi DOT. The student workers used new 2014 versions of GeoMediaPro geospatial software packs which were installed on all CAIT Lab computers.

Dr. Uddin directed the three assigned graduate MS students for data collection and geospatial mapping of multimodal corridors (highways, Mississippi River, and rail lines) for the state of Mississippi and the Gulf Coast counties. Two MS student (previously senior UG research assistant) continued working on this project creating geospatial maps and geospatial analysis of intermodal integration benefits using value engineering tools. Three PhD students and one M.S. student, supported by their government scholarship, also worked partially on the project. Total four PhD students, four M.S. students, and eight UG students were partially supported and trained on the project.

1.3 Results Dissemination and Outreach

UM School of Engineering Online

The University of Mississippi School of Engineering featured a full page story in July 2016 issue.

2016/07-ENGINEERING NEWS JULY 2016, ENGINEERING NEWS ARCHIVE, SCHOOL OF ENGINEERING

“UM Engineering Partnership Producing Problem-Solving Research

National Center for Intermodal Transportation for Economic Competitiveness funds projects”

<http://news.olemiss.edu/um-engineering-partnership-producing-problem-solving-research/>

Presentations to External Organizations

All three PIs were involved in outreach activities associated with the project results. Dr. Uddin participated in several international conference and other venues of invited lectures at

universities. The PIs presented the project highlights and key results to the visiting professors and professionals, at professional meeting, and in other on-site presentations:

August 1, 2016, Universiti Sains Malaysia (USM), Penang, Malaysia: Invited lecture "Natural Disaster Resilience of Public Infrastructure Assets." (Invited presentation by Dr. Uddin)

July 26-29, 2016, MAIREPAV8 International Conference, Singapore. Dr. Uddin was one of the welcome speakers and a session chair. He received the 2016 international iSMARTi achievement award at the conference.

July 21, 2016, Asian Institute of Technology (AIT), Bangkok, Thailand: Invited seminar presentation at AIT Workshop "Disaster Resilience Education Capacity Building in South-East Asia". (Invited presentation by Dr. Uddin)

April 3-5, 2016, The 2016 Critical Infrastructure Symposium, Tech Session 2B Infrastructure Protection and Resilience, The Infrastructure Security Partnership (TISP) and the Society of American Military Engineers (SAME), Charleston, South Carolina. (Dr. Uddin presented the NCITEC project results on floodwater impacts and a new disaster risk assessment methodology for municipal infrastructure assets.)

9 January 2016, Pavement Performance Data Analysis Forum, Sponsored by TRB Data Analysis Working Group (DAWG) at 95th TRB Annual Meeting, Washington, DC. (PhD student Jaafar, Zul Fahmi Mohamed and Dr. Uddin presented on Development of Asphalt Pavement Roughness and Rutting Models By Using LPP Database and Considering Maintenance and Rehabilitation History.)

9 January 2016, Pavement Performance Data Analysis Forum, Sponsored by TRB Bridge Data Analysis Working Group (Bridge DAWG) at 95th TRB Annual Meeting, Washington, DC. (Dr. Uddin presented research results of PhD student Alper Durmus on Assessing Structural Integrity Of Bridge Superstructure Subjected To Extreme Flood Simulation.)

September 14-16, 2015, 9th Congress and Exhibition – CBR&C 2015 and BRASVIAS 2015, Brazilian Association of Highway Concessionaires – ABCR, Brasília, Brazil. (Invited presentation, all expenses supported by the host. Dr. Uddin presented on Flood Modeling & Evaluation of Impacts on Infrastructure.)

April 20-21, 2015, The 2015 Critical Infrastructure Symposium, The Infrastructure Security Partnership (TISP) and the Society of American Military Engineers (SAME), Baltimore, Maryland. (Dr. Uddin presented on Extreme Flood Simulations to Assess Inundation Impacts and Structural Integrity of Transportation Infrastructure Assets.)

March 26-27, 2015, University Transportation Center (UTC) Conference for the Southeastern Region, University of Alabama at Birmingham, Birmingham, Alabama. (3 presentations by Uddin, 2 by graduate students Cobb and Durmus)

April 20-21, 2015, The 2015 Critical Infrastructure Symposium, The Infrastructure Security Partnership (TISP) and the Society of American Military Engineers (SAME), Baltimore, Maryland. (Dr. Uddin presented on Extreme Flood Simulations to Assess Inundation Impacts and Structural Integrity of Transportation Infrastructure Assets.)

January 29-31, 2015, Denver, Colorado: Dr. Sherry interacted with the rail stakeholders who are involved in his center's advisory panel. He will be soliciting stakeholder survey feedback at the OPERATION STIMULUS 2015 conference on January 29-31, 2015, organized by Denver Transportation Club, Colorado.

January 13, 2015, Washington DC: Dr. Sherry invited rail industry executives at the 2015 TRB annual meeting exhibit hall on January 13, 2015 to share the project results of rail-highway integration. Dr. Uddin presented the background on exhaustive commodity flow data analysis and key findings. Positive feedback was provided by the stakeholders and an implementation plan will be pursued by Dr. Sherry for Denver region.

January 10-14, 2015, TRB 94th Annual Meeting: Dr. Uddin presented research results of NCITEC 2012-25 project on numerical modeling and simulation of extreme flood inundation to assess vulnerability of transportation infrastructure assets (Durmus et al. 2015, Uddin and Altinakar 2015).

January 10-14, 2015, TRB 94th Annual Meeting: Mississippi DOT Research Division was invited and presented a poster on the 2014 AASHTO award of Sweet Sixteen projects won by the MDOT's roundabout project (Dr. Uddin was the project PI).

October 29-30, 2014: Acey Roberts, Mississippi DOT ITS Engineer and GRITS President, lectured both days about the video panel wall installed in CAIT Laboratory in collaboration with the MDOT. Visiting attendees of the winter workshop of the Gulf Region Intelligent Transportation Society toured the CAIT Transportation Lab on October 30. The workshop was held at the University of Mississippi Campus in Oxford, Oct 29-30, 2014. Dr. Uddin provided brief overview of the Lab facilities, the NCITEC projects, and history of the Lab evolution in cooperation with the Mississippi DOT Traffic Engineering Division as a part of the establishment of a model ITS Lab.

October 24-25, 2014: Dr. Uddin's teaching and research profile was compiled and presented at the annual banquet on 24th October in Austin, Texas to honor 2014 inductees of the University of Texas CAEE Academy of Distinguished Alumni where he received the award.

October 21, 2014: Dr. Uddin attended the annual board meeting as 2014 appointed member and the conference of the Mississippi Transportation Institute (MTI), in Convention Center, Jackson, Mississippi. He briefly interacted with State Senator and Representative who were the workshop speakers, the Mississippi DOT Executive Director, as well as, Chief Engineer, Bridge Engineer, Aviation Engineer, and Research Division engineers.

October 3, 2014: Dr. Lucy P. Priddy visited the Lab. She is Research Civil Engineer with the ERDC Airfields and Pavements Branch in Vicksburg, Mississippi. After welcome remarks by Dr. Uddin, Dr. Priddy reflected on her experience during her University of Mississippi years as one of the first UG RAs who worked on CAIT research projects during 1999-2002.

September 14-17, 2014: Dr. Uddin attended the ITS3C regional conference and presented overview of NCITEC projects and Gulf Coast rail study results. The conference was organized by the Gulf Region Intelligent Transportation Society (GRITS), the Intelligent Transportation Society of Florida (ITSFL) and the Intelligent Transportation Society of Georgia (ITSGA). The joint conference was held September 14-17, 2014 at the Arthur R. Outlaw Convention Center in Mobile, Alabama.

Collaboration

The PI collaborated with the following organizations, who provided support to the project team:

- Intergraph for continuing academic license of GeoMedia Pro at no cost to the University of Mississippi for use on CAIT projects (worth \$118,000 per year).
- As Intergraph Registered Research Lab, CAIT Remote Sensing and Geospatial Analysis Laboratory and CAIT Transportation Modeling and Visualization Laboratory is receiving geospatial industry support for education and training of students in GIS applications through the project research tasks.

This Intergraph software grant is a cooperative feature of this project. Since January 2014 the statewide license has been provided by MARIS. This software and ArcGIS software, provided by Mississippi Mineral Resource Institute, were used to create planimetrics of roads, bridges, and buildings from high resolution aerial imagery.

The following organizations were cooperative features for this project:

- 1) Mississippi Department of Transportation (MDOT): MDOT Roadway Design Division has been contacted for access to aerial imagery.
- 2) MDOT Planning Division through contact with Dr. Uddin's former student and EIT for accessing overlapping aerial imagery scenes of the study sites.
- 5) MDOT Transportation Information Director (Mike Cresap) and MDOT Director of Structures -State Bridge Engineer (Justin Walker) have been especially helpful to provide drawings and photos for the I-55/US-51 highway bridges in northern Mississippi and updated geospatial database of all state maintained highways and bridges of Mississippi. Photos of major highway bridges damaged during the 2005 Hurricane Karina disaster were also provided by the Bridge Division.
- 6) US Army ERDC Coastal & Hydraulics Lab, Vicksburg, Mississippi (Dr. Kenneth Ned Mitchell). Dr. Mitchell collaborated with member agencies of the federal Committee on the Marine Transportation System (CMTS), namely the National Oceanic and Atmospheric Administration (NOAA), the United States Coast Guard (USCG), and the US Department of Transportation's Federal Highway Administration (FHWA).

Workshop and Symposium

December 5, 2014 Workshop: "Extreme Flood Inundation Mapping and Risk Modeling of Transportation Infrastructure Assets." The workshop was opened to all by email invitations and

CAIT web page posting. It was held in NCCHE Conference Room, Brevard 3rd Floor, University of Mississippi Oxford campus. Presentations were made by Dr. Uddin, Dr. Altinakar (jointly with NCCHE researchers Marcus McGrath and Vijay Ramalingam), Alper Durmus, Quang Nguyen, with closing remarks by Dr. Altinakar.

1.4 Impacts on The Principal Discipline(s), Research Infrastructure, and Workforce

The project improved computing facilities, geospatial laboratory, geospatial software, and transportation corridor/traffic flow simulation capabilities.

- Enhancement of CAIT Transportation Modeling and Visualization Lab at off-campus location of Ole Miss Jackson Center was a major impact of the project. (An additional eight computer workstations and visualization equipment were procured using project funds and installed in CAIT Transportation Modeling & Visualization Laboratory in UM Jackson Center after approval by the DOT RITA sponsors.) These new computers and 6 old computers from CE Graphics Lab have been functioning fully since Fall 2013 after installation of geospatial software and other programs.
- The Lab is being used mostly to conduct research, offer geospatial UG and graduate courses, and train students in geospatial visualization and mapping technologies. New 2014 versions of GeoMediaPro geospatial software packs were installed on all CAIT Lab computers after creating full backup up of all project files and folders by project staff. The Lab is being used mostly to conduct research, offer geospatial UG/graduate courses, and train students in geospatial visualization and mapping technologies. The CAIT lab expanded recently with new high performance computer equipment, new computer furniture, large video monitor for presentations, and seminar/meeting tables, chairs, and accessories. The geospatial course has been taught in this facility since 2013 and most of the NCITEC project research work is conducted in this lab.
- The UM's CAIT Transportation Modeling & Visualization Lab (Figure 2) also houses a model ITS Laboratory (Figure 3). The Mississippi DOT's Intelligent Transportation System (ITS) section has been collaborating for many years with the University of Mississippi to provide traffic video display wall and extend the fiberoptic backbone to the JAC building and the CAIT Transportation Modeling & Visualization Laboratory facility in order to establish a model ITS lab. In October 2014 the CAIT Transportation laboratory was provided a video panel wall by the Mississippi DOT ITS section as a part of a model ITS lab to monitor real-time traffic flow on roads and barge under bridges over the Mississippi River. Since Fall 2015 the lab has been used for real-time traffic data collection and teaching UG for research use to monitor flow attributes by UG and graduate students.
- Dr. Uddin's NCITEC projects at CAIT supported 4 PhD students, 4 M.S. students, 5 UG Civil Engineering students, 3 UG non-engineering students, and 4 UG exchange students from Brazil and Mexico.

- New graduate and undergraduate CAIT student workers were trained for geospatial analysis and transportation demand modeling research. The contents of the Transportation and Geospatial course are enhanced using the NCITEC project products.
- It is expected that the research accomplishments will lead to a specialized transportation course and disaster mitigation and safeguard courses, as well as a trained geospatial workforce.
- The contents of geospatial courses CE495 and ENGR597 Section 25, taught by Dr. Uddin, were updated using the NCITEC project work. CE495 was offered in the 2014 May intersession. These courses were offered again in Spring 2015 and 2015 May intersemester. Beginning Spring 2017 a new section of CE495 will be offered by Dr. Uddin as regular UG technical course every year.
- Dr. Uddin incorporated research results in several transportation related courses, as follows:
 - The contents of geospatial courses CE495 (3 credit hours) and ENGR597 Section 25 (3 credit hours) updated using the NCITEC project work.
 - CE 481 – Transportation Engineering I (3 credit hours), every Fall semester
 - CE 495 – Geospatial Visualization for Engineering Applications (3 credit hours)
 - CE 570 – Infrastructure Management (3 credit hours), Fall 2013 and Fall 2014
 - CE 585 – Highway Pavements (3 credit hours), Fall 2014
 - CE 590 – Airport Planning and Design (3 credit hours) , Fall 2015
 - New course ENGR 692 Section 2 (3 credit hours) – Numerical Methods for Optimization and Nonlinear Time Series Modeling, Spring 2015
- CE 570 course was offered by Dr. Uddin in Fall 2013 and Fall 2014. It is being taught in Fall 2016 to UG seniors and graduate students. The textbook for CE570 course was 2013 McGraw-Hill book *Public Infrastructure Asset Management* (Uddin, Hudson, Haas).
- CE495 (Geospatial Visualization for Engineering Applications) will be offered by Dr. Uddin as regular UG technical course every year starting in Spring 2017 semester.
- It is expected that the research accomplishments will lead to a specialized transportation course and disaster mitigation and resilience management course, as well as a trained geospatial workforce.

Students Supported and Degrees Completed

The project supported the following graduate and undergraduate students: 4 PhD, 4 M.S., 8 UG. Additionally, four exchange UG students (Two from Brazil and two from Mexico) contributed to the project.

Graduate students who received project funding and completed degrees: 1 PhD, 2 M.S. Ahlan, M., (M.S. 2014); Cobb, Seth (M.S. August 2015); Durmus, Alper (PhD August 2016) Richardson, Robert C. Jr. (M.S. December 2016) expected; Nguyen, Quang (PhD May 2017) in progress.



Figure 2. UM’s CAIT Transportation Modeling & Visualization Lab, JAC 102, Oxford, MS



Figure 3. Model ITS Laboratory (video wall for accessing statewide traffic video network)

The project had a significant impact on transportation workforce development. For example, the project:

- Provided opportunities to UG students, Master’s and Doctoral graduate students, other participating specialists for research in transportation management of commodities, supply chain logistics, intermodal network optimization, geospatial visualization, and related disciplines.
- Enhanced intermodal transportation education by supporting graduate and UG students. Led four PhD graduate students, four M.S. students, and eight UG students to work on project related assignments at UM. Some of them completed their course projects on project related topics.
- Supported one M.S. student to complete his graduating research report in December 2014 by using his geospatial and CO₂ prediction results accomplished in passenger train and freight mobility projects. He implemented the research framework to his own country, Indonesia, by analyzing traffic related emissions and impacts of the loss of tropical forest cover on CO₂ production.
- Supported one more M.S. student and one PhD student to complete M.S. thesis (August 2015) and doctoral dissertation (July/August 2016).
- Improved the performance and modern computer modeling and visualization skills of main stream professionals and members of underrepresented groups (minority students)

that will improve their access to or retention in transportation research, teaching, supply chain management, or other related professions.

- Developed and disseminated new educational/training materials and provide exposure to transportation, science and technology for practitioners, public works professionals, teachers, young people, media, supply chain stakeholders, and general public. This has been accomplished through geospatial workforce training in the teaching lab, classroom, tweets, YouTube videos, and SlideShare presentations.
- Involved the Student Chapter of the Institute of Transportation Engineers (ITE) and both graduate and undergraduate transportation students in project activities. A major goal to support undergraduate students is to motivate them to pursue graduate studies in transportation systems and professional careers in transportation engineering discipline.
- Enhanced information resources and electronic means through CAIT web pages, news interviews by journalism students, YouTube video and SlideShare production, blog posts, tweets, and scientific papers.
- Continued tweeting about related topics. The Twitter social media has proven highly effective to access the latest research efforts and studies by transportation and logistics industry organizations.
(Over 16,000 SlideShare views of 9 presentations on transportation and infrastructure and over 9,000 views of project related YouTube videos.)

1.5 Website(s) or other Internet site(s)

Web Site, Social Media and Online Postings

UM CAIT web page: <http://www.olemiss.edu/projects/cait/ncitec/>

The NCITEC project tab on the University of Mississippi CAIT web site, linked to Mississippi State web site, provides useful background of NCITEC goals, university partners, and UM project summaries.

Blog: <http://infrastructureglobal.com/> Dr. Uddin's blog about infrastructure and natural disasters.

SlideShare: Over 16,000 SlideShare views of 9 presentations. Recent SlideShare presentation were posted, based on 2014 workshop presentations, 2015 and 2016 conference presentations, . <http://slidesha.re/1CiiDn> Other slide presentations were posted on "NCITEC Projects at CAIT." <http://www.slideshare.net/waheeduddin/uddin-trb201513-janflooddisastersshare>
<http://www.slideshare.net/waheeduddin/university-of-mississippi-ncitec-cait-projects-news>

Twitter: <https://twitter.com/drwaheeduddin> Started in January 2012; several lists and "Global Infrastructure" timeline created; over 22,500 tweets to date.

YouTube Videos: Over 1,680 views of project related seven YouTube videos were reported. <http://youtu.be/8JjM2QEexFE> <https://youtu.be/8JjM2QEexFE>

2. INTERMODAL INTEGRATION AND OPTIMIZATION OF FREIGHT CORRIDORS

2.1 Geospatial Analysis of National and Global Multimodal Freight Infrastructure

Geospatial Visualization of Multimodal Freight Infrastructure and Commodity Flow

Geospatial visualization of infrastructure features and attributes are imperative for spatial mapping and meaningful spatial analysis. This requires the use of geospatial software, such as GeoMediaPro (Intergraph 2013) for planimetric analysis of spaceborne satellite imageries and/or aerial photo and digital images (Uddin 2011) for the area of interest (AOI). Detailed description and examples are discussed in a previous report of NCITEC Project 2012-27 (Uddin et al. 2016). Figure 3 shows an example of a spatial map of NAFTA countries showing all major border posts on the north and south borders of the United States which are gateways to overland freight corridors (NAFTA 2012).

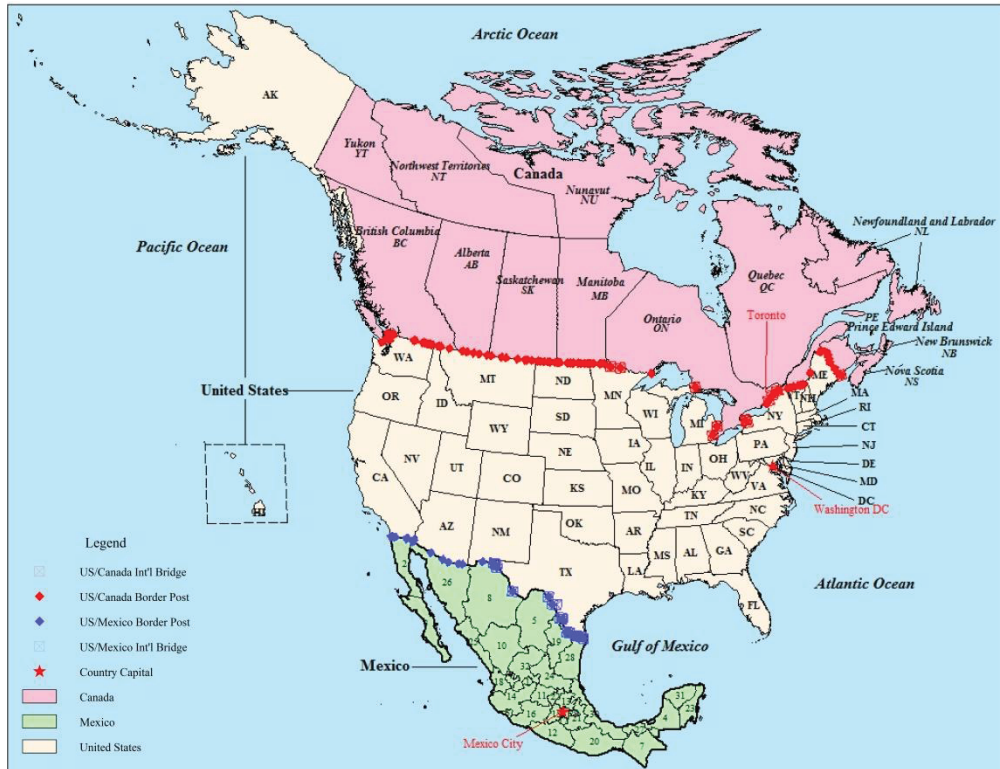


Figure 4. Spatial Map of NAFTA Countries shown Border Post Locations

Sustainable Global Supply Chain, Logistics, and Freight Transport Stakeholders

The global supply chain network is made up of manufacturing facilities (in country, offshore, and abroad), transporters, suppliers, logistics, distributors, storage facilities, and retailers. Figure 5 shows a general schematic of how the supply chain works (Oblates 2015, Seth 2015). All goods that are bought, consumed, or manufactured in the U.S. at some point will be transported

by truck. Freight logistic in the United States values about a trillion dollars or about 10% of the U.S. Gross Domestic Product (GDP) (NCFRP 2012a). Figure 6 shows the U.S. domestic freight shipment by mode in 2007 with 72% freight shipped by trucks that reduced by 5% in 2012. Figure 7 shows the domestic shipment distribution by mode in 2012, which shows 67% shipped by trucks nationwide, followed by 10% rail shipment. A national study through National Center for Intermodal Transportation for Economic Competitiveness (NCITEC), 2012-2014 sustainable intermodal integration supply chain project, stated that the road and rail surface modes of freight transportation encourages economic competitiveness in the U.S. (Uddin et al. 2015). However the efficiency of surface mode of freight transportation is fading out because the system reached its capacity. The study identified that trucks are the dominant modes of freight transportation. In the state of Mississippi, about 84% of the freight was moved by trucks (Uddin et al. 2016).

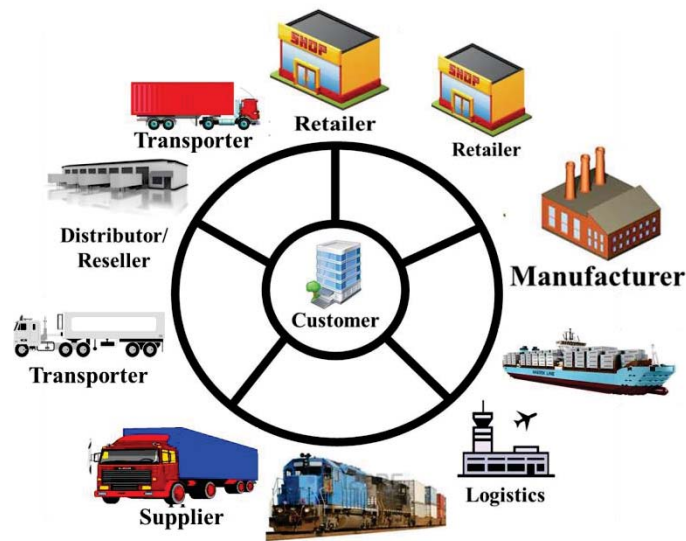
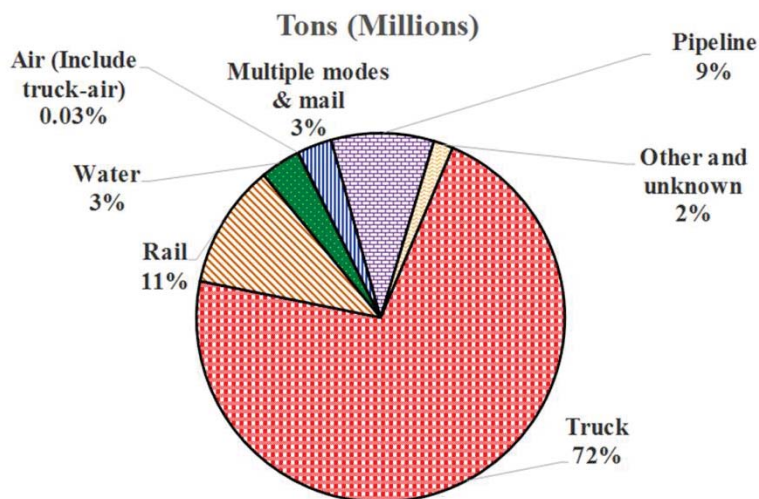


Figure 5. Global Supply Chain Network, After (Oblates 2015)



2007 Total Freight Shipments = 18,579 Million Tons

Figure 6. U.S. Domestic Freight by Mode, 2007

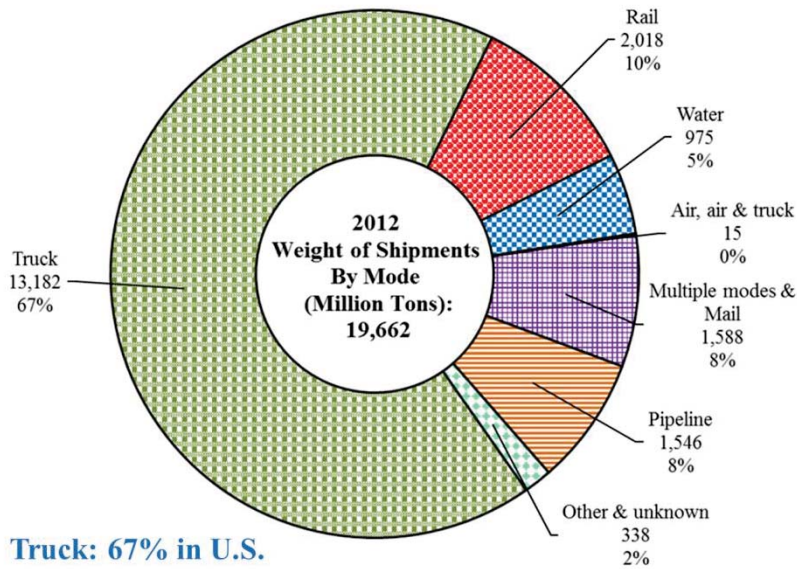


Figure 7. U.S. Domestic Freight by Mode, 2012

The USDOT’s FHWA provides a perspective on freight congestion; “the American Trucking Associations have documented that if truck movement stopped in American, within 24 hours, service stations would begin to run out of fuel, manufacturers would develop part shortages, and U.S. mail and package deliveries would cease, putting thousands of Americans out of work (FHWA 2006). For freight companies in the U.S., congestion is diminishing productivity and is increasing the cost of transportation services. These increased costs can come from higher fleet operation costs, decreased fleet utilization, a decrease in fuel efficiency of the fleet vehicles, and decreased hours of service for truck drivers.

Highway traffic congestion resulting in increased trip times and late deliveries can have major economic implications. Because of the reliability of the components that make up the supply chain network, a ripple effect may occur that adds costs at every component in the supply chain (FHWA 2006). As the population of the U.S. continues to grow, the demand for goods and services continues to increase. This in turn is increasing the number of freight trucks being operated on highways, which is increasing congestion, primarily at bottlenecks, and decreasing efficiency of the service. This congestion is most notable at urban areas with higher population having a higher demand for goods. The cost of this congestion to the economy is becoming too high. More investment must be made in finding solutions to truck freight congestion on the U.S. highways, whether it is expanding infrastructure or exploring alternative modes (UWISC 2015). Therefore, there is a need to look into integration of multiple freight transportation modes, instead of relying only on single mode of transportation such as freight trucks.

Intermodal integration can increase the efficiency of freight transportation, including the integration of freight transported by trucks to waterborne freight shipment. Previous NCITEC Project 2012-27 results showed by diverting 30% of freight trucks from the port of Gulfport to the integrated Mississippi River corridor, lower operating cost was calculated. For base case scenario, where 100% of the commodity was transported by trucks, the cost was 2.6 times higher compared to a scenario with 30% of the freight moved by barge. Additionally, the travel time is reduced by almost 33%, which resulted in lower CO₂ emissions as well (Uddin et al. 2016). Therefore, intermodal integration and optimization of surface and waterborne freight transport is an important consideration for sustainable supply chain.

Overview of U.S. International Trade and Freight Transportation by Mode

In today’s global economy, the international trade overwhelmingly involves freight shipment by waterborne cargo vessels. Waterborne shipment was 58% of all U.S. inbound trade in 2011 (Figure 8), followed by 14% by pipeline, 13% by truck, and 13% by rail. Recall, Canada and Mexico are among the largest trade partners with the U.S. and both have land borders as shown in Figure 4. Figure 9 shows that by trade merchandise value, 47% waterborne shipment was still the largest share among all freight modes.

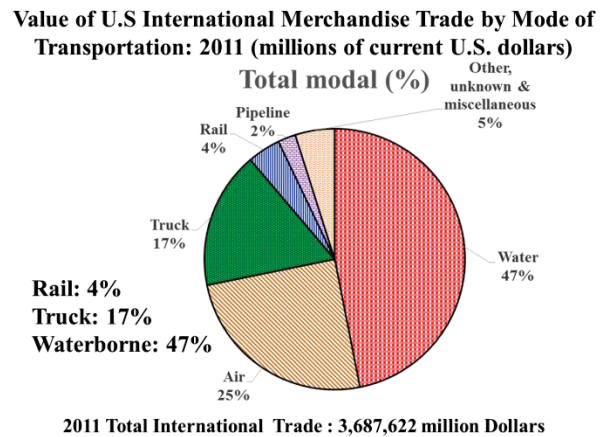
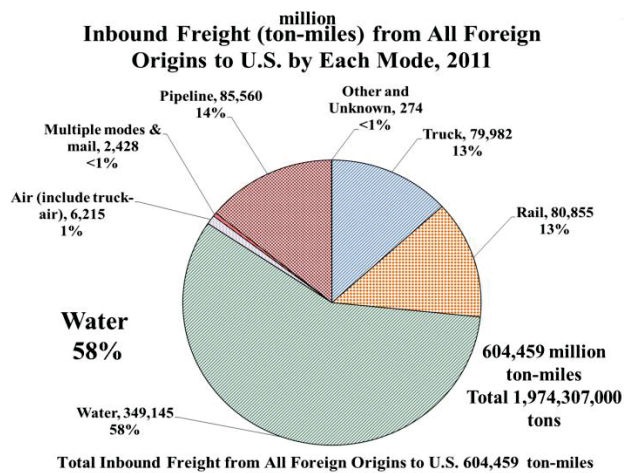


Figure 8. Left: International Inbound Trade Freight Shipment by Mode, 2011

Figure 9. Right: International Trade Merchandise Value by Mode, 2011

The international trade freight of U.S. includes NAFTA partners, Canada and Mexico. This data is synthesized in detail by Uddin et al. (2016) and shown in Figure 10. Canada traded 95% with the U.S. and 5% with Mexico in 2014. Mexico traded 96% with the U.S. and only 4% with Canada. The U.S. traded 57% with Canada and 43% with Mexico for total \$1,251 billion annually. It is estimated by (@TheWilsonCenter that “Every minute of every day, the US trades \$2.4 million with Canada and Mexico” (Wilson Center 2014).

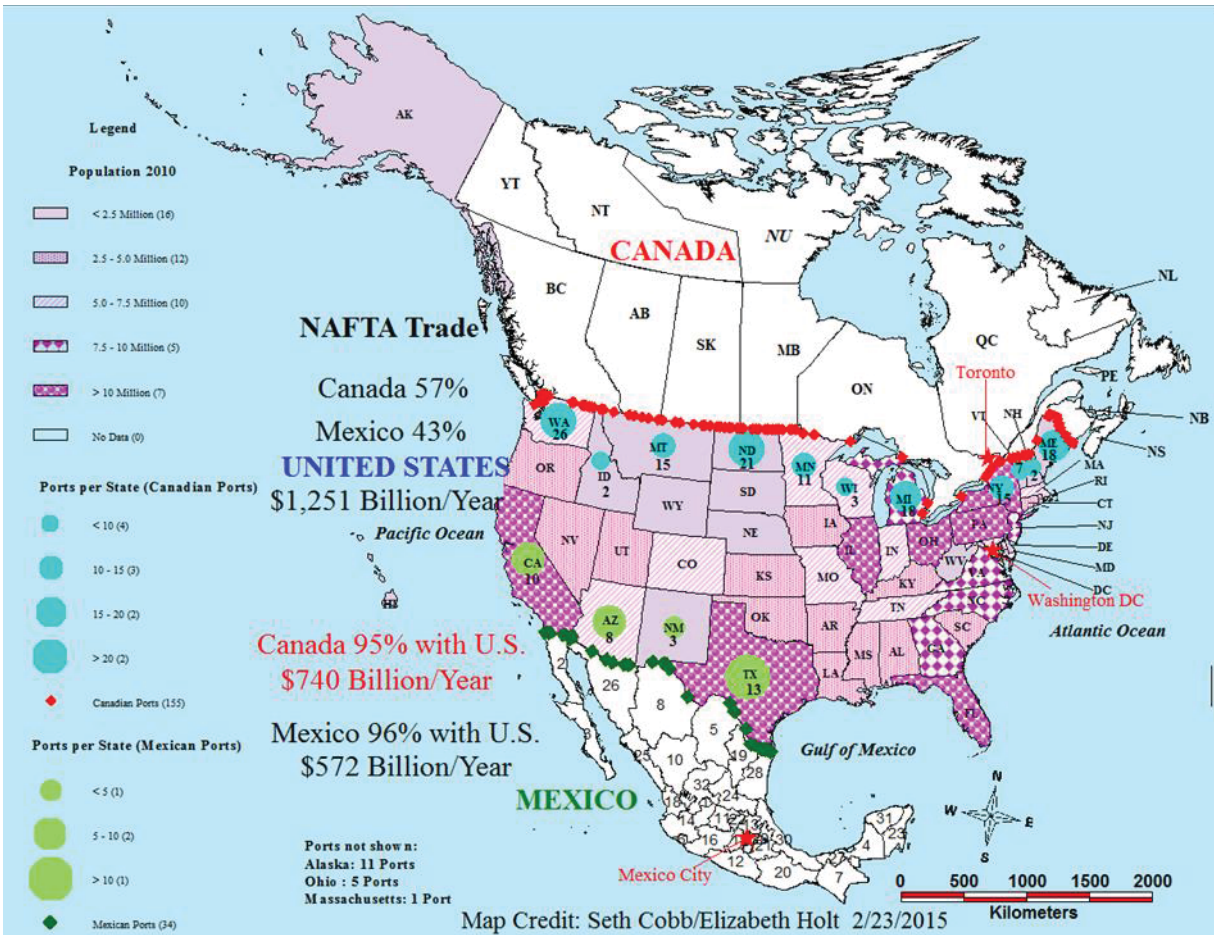


Figure 10. Spatial Map of NAFTA Countries and Trade Merchandise Value, 2014

Synthesis of Commodity Data Flow within United States

In the U.S., domestic freight movement either from an origin state or within the state itself was recognized as one of the factors that ensure nation's economic competitiveness and well-being of the nation and its people. Currently, the efficient, safe, and secure freight shipments from the origin and destination points, greatly depends on both surface (highway and rail) and waterway systems for freight shipments. The freight movement used either single or multiple modes of transportation, depending on the location of the final destination points. Detailed commodity flow data by state has been synthesized by Uddin et al. (2016). Only selected highlights of the 2012 commodity flow survey data in the U.S. (Census 2014) are presented in this section.

- Five single modes of transportation include (1) truck, (2) rail, (3) water, (4) air, and (5) pipeline.
- In contrast, the multiple modes shipment used the U.S. postal service or courier, truck and rail, truck and water, rail and water, and combination of multiple modes.
- Commodities in the U.S transported using single modes were about 96.5 % of a total of 11,299,409 tons.

- Transportation by multiple modes of transportation was only 3.2%, and about 0.3% of the commodities were transported by other modes.
- Freight trucks were dominantly used as the main mode of transportation.
 - About 71.3% of total tons of commodities in 2012 were transported by trucks, followed by rail (14.4%), water (5.1%), and
 - Approximately 10% of the freights were transported using multiple modes.

The above database shows that 67% of the commodities were shipped by freight trucks (Figure 7). Another study described that approximately 68% of total tonnage of commodities in 2012 were transported by trucks (Liao 2014).

The 2012 commodity flow survey was conducted for different commodity types, grouped by specific Standard Classification of Transported Goods (SCTG) codes. Figure 11 shows the top 10 commodities from Mississippi to other states. The commodity flow survey included a total of 42 commodities characterized by two-digit codes. Figure 12 shows percentages out of total tons for top five commodities in 2012. A total of 11,299,409 short tons of commodities were identified for commodity shipment within the U.S market. The total tons for the top five commodities are almost half of total weights for all 42 commodities. Gravel and crush stone (excluding dolomite and slate) was identified as the highest 2012 total commodity shipment in the U.S (14%). Gasoline, aviation fuel, and ethanol, was the second highest commodity which is 3% less than the highest commodity tonnages. Coal was 9% out of the total weight of commodities transported within the U.S. On the other hand, fuel oils and nonmetallic mineral products shared the same percentages of 7% out of approximately 11.3 million short tons of total commodities in 2012 (Census 2014).

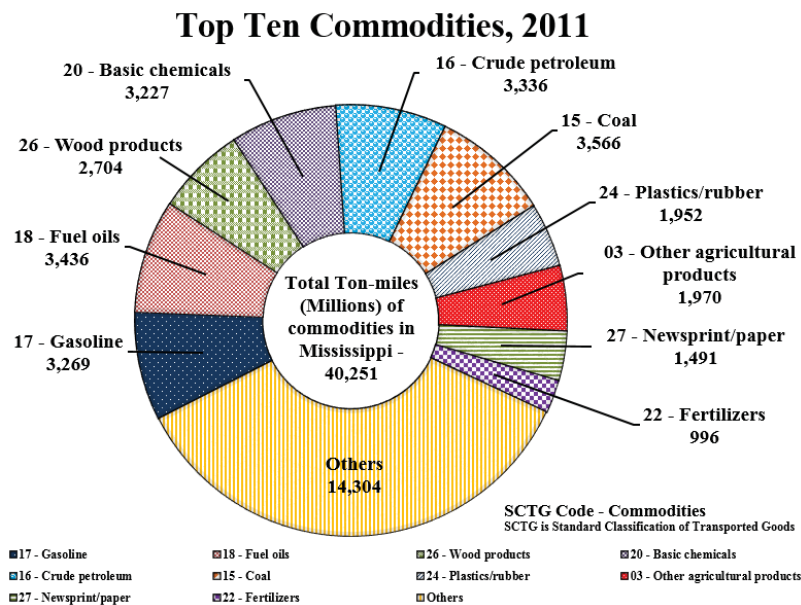


Figure 11. Top 10 Commodities from Mississippi to Other States, 2011

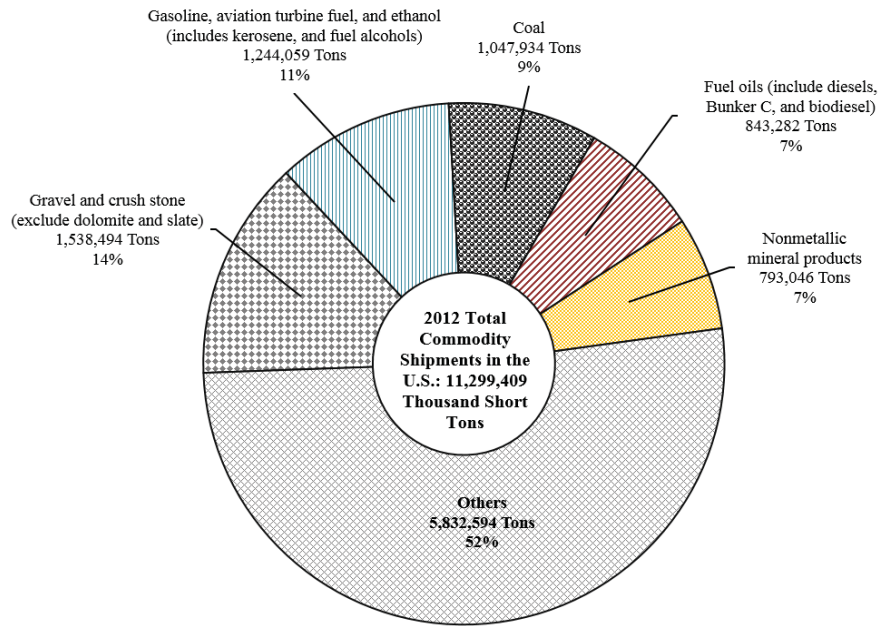


Figure 12. Top Five Commodity Shipments in the U.S, 2012

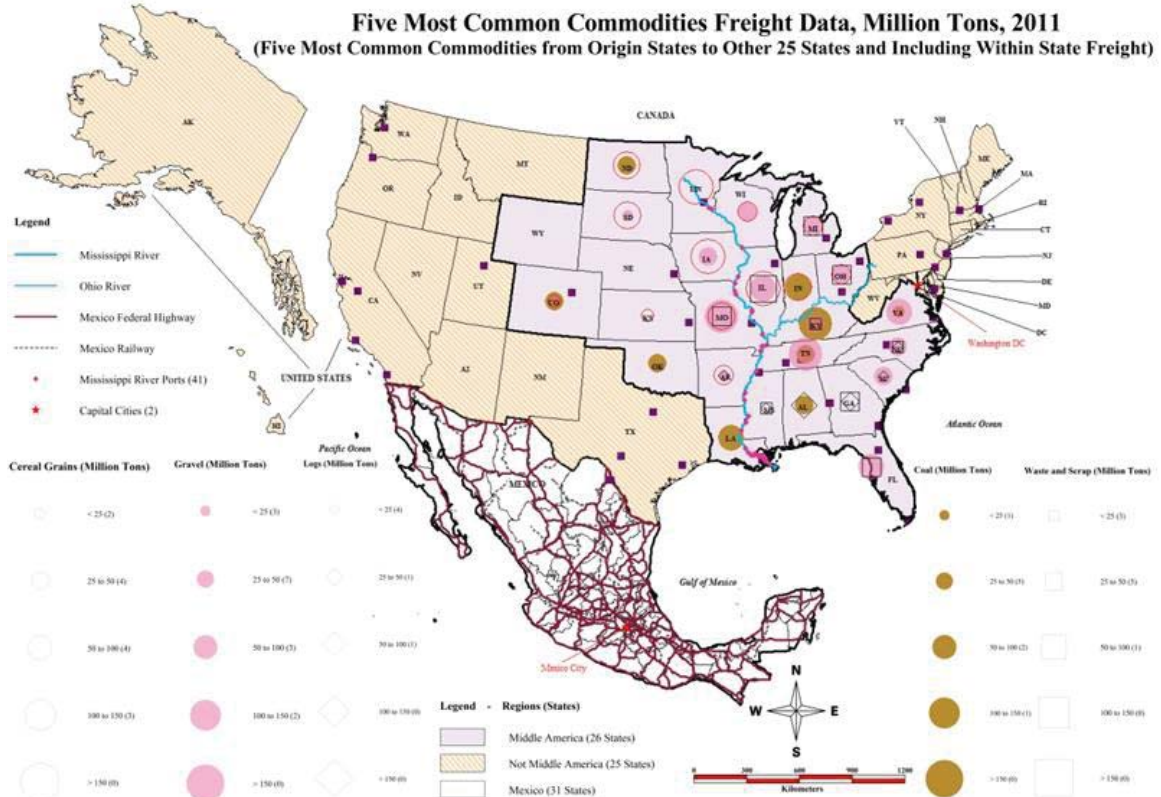


Figure 13. Spatial Map of Top 5 Commodities Flow From The Middle America States

Figure 13 shows a spatial map of the distribution of top five commodities by state. The top five commodities within the U.S were further studied to look into modes of transportation used to

transport the commodity. Out of 1,538,494 short tons of gravel and crush stone, 89.4% of the commodity was transported using trucks. About 4.7% of gravel and crush stone was transported by rail, 3.3% of the commodity was shipped via waterways. Additionally, only 1.3% was transported using both truck and rail. A combined trucks and waterway freight modes of transportation recorded only 0.8%, and a very small percentage of 0.1% of the commodity was shipped using both rail and water transportation modes (Census 2014).

The second highest commodity (gasoline, aviation fuel, and ethanol) also showed that trucks were dominant mode of transportation with 64.4% out of 1,244,059 short tons. About 27.6% of the commodity was delivered using pipeline. The rail and water modes of transportation showed 1.7 and 5.5%, respectively. Only 0.7% of the commodity was transported using both truck and waterway systems.

In general, the freight transportation relies heavily on trucks, compared to other modes. It is estimated that truck freight share will increase by more than four times from 2007 to 2040 (Figure 14). On a positive side, this scenario indicates that there is a chance to improve the efficiency of freight transportation by increasing the percentages of freight transported by multiple modes, for example, truck and waterway. Therefore, the integration between truck and waterway modes of freight transportation was discussed in this report. The analysis indicated that the integration between these modes of transportation benefited the community through much lower CO₂ emissions, lesser travel time to deliver commodity from origin to destination points, and lower ton-mile costs per year.

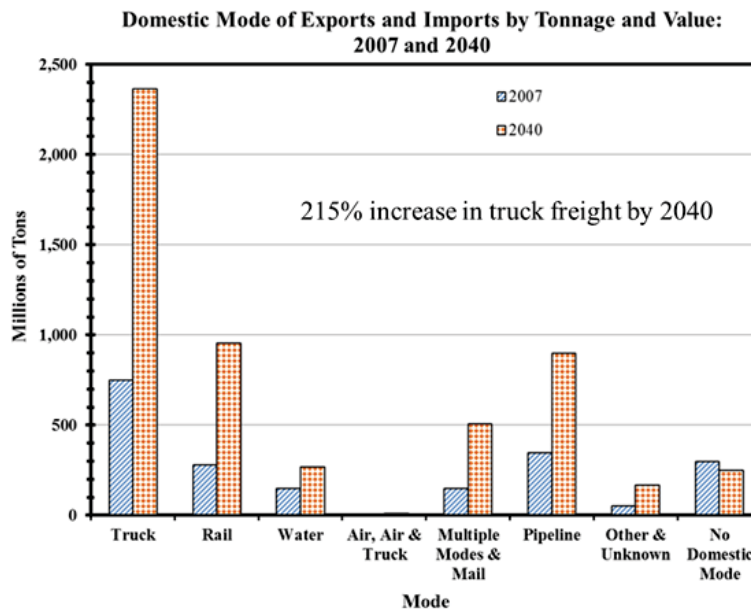


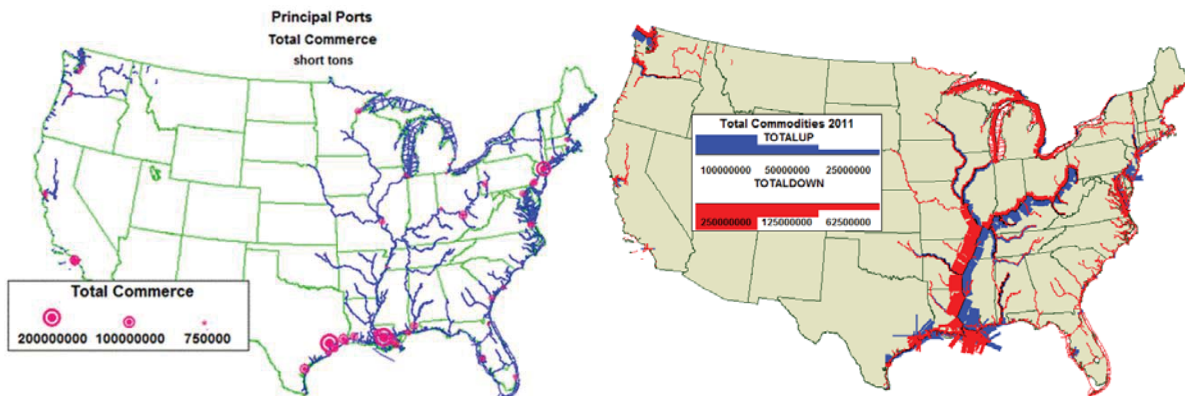
Figure 14. Domestic Shipments of Inbound and Outbound Freight Tonnage by Mode for 2007 and 2040

Current Status of Multimodal Freight Infrastructure and Operations

Waterways and River Ports

The four transportation modes (shipping port, aviation, rail, and highway) are owned and operated by different entities in the U.S. For example, shipping channels are mostly maintained by the US Army Corps of Engineers/ERDC (Figure 15). Inland waterways like Mississippi River (Figure 16) need annual funding for dredging operations and maintaining locks and dams for bulk barge traffic. Realizing the critical role of waterways to reduce traffic congestion and CO₂ emissions, the U.S. DOT has initiated “marine highway” classification for inland waterways and coastal navigation channels, as discussed in a recent TRB report (NCFRP 2010). The NCFRP report identifies the following North American Marine Highway (NAMH) data for the United States (NCFRP 2010):

- There are 20 NAMH operations serving coastal ports, harbors, and inland waterway ports. Their operation histories is presented in the following summary:
 - 2 Operations began in 1932 and 1950
 - 5 Operations began during 1951 and 1990
 - 5 Operations began during 1991 and 2000
 - 8 Operations began after 2000
- Inland waterways barges and vessels used for inland waterways and rivers can handle 80 to 250 Twenty Foot Equivalent Unit (TEU) containers.
- Inland waterway vessels which transport up to 30 trucks (Detroit-Windsor Truck Ferry).
- Inland waterway vessels which transport up to 16 truck trailers and 219 TEU containers (Great Lakes Feeder Lines).
- Ocean barges and ships operations can handle 219 to 2,824 TEU containers.
- Average speed range about 8 to 20 kn per hour.



Sources: <http://www.navigationdatacenter.us/ports/ports.asp>

<http://www.navigationdatacenter.us/lpms/lock2012webunavail.htm>

Figure 15. Principal Ports (left) and Commodity Flow Map for Waterways (right)

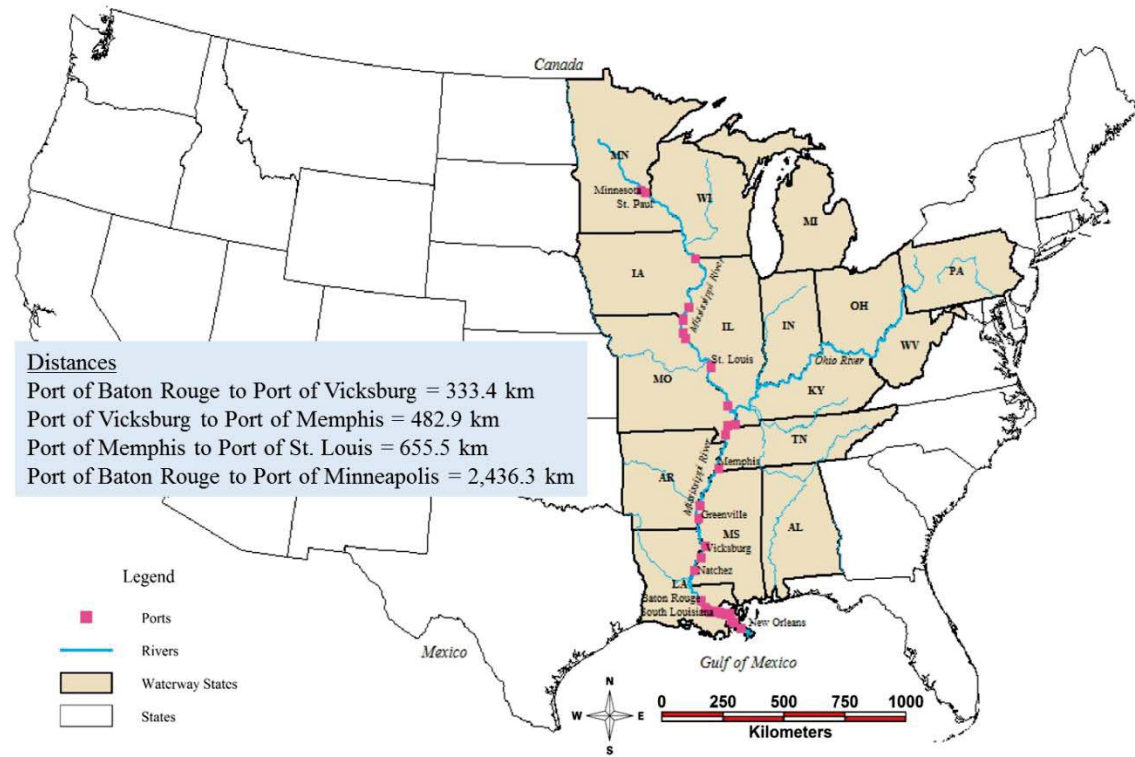


Figure 16.

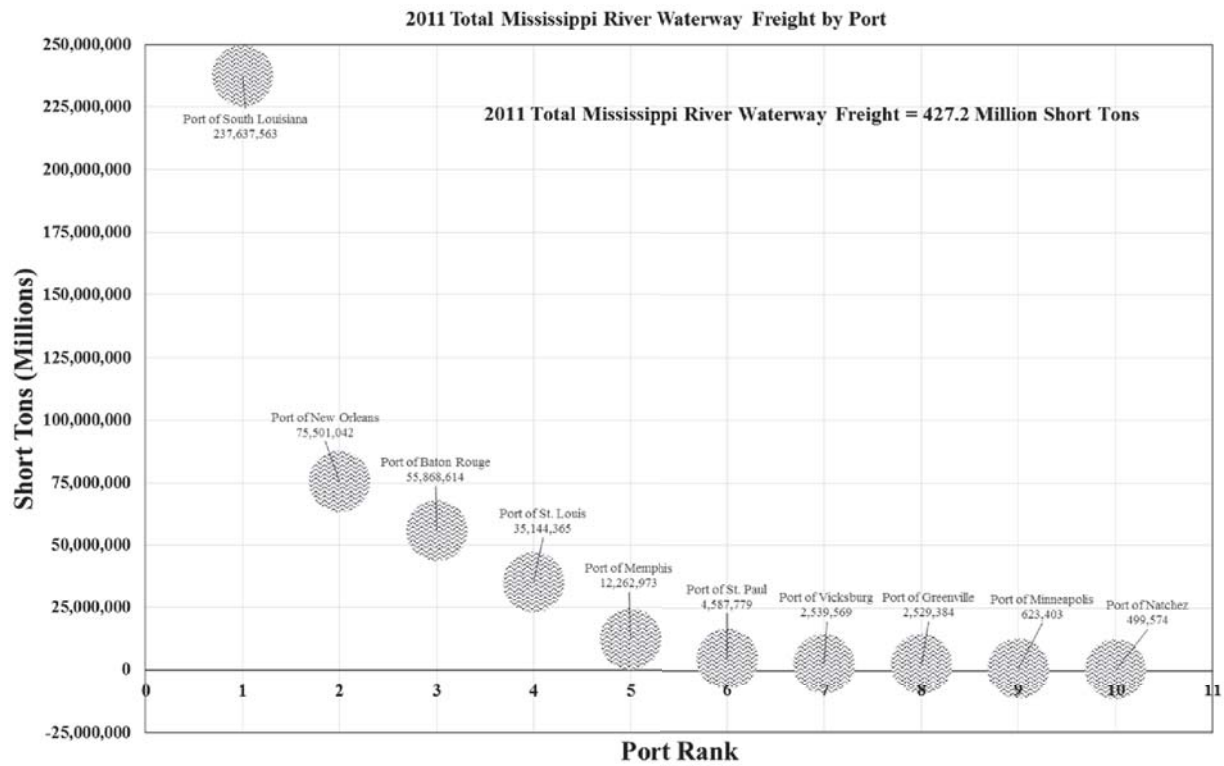


Figure 17. Freight Shipped by Barges through Mississippi River Ports, 2011

Sea Ports

The U.S. ports are owned by local government bodies. Figures 18 to 21 show spatial maps of major ports in the U.S., Mexico, and Brazil. These are major trading partners with shipping traffic from Far East Asian countries in the Pacific Ocean and from Europe, Africa and Asian countries through Atlantic Ocean. Figure 21 shows top 50 ports in the world (AAPA 2012). Ports are generally revenue producing operations unlike highway networks. Despite being publicly owned ports are largely operated by private companies who lease space from municipalities and port authorities. In addition, the on doc labor is provided most frequently by longshoremen of the ILWU. Ports needs funding to upgrade for intermodal infrastructure and modern container ships designed for 8,000 or more TEU containers.

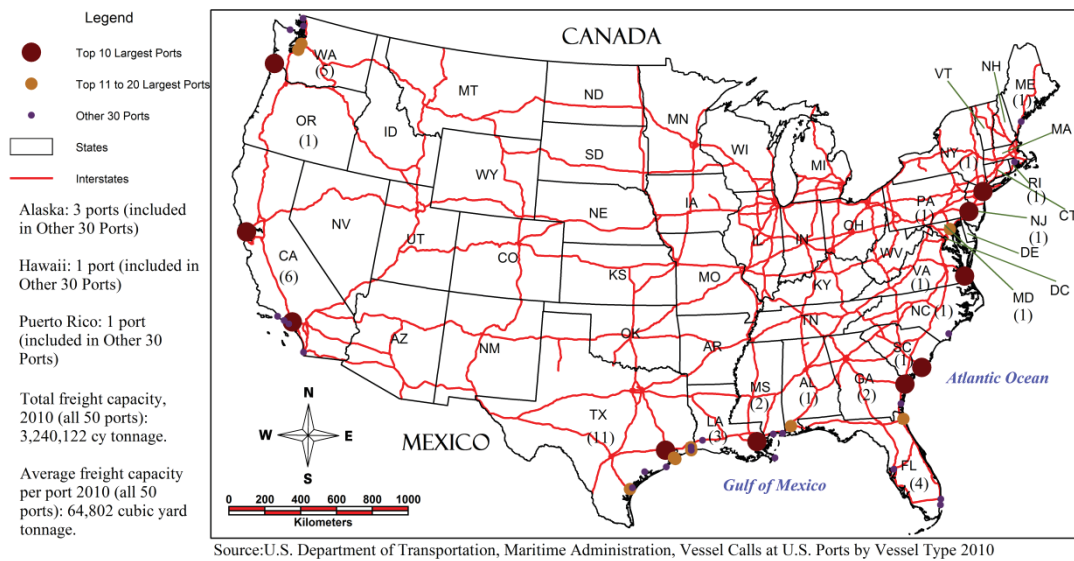


Figure 18. Spatial Map of Top 50 Major Ports and Interstate Highways in the U.S., 2010

Figure 19 shows the top 50 ports in the United States and the top 40 ports in Mexico. Based on this figure, there are 12 ports in the United States with more than 80 million DWT capacity, including: 1-Houston, TX, 2-Los Angeles/Long Beach, CA, 3-New Orleans, LA, 4-New York/New Jersey, NY and NJ, 5-San Francisco, CA, 6-Virginia Ports, VA, 7-Savannah, GA, 8-Columbia River, OR, 9-Philadelphia, PA, 10-Charleston, SC, 11-Baltimore, MD, and 12-Galveston, TX.

As shown in Figure 19, there is one port in Mexico with 40 to 80 million metric tons, and three ports with 20 to 40 metric tons, including: 1-CAYO ARCAS, 2-COATZACOALCOS, 3-LAZARO CARDENAS, and 4-MANZANILLO, respectfully.

The numbers shown below the state names represent the number of top ports in each state. The state of California ranks the highest, with 6 out of 50 top ports in the United States. The state of Washington ranks second, with 5 out of 50 top ports in the United States.

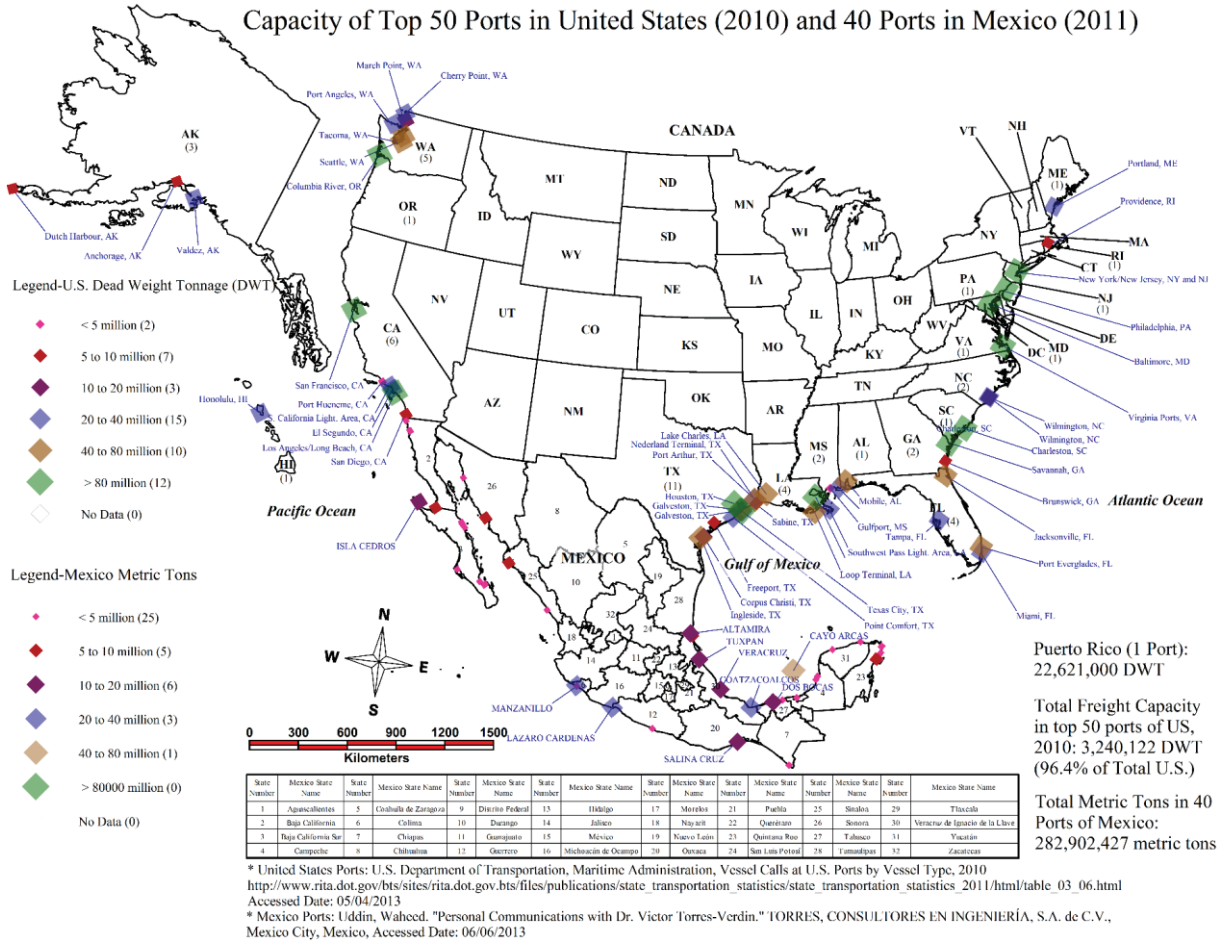


Figure 19. Capacity of Top 50 Ports in United States (2010) and 40 Ports in Mexico (2011)

South America Spatial Map of Amazon Rainforest and China's Proposed Rail Corridor



Figure 20. Spatial Map of Brazil's Amazon Region and Ports in the Northern Area

Brazil is a major trading partner with the U.S. Figure 20 shows the Amazon region and ports in Northern areas which provide bulk raw materials like Bauxite to extract Aluminum, as well orange juice to the U.S. Brazil's states and inland ports and other major ports are shown in Figure 21.

Brazil Inland Port by States, 2015

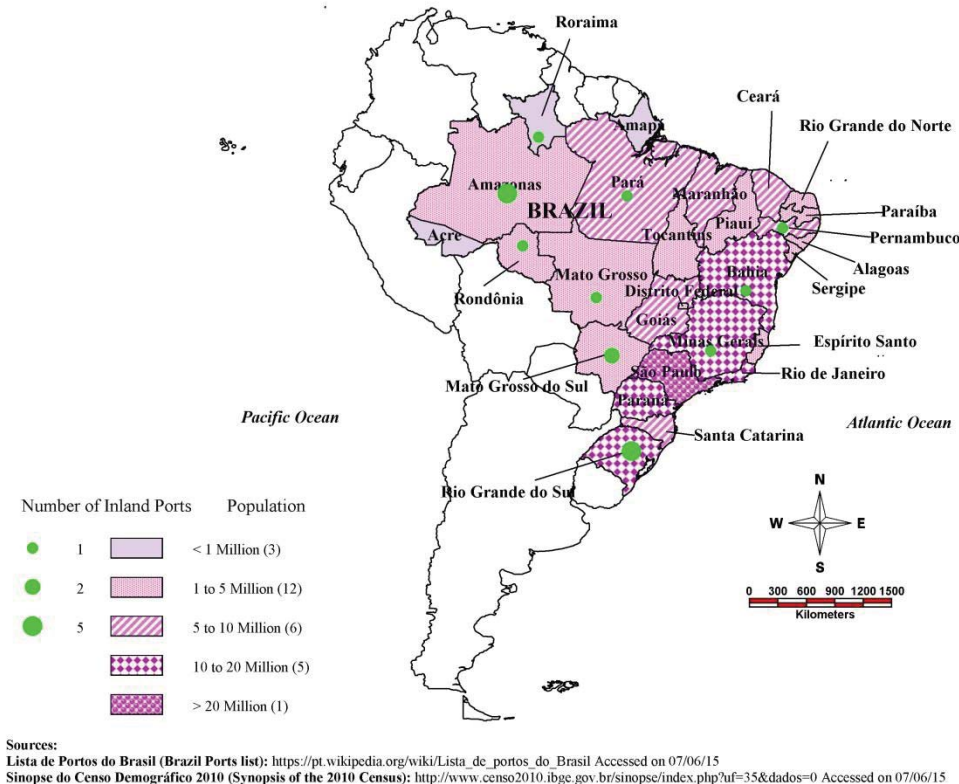


Figure 21. Spatial Map of Brazil's States and Inland Ports, 2015

Although ranked 50th in terms of deadweight capacity, the Port of Gulfport on Mississippi Gulf Coast is the second largest importer of green fruit in the United States and the third busiest container port on the U.S. Gulf of Mexico (<http://www.shipmspa.com/cargo.htm>). Figure 22 shows the freight type processed at the port in 2012 and commodity receipts and shipments are shown in Figure 23. In 2011 the Port of Gulfport handled more than 2.2 million tons of cargo, in excess of 216,000 TEUs with 80 percent of the containers moved by trucks. Recent news about exporting lumber from Mississippi to Europe is noteworthy in view of its economic impacts and the port expansion taking place at Gulfport. Imagine congestion and safety risks to other vehicles if loads of lumber truck trailers speed on Mississippi roads to the port. The use of freight train to carry these bulk exports loads from selected collection points (intermodal terminals) makes this freight operation more economical and safe. As learned at the 2016 Railroad Academic Conference (TRAC) and field visit (AREMA 2016), the trucking industry and rail stakeholders

cooperating for increased intermodal integration. This effort is increasing more efficient transport of containers on long haul rail routes, while increasing the share of short haul trucks.

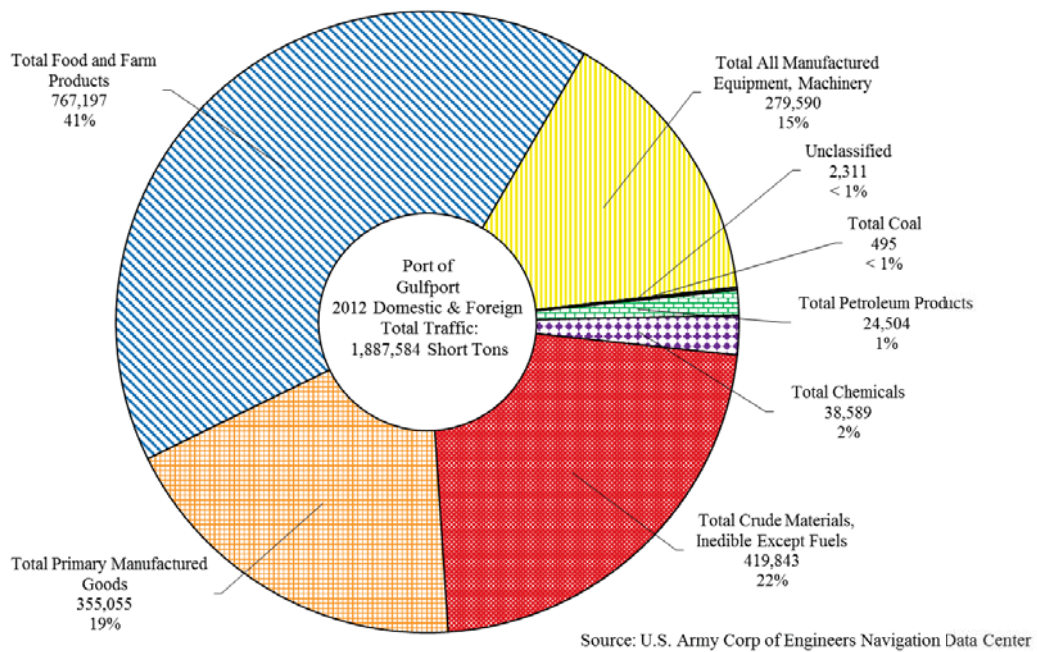


Figure 22. Commodity Type Distribution at Gulfport Port, 2012

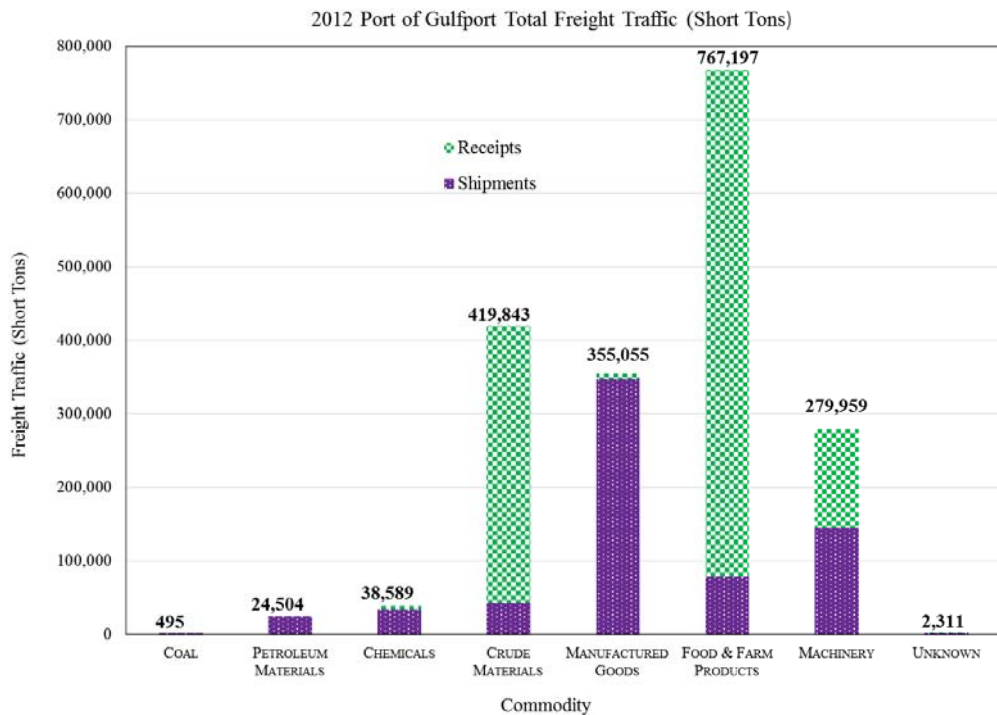
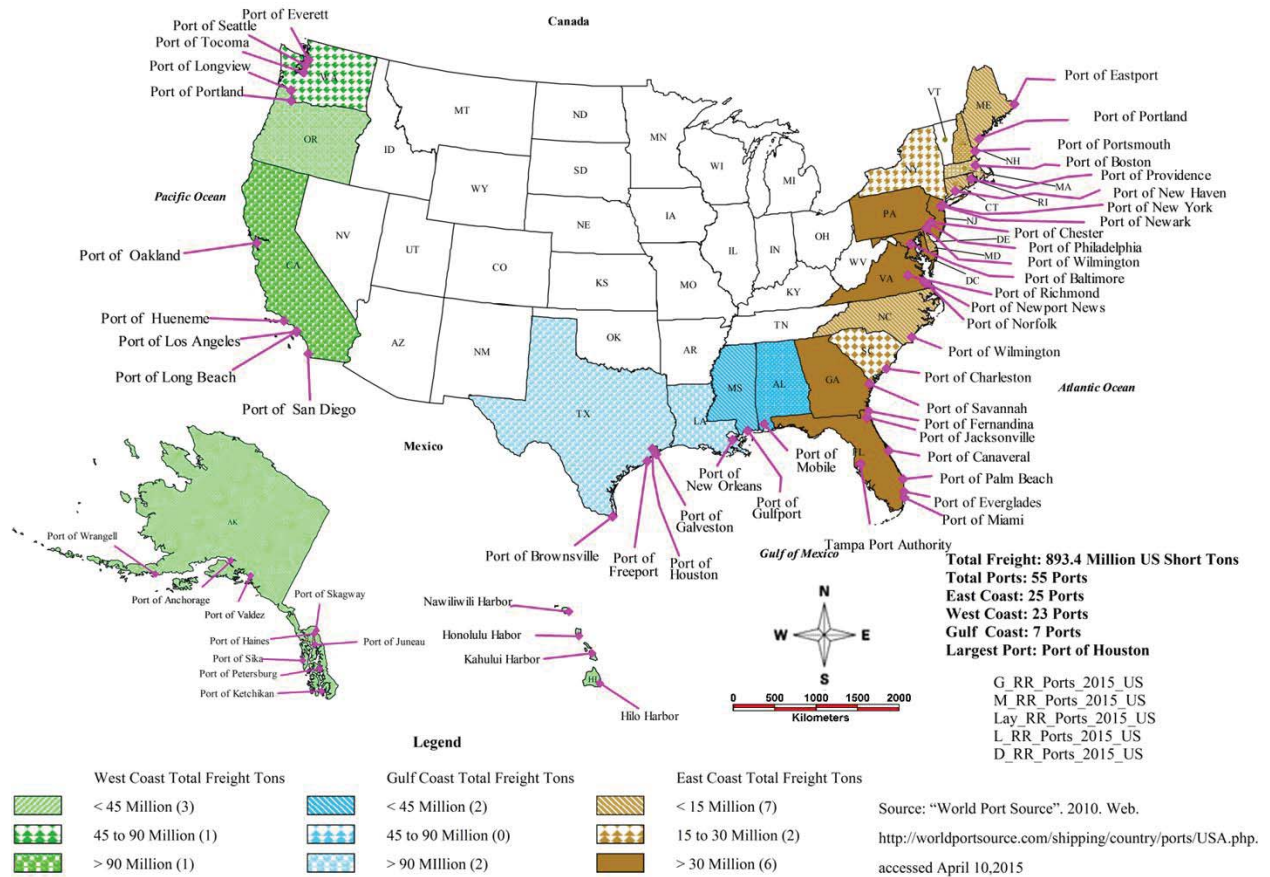


Figure 23. Commodity Type Distribution of Domestic and Foreign Goods at Gulfport Port, 2012

Figures 24 to 27 show the spatial maps created in the project and the results of a synthesis study of 55 major ports on the West Coast, Gulf Coast and East Coast of the U.S. Total freight of 893.4 million U.S. short tons was processed in these ports in 2010 (Richardson 2016).



U.S. Port Area	Number of Container Liner Service Ports	Comments
East Coast	25	<ul style="list-style-type: none"> West Coast has 2nd highest amount of container liner service ports of the 3 U.S. port areas
West Coast	23	
Gulf Coast	7	
Total Ports	55	<ul style="list-style-type: none"> Total freight: 893.4 million U.S. short tons

Figure 24. Spatial Map of All U.S. Container Liner Service Ports, Total Import and Export (Short Tons), 2010

Total Freight for Each coast's Container Liner Service Ports and Percentages of Total Freight, 2010

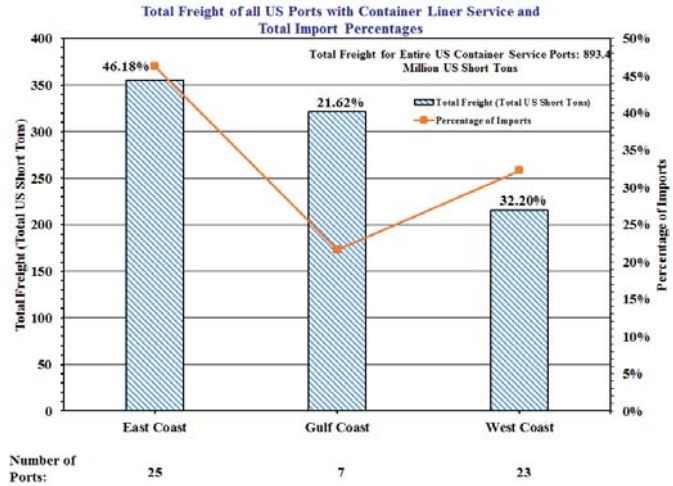
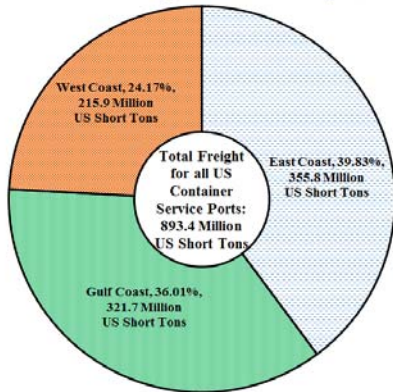
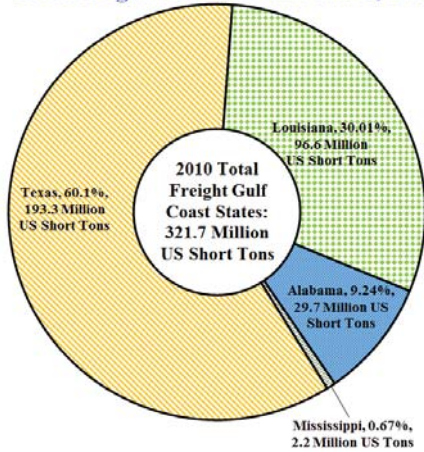


Figure 25. Freight Data for the Container Ports on West Coast, Gulf Coast, and East Coast, 2010

Total Freight for Gulf Coast States, 2010



Total Freight for Gulf Coast States and Total Percentage of East Coast States Imports

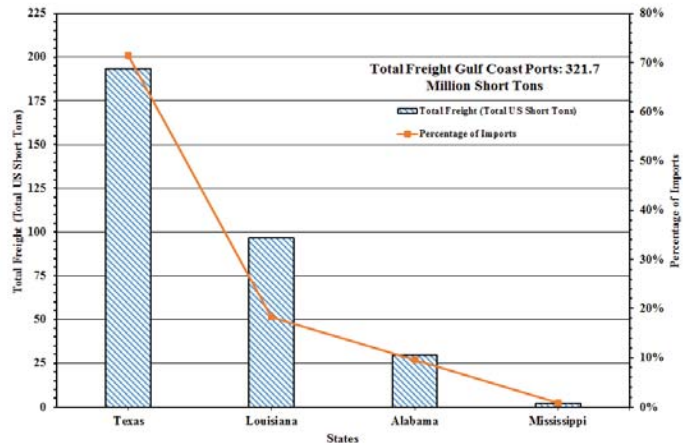


Figure 26. Freight Data for the Container Ports on Gulf Coast, 2010

Total Import and Export Freight for Gulf Coast Ports, 2010

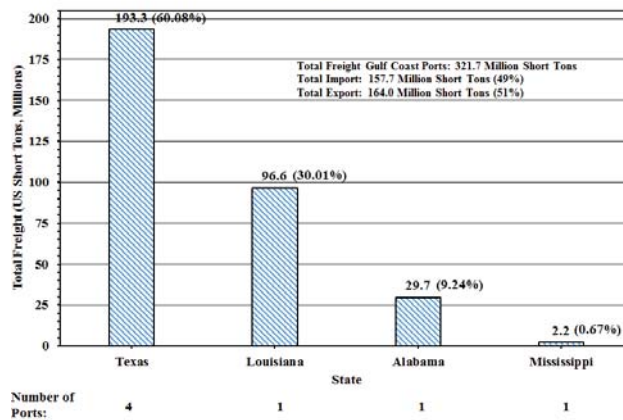


Figure 27. Freight Data for the Container Ports on Gulf Coast by State, 2010

Figures 28 and 29 show that the five ports on the California coast processed about 64% of all import and export freight containers annually, as well as these figures show the distribution to other states by freight intermodal rail and highway trucks.

Total Freight for West Coast States, 2010

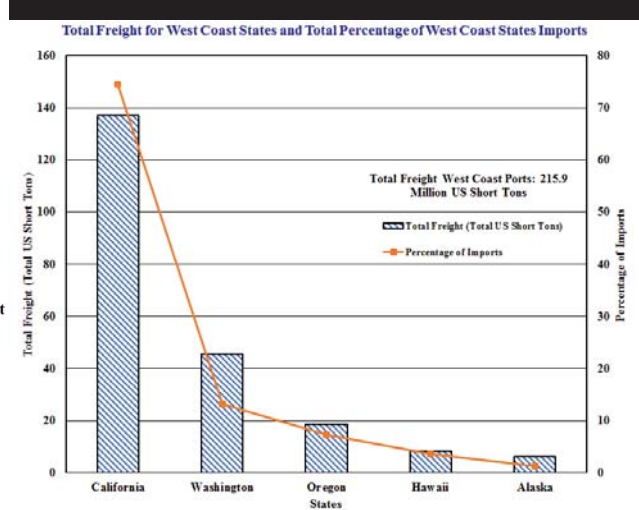
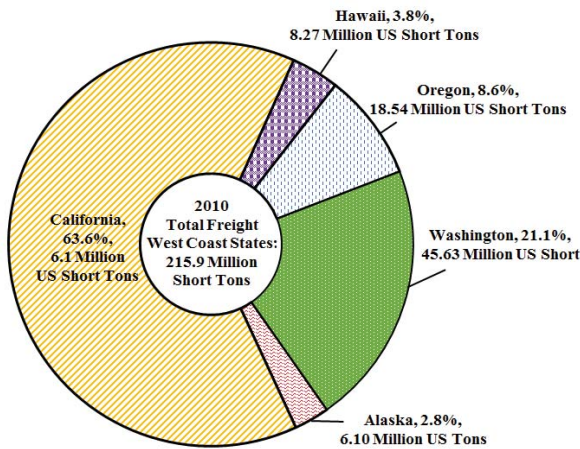


Figure 28. Freight Data for the Container Ports on West Coast, 2010

Total Import and Export Freight for West Coast Ports, 2010

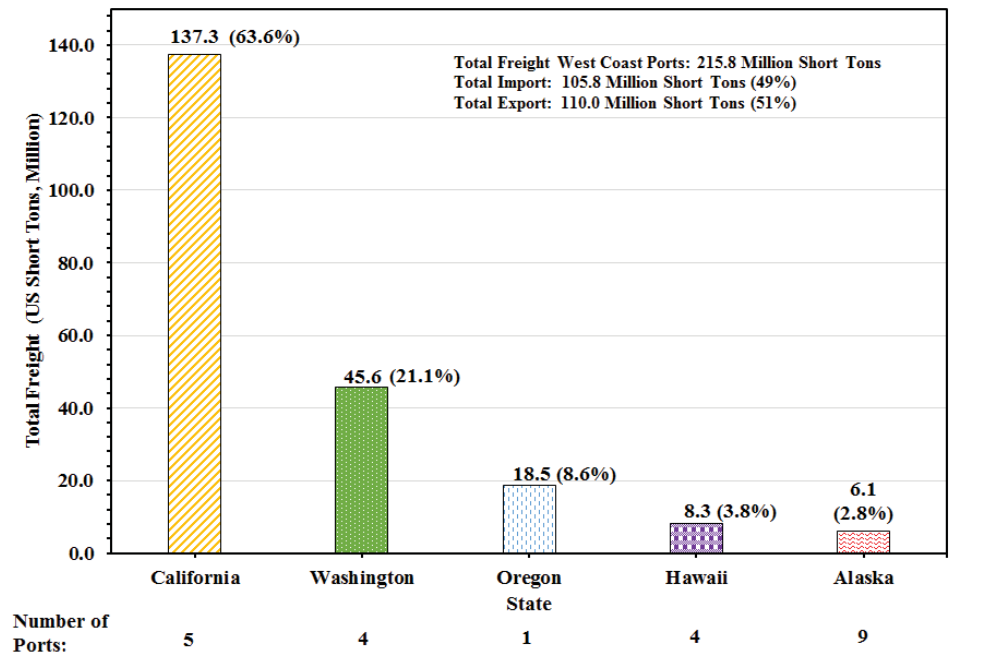


Figure 29. Freight Data for the Container Ports on West Coast by State, 2010

Revenue Mechanisms and Funding for Public Transportation Infrastructure

Public transportation infrastructure assets include: public roads and highways, inland waterways, harbors and coastal navigation channels, ports, and public airports. Uddin et al. (2016) discuss the revenue and finding mechanism for waterways and harbors and ports, as follows:

“The Inland Waterways Fuel Tax was established by Congress in 1978 to support the development and rehabilitation of inland waterway infrastructure, which includes 257 locks at 212 sites on more than 12,000 miles (19,200 km) of inland waterways. Revenues from the tax fund 50 percent of the cost of inland navigation projects each year as authorized. The amount of tax paid by commercial users is \$0.20 per gallon of fuel, generating approximately \$85 million in contributions annually to the Inland Waterways Trust Fund (IWTF). In December 2014, tax extension legislation included a 9 cent per gallon increase to IWTF collections. As of April 1, 2015, tow boaters transiting the inland waters of the U.S. now contribute 29 cents per gallon to the fund (PNWA 2015).

The Harbor Maintenance Trust Fund (HMTF) was established by Congress in 1986 to fund operation and maintenance work on coastal navigation channels, including dredging. The HMTF brought in about \$1.8 billion in 2014 in taxes on cargo from importers and domestic shippers using coastal and Great Lakes ports (Roll Call 2015).” The Federal Aviation Administration (FAA) reauthorization legislation, H.R. 658, the FAA Modernization and Reform Act of 2012, was major funding source for capital expenditure on public airports until FY 2015 (FAA 2012).

The milestones of government fuel tax in the U.S. from the early 1900 to 2015 (FHWA 2015, Sweet 1993) are summarized by Uddin et al. (2016). The Highway Trust Fund, founded upon federal fuel taxes on auto and trucks, has been on the brink of depletion for the last two decades. The inaction of the Congress to increase the tax base could lead to additional shortfalls down the road. States established additional state fuel taxes, realizing the backlogs of roads and bridges for maintenance and rehabilitation or replacement.

There is still a shortfall of revenue. This revenue issue gets complicated as there are Electric Vehicle (EV) and Autonomous Vehicle (AV) technologies on the horizon with increased car share and less car ownership. These new travel modes do not consume gasoline or diesel. These issues should be considered while formulating a user fee and tax alternative. The guiding principles must consider (Uddin et al. 2016):

- Equity based on both fuel types
- Space shared on highways and roads
- Commercial use vs. work and other travel purposes
- Damage potential to pavements

A life cycle approach for costs and benefits can help to analyze the long term impacts of a road user fee for any of the current travel models and the future of autonomous vehicle (AV) technologies that may lead to less auto ownership. These topics and recommendations for innovative transportation revenue mechanisms by the federal and states are discussed in detail in the final report of NCITEC Project 2012-27 (Uddin et al. 2016).

Highway and Rail Infrastructure

Figure 30 shows a comprehensive spatial map of major highway networks in NAFTA countries. Highway infrastructure assets (pavement, bridge, right of way) are owned by states/federal government agencies. The bulk of funding support to state DOTs in the U.S. for all federal-aid highways is provided from Highway Trust Fund’s federal appropriations through US DOT. The truck freight operation is wholly owned and operated by private sector companies. Trucks pay only the nominal annual registration license fee to the US DOT while all their operations are mostly on publicly funded highway infrastructure. On the other hand, rail infrastructure and rail vehicle stock as well as rail freight operation have historically been wholly owned and operated by private sector companies in the U.S. unlike most other countries where these are owned by the government. According to the Association of American Railroads (AAR 2011): “America’s freight railroads move 43 percent of intercity freight traffic -- more than any other mode of freight transportation -- delivering for every sector of the U.S. economy. Freight rail, which moves 1/3 of U.S. exports to ports, will be even more important to our future as the nation strives to double exports by 2015.”

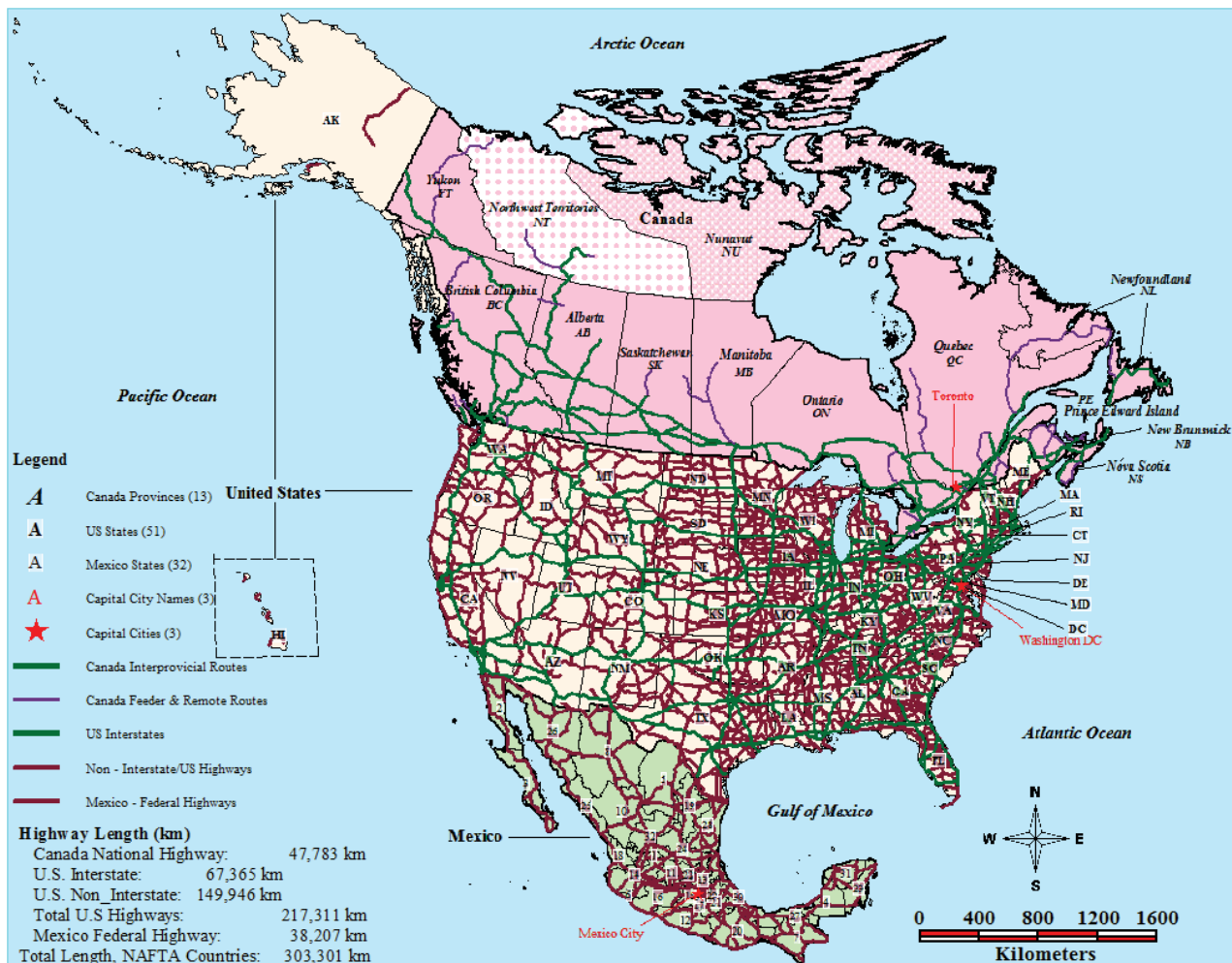


Figure 30. Spatial Map of Major Highway Infrastructure Networks in NAFTA Countries

Two major types of roads in the United States are Interstates and Non-Interstate highways. A major type of road in Mexico is Federal highways. These three types of roads in the United States and Mexico are shown separately in Figure 30.

- The total length of the Federal highway system in Mexico is about 17% of all Interstate and Non-Interstate highway systems in the United States.
- The density of all Interstate and Non-Interstate highway systems in the United States is about 21% greater than Mexico’s Federal highway density.

By calculating the length of highway system per capita in the United States and Mexico, it is concluded that the length of highway per capita in the United States is two times greater than the length of highway per capita in Mexico. This shows that the accessibility to highway systems in the United States is two times greater than Mexico’s accessibility to highway systems.

Figure 31 shows a spatial map of the rail networks in NAFTA countries. The U.S. freight network rail length is 65.66% of total 207,739 km rail length in all three NAFTA countries.

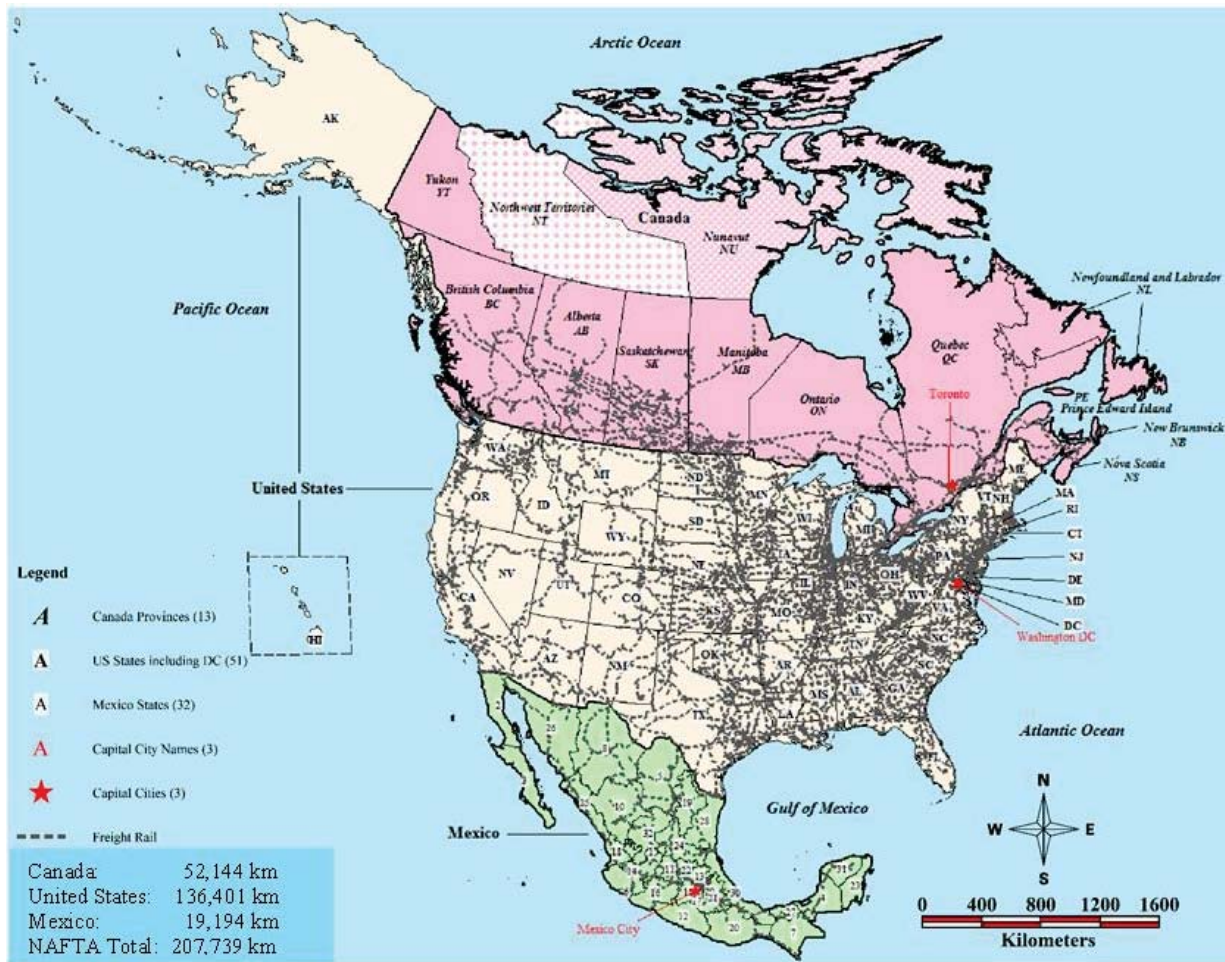
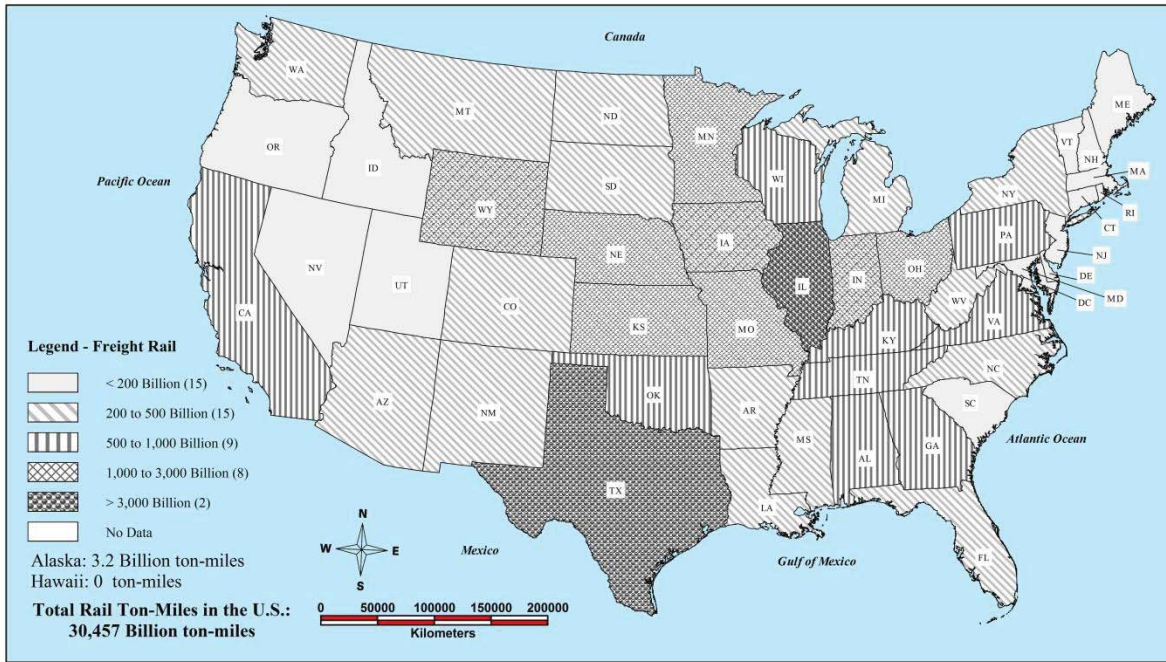


Figure 31. Spatial Map of Freight Rail Network in NAFTA Countries (Uddin et al. 2016)

Figure 32 is a spatial map of rail ton-mile distribution by state for the U.S. with 30,457 billion ton-miles in 2010. This map shows that Illinois and Texas were two top states in 2010 for ton-mile statistics. A detailed spatial map of freight rail network by rail companies in the U.S. is shown in Figure 33.

2010 Rail Ton-Miles in the United States



Data Source: 2010 STB Waybill Sample

Figure 32. Spatial Map of Rail Ton-Mile for the U.S. by State, 2010

AAR Freight Rail Network for the United States by Company

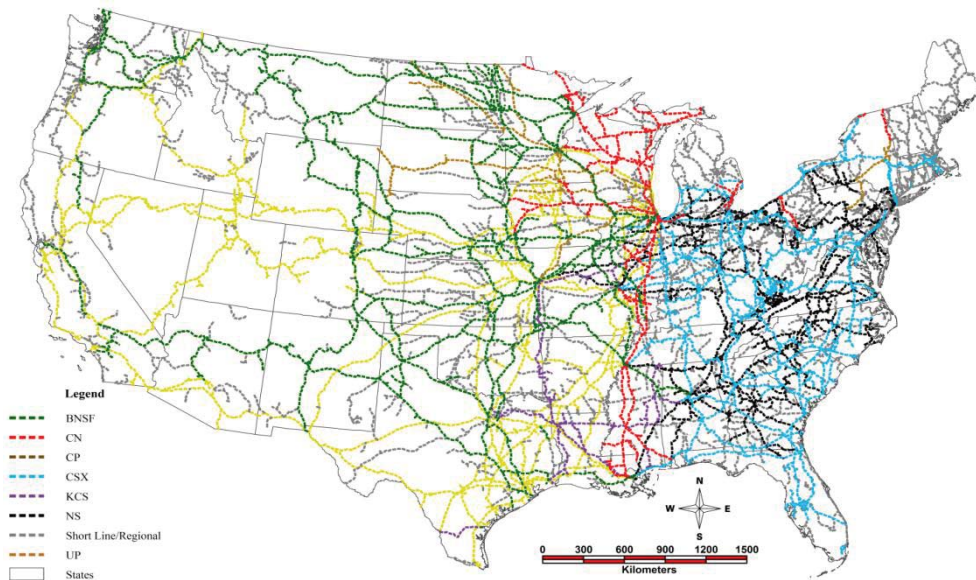


Figure 33. Spatial Map of Freight Rail Network by Rail Companies in the U.S.

The U.S. National Highway System (NHS) infrastructure is displayed in Figure 34. Comparing shipment values in millions of dollars, trucks account for 85% to Mississippi and 48% to Louisiana. About 49% of 151.9 million ton shipment in 2008 through the Mississippi Gulf Coast corridor was by through truck traffic, according to the 2035 Multiplan report of the Mississippi DOT (MDOT 2011). The modal split is 70.7% trucks, 17% by waterways, and 12.3% rail. A major portion of this truck traffic was through I-10 which in turn produces congestion and traffic bottlenecks around major cities on the Mississippi Gulf Coast.

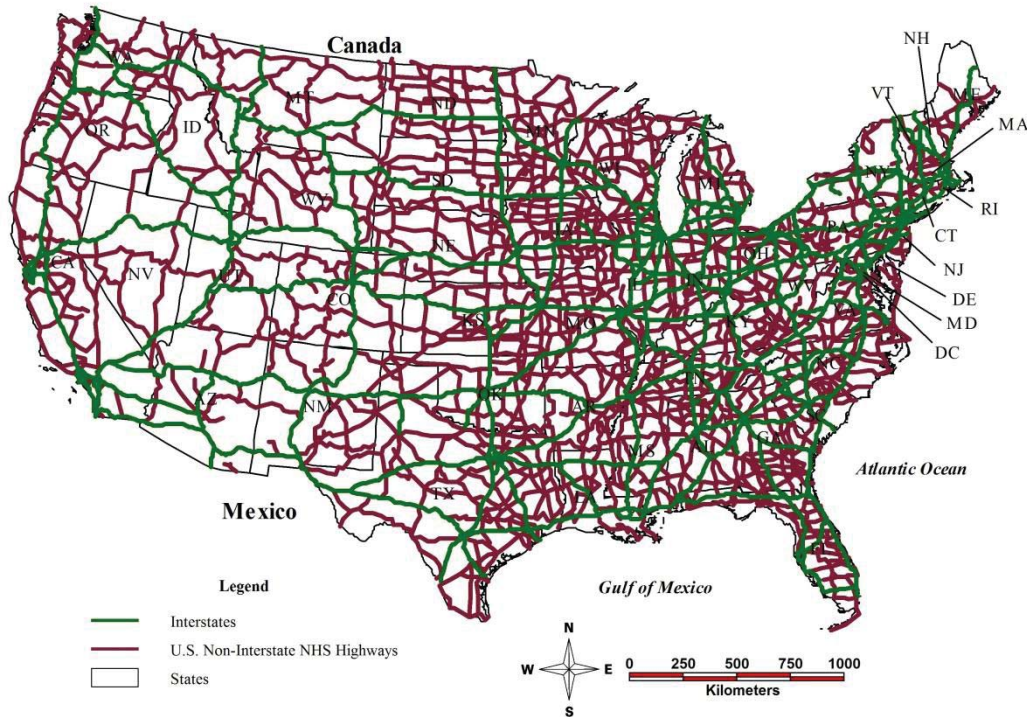


Figure 34. Spatial Map of the U.S. National Highway System (NHS) Infrastructure

About nine percent of all highway fatalities in 2009 involved large trucks. Fatality rate per 100 million vehicle-mile-traveled is higher for large truck related fatality (1.585 per 100 million truck mile traveled) than other vehicles (1.336 per 100 million non-truck mile traveled). This fatality rate is less than 1.0 for many European countries who use it as a national road safety performance measure while relying heavily on rail freight and rail passenger transport. Reducing numbers of large freight trucks from congested highways, to reduce congestion and transport emissions, should be given serious attention considering that road safety and sustainability is a clear priority in the “Moving Ahead for Progress in the 21st Century (MAP-21)” reauthorization of the transportation bill by the US Congress (FHWA 2012).

Figure 35 shows top 20 cargo airports in the U.S. A global supply chain infrastructure network includes a system of airports an many serve major global freight airlines, as well as sea ports.

Figure 36 Shows the top 20 ports in the world. Figure 37 shows the distribution of total inbound freight in 2011 by geographic region. About 44% freight is from outside NAFTA partner countries and shipped by cargo vessels or cargo planes.

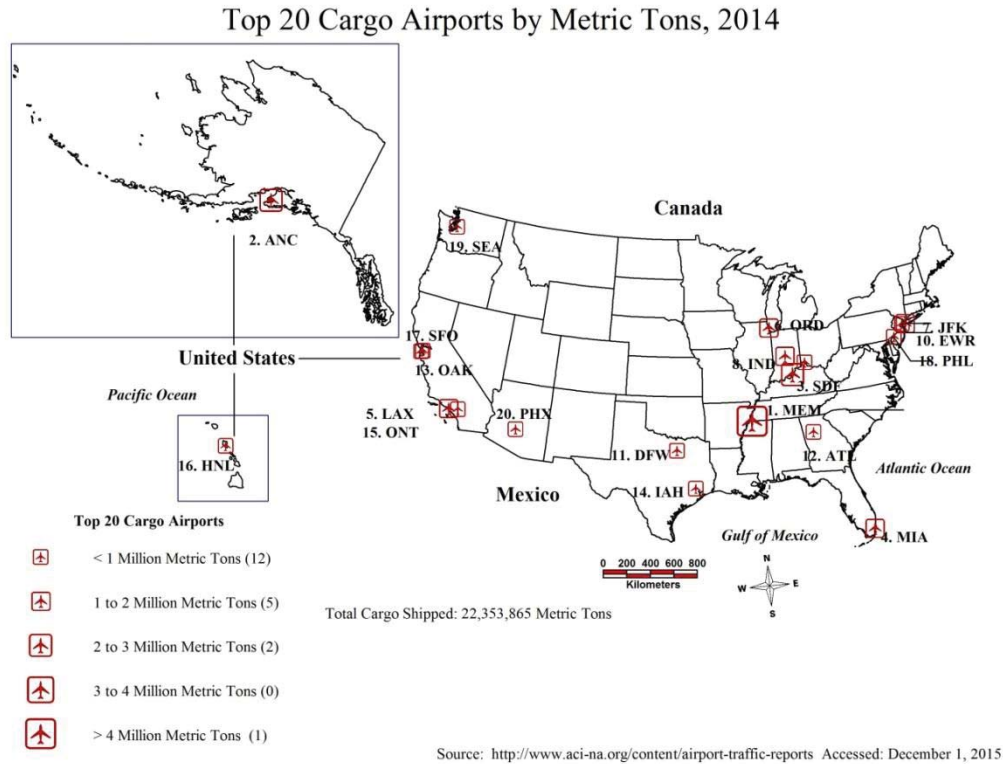


Figure 35. Spatial Map of Top 20 Cargo Airports in the U.S.

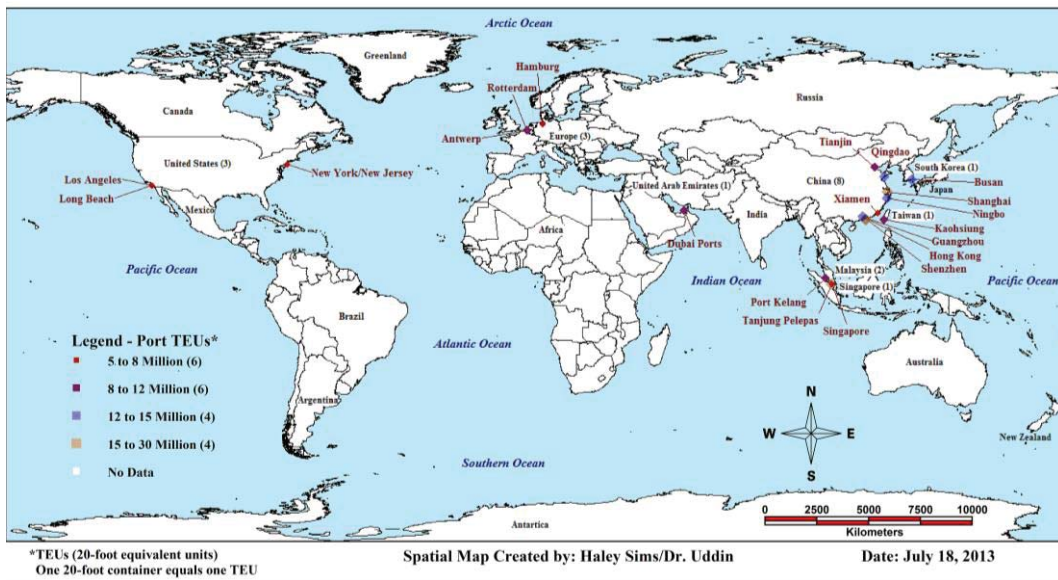


Figure 36. Spatial Map of World's Top 20 Ports

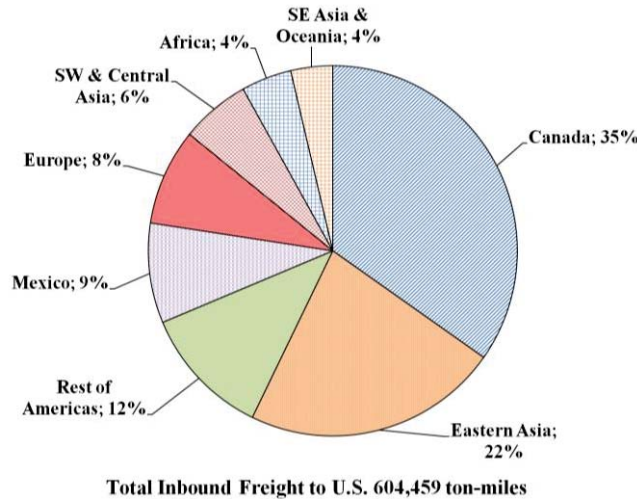


Figure 37. Freight from All Foreign Origins to the U.S., 2011

Figure 38 shows a spatial map of U.S. national freight transportation infrastructure and tonnage of freight flows by various different transportation modes in year 2010



NOTES: Air gateways include a low level (generally less than 3% of the total value) of freight shipped through small user-fee airports located in the same area as the gateways listed. Air gateways not identified by airport name (e.g., Chicago, IL) include major airport(s) in that area and small regional airports. Due to Census Bureau confidentiality regulations, courier operations are included in airport totals for only New York (JFK), Los Angeles, Chicago, and Anchorage.

SOURCES: **Air**—U.S. Department of Commerce, U.S. Census Bureau, Foreign Trade Division, USA Trade Online, **Land**—U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, TransBorder Freight Data, **Water**—U.S. Army Corps of Engineers, Navigation Data Center, personal communication, as cited in U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, National Transportation Statistics, table 1-51, available at http://www.bts.gov/publications/national_transportation_statistics/ as of October 2012.

Source: http://www.rita.dot.gov/bts/sites/rita.dot.gov/bts/files/ch3_tsar2012.pdf

Figure 38. Spatial Map of U.S. National Freight Transportation Infrastructure and Freight Flows

Multimodal freight corridors provide new opportunities for efficient mobility, job creation, and economic growth. By intermodal integration, shipping costs and emissions can be reduced substantially, compared to freight truck transport only. These aspects were evaluated and life cycle costs and benefits were calculated for several case studies of integrated freight modes using Uddin’s related research (Uddin 2013, Uddin et al. 2015). These case studies include NAFTA routes and major freight ports such as Gulfport, Vicksburg, St. Louis, and St. Paul-Minneapolis.

2.2 Highway and Rail Corridor Integration Studies for Colorado and NAFTA Corridors

Shipping Costs and External Costs Associated with Social and Environmental Factors

The average unit costs of freight shipping by mode considering diesel fuel are shown in Table 1 (MODOT 2012, Seth 2015, Uddin et al. 2016). These shipping unit costs are used to calculate freight shipping costs for freight intermodal integration studies. Table 2 shows external costs due to social and economic factors based on the Congressional reports (GAO 2011, CBO 2015). Both tables show truck to have the highest ton-mile shipping cost with the lowest net freight ton-miles per gallon of diesel and highest external costs.

Table 1. Net Freight Ton-Mile per Gallon of Diesel by Mode (MODOT 2012)

Mode	Net Freight (Ton-Mile) per Gallon of Diesel	Average Shipping Cost, Cents per Ton-Mile	Average Shipping Cost, \$ per Million Ton-Miles
Truck	155	34.39	343,900
Rail	413	3.95	39,500
Barge (Waterway)	576	2.17	21,700

One barge can transport 1,500 tons cargo, 52,500 bushels, or 453,600 gallons. One freight truck carries 25 tons cargo, 910 bushels, or 7,865 gallons. One rail car transports 100 tons cargo, 3,500 bushels, or 30,240 gallons.

Source: <http://business.tenntom.org/why-use-the-waterway/shipping-comparisons/> Accessed April 2015.

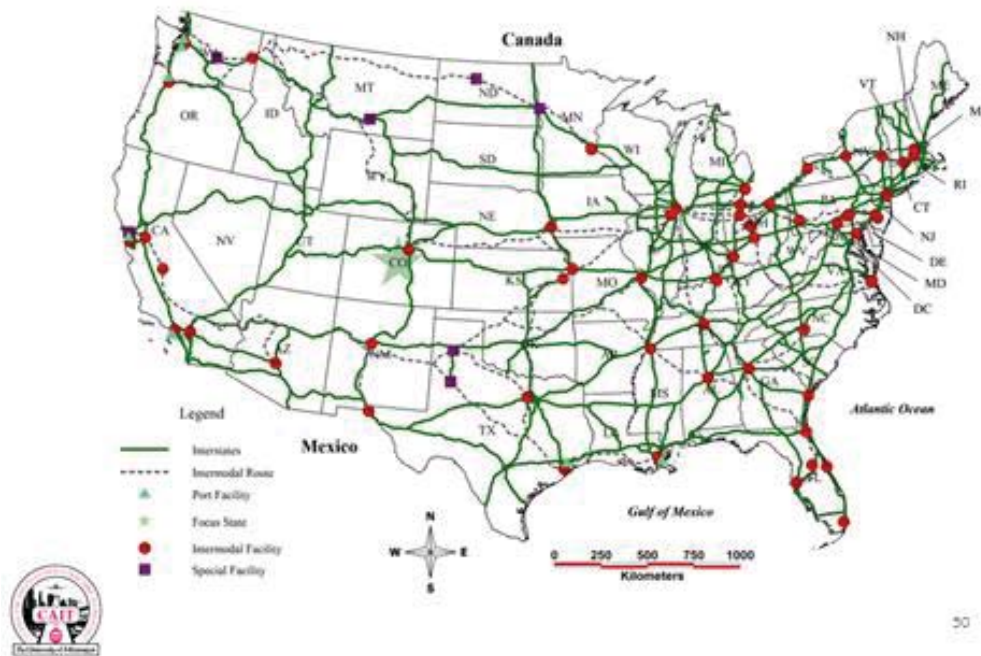
Table 2. Cross-Modal Comparisons of External Costs for Social and Environmental Factors

Category of External Cost	Unit Cost in 2010 Dollars per Million Ton-Miles			Unit Cost Ratio per Million Ton-Miles	
	Trucking	Railroad	Waterways	Trucking to rail ratio	Trucking to waterways ratio
Air pollution: PM and NOx	44,000	8,000	6,000	5.50	7.33
Accident	8,000	1,000	-	8.00	-
Congestion	7,000	-	Unknown		
Marginal public infrastructure costs *	7,000	-	-		
Marginal taxes and fees (freight)	11,000	-	-		
Unpriced costs —marginal social costs minus taxes and fees (Freight)	~ 55,000	~ 9,000	~ 6,000	6.11	9.17
Average CO ₂ cost in 2014 Dollars (CBO 2015) ✓	2,200 ✓	500 ✓	< 500 Est.	4.44	< 4.44 Est.

* FHWA data shows that trucks imposed an average marginal cost to pavement of \$7,000 per million ton-miles (pavement preservation expenditure). These are hidden costs are not passed to the truck owners (GAO 2011).

Geospatial Mapping and Optimization of Colorado-California Corridors for Highway-Rail Integration

For Colorado case study the previous Project 1202-27 (Uddin et al. 2016) detailed commodity flow analysis was done from Colorado to other states to find good which are transported by trucks only. The candidate destination state was California for which a new intermodal line was explored. The first step for this case study was to develop a spatial map which shows an existing intermodal network that is in place. BNSF has one of the largest intermodal networks in the country, so their network was used to develop the spatial map (Figure 33). The BNSF intermodal network is made up of different rail lines throughout the U.S., including BNSF, CSX, NS, KCS, FEC, and FXE, which allows it to reach all regions of the U.S. Using the image registration and planimetrics geospatial analysis tools, the map in Figure 39 was developed. In Figure 39, the intermodal routes can be seen as grey dashed lines. Intermodal facilities are shown throughout the U.S. as red squares, and BNSF “Special-Use” facilities are shown as purple squares. All major coastal ports in the intermodal network are also shown as magenta diamonds.



Source of data: BNSF Intermodal Map.

<http://www.bnsf.com/customers/pdf/maps/small-intermodal-map.pdf> Accessed July 27, 2014

Figure 39. Freight Truck - Intermodal Rail Networks in the U.S. (Uddin et al. 2016)

Once the opportunity for integration was found, possible highway and rail routes were determined. This was done by using spatial analysis with the NHS and AAR Freight Rail maps. Using these spatial maps (Figures 33, 34, 39), two highway routes and one rail route were identified using infrastructure already in place that would run directly to a major freight hub in California. The routes selected run directly from Denver, CO, to Oakland, CA. Oakland, CA, is home to two intermodal facilities, a major port facility, and also a special-use facility. Economic

analysis was performed for each highway route and for the rail route to determine the benefits of diverting a portion of freight from highway trucks to rail freight cars.

Figure 40 shows the spatial maps of the proposed corridor routes. The two proposed highway routes for study are shown in the pink diagonal buffer zone. The routes are labelled “North Route” and “South Route” based on where they are located with respect to the rail line. The proposed line selected from the AAR freight rail network to be added to the BNSF intermodal network is highlighted in a light green dashed line. These proposed corridors provide direct shortest routes from Colorado to California which are lacking in the existing intermodal network. Other possible routes will be not viable because of longer route length. The proposed northern highway corridor consists of portions of I-25 and I-80, and stretches 1,231 miles. The southern highway corridor includes parts of I-70, I-15, I-80, US-50, US-6, and US-50. The southern corridor is slightly shorter than the northern route at 1,201 miles. The proposed rail corridor is owned by Union Pacific railroad and is 1,353 miles in length, making it the longest of the three routes.

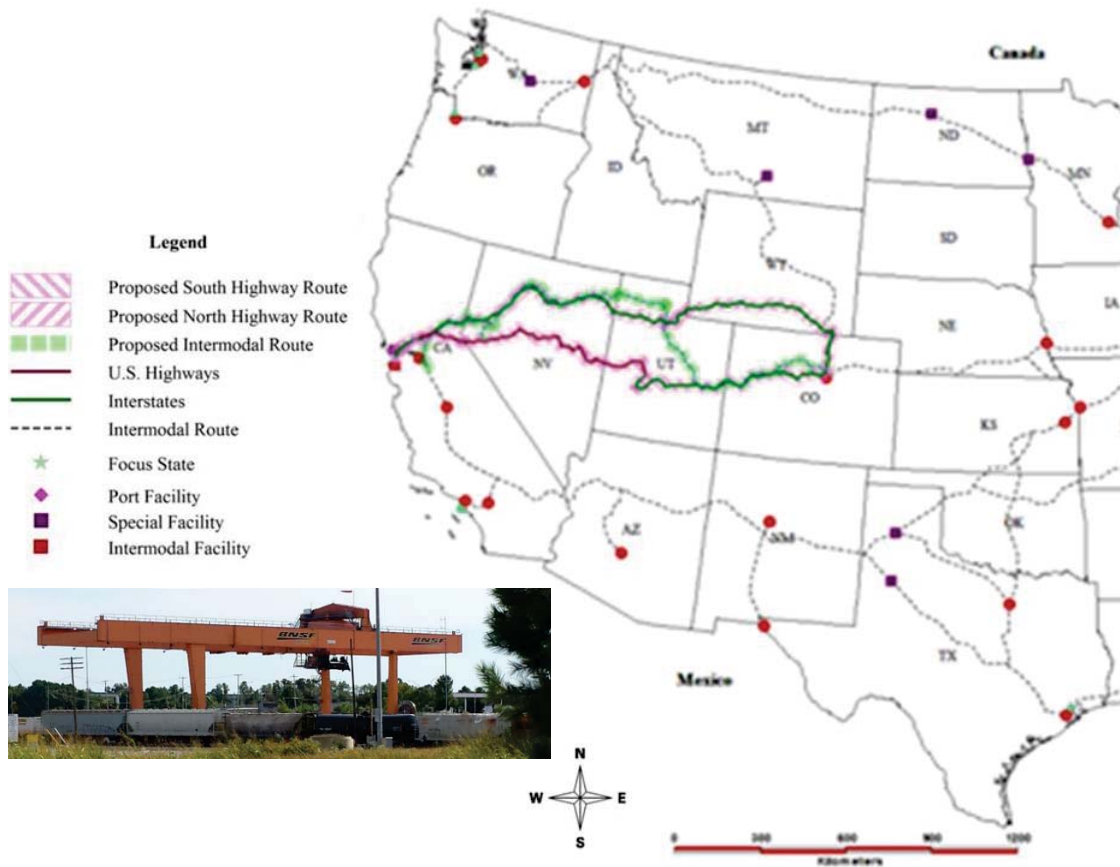


Figure 40. Spatial Map of Proposed Routes without Other Existing Infrastructure

Shipping Cost Calculations

Shipping costs for a given freight (tons) are calculated using Equation 1.

$$\text{Shipping Cost per Year (\$)} = (\text{Tonnage} \times \text{Route Length}) \times \left(\frac{\text{Average Ton-Mile Cost (Cents)}}{100} \right) \quad \text{Eq. 1}$$

Unit cost in cents per ton-mile for each mode is provided in Table 1.

Fuel Cost Savings

An important indirect benefit of intermodal integration is truck fuel cost savings from diverting trucks from highways to other fuel efficient modes. This savings is calculated using Equation 2, as follows:

$$\text{Fuel Cost Savings per Truck} = \left(\frac{\text{Route Length}}{\text{Fuel Efficiency}} \right) \times \text{Fuel Cost} \quad \text{Eq. 2}$$

According to Uddin (2012), the average fuel efficiency for a diesel engine heavy duty truck is 5.9 miles per gallon. The fuel cost for these calculations used \$2.50 per gallon at the general market price in 2015. Although diesel prices may be slightly higher, the larger the increase in price, the more the amount of savings will increase.

Calculation of CO₂ for Freight Shipping Routes

The CO₂ emission is calculated using Equation 3 (Uddin 2012). Also, the net freight ton-miles per gallon values from Table 1 were used in these calculations. According to the U.S. Environmental Protection Agency (EPA), the average CO₂ emissions per gallon of diesel fuel are 22.2 lbs/gal (EPA 2005, Uddin 2012).

$$\text{CO}_2 \text{ Emissions (Short Tons)} = \left(\frac{\text{Tonnage} \times \text{Length (Miles)} \times \text{Emissions per Gal of Diesel} \left(\frac{\text{lb}}{\text{gal}} \right)}{\text{Net Freight Ton-Miles per Gallon} \left(\frac{\text{Ton-Mile}}{\text{Gal}} \right)} \right) / 2000 \text{ lb} \quad \text{Eq. 3}$$

Key Results of Colorado-California Intermodal Freight Study

Based on the results from the calculations (Uddin et al. 2016), significant savings can be observed by moving just 30% of the total non-perishable, bulk freight from highway to rail between Colorado and California. Based on the results summarized in Table 3, the rail intermodal route showed a significant reduction in travel time per year at just over 2,400 hours, where the highway routes were each well over 219,000 hours. Therefore there is no need to make near as many trips as the trucks. Ton-mile costs to move 30% of the proposed freight amount were also significantly lower for the rail route at just \$33 million, whereas both highway routes were over \$252 million. The CO₂ emissions for the rail route were 22,250 tons of CO₂ at 42% of that of the highway route. The highway routes both emitted just over 52,600 tons of CO₂ each.

Table3. Summary of Colorado Corridor Results for 30% Annual Freight

Route	Total Ton-Mile Cost, Million \$	Total Travel Time per Year (hours)	Total CO ₂ Emissions per Year (Tons)
Highway Freight Route – North	\$259	223,111	53,947
Highway Freight Route – South	\$253	219,118	52,636
Proposed Rail Intermodal Route	\$33	2,436	22,250

Cost reductions and benefits for 30% trucks diverted to rail from the shorter highway route (South) are:

<u>Travel Time Reduction</u>	<u>Ton-Mile Cost Savings</u>	<u>CO₂ Reduction</u>	<u>Fuel Savings</u>
98.9%	87%	57.7%	\$3,737,349

The same results are valid for diverting 10, 20, or 100% of freight to rail shipping. These cost-benefit calculations determined that the proposed intermodal rail route provides a good opportunity for utilizing the existing rail line for diverting a portion or all of selected freight between Colorado and California. Rail shipment of non-perishable, bulk freight, time would be not an issue.

Study of Highway and Rail Corridor Integration for NAFTA Freight Transport

Overview

The summary data and results of NAFTA corridor study are extracted from the detailed analysis presented in the final report of NCITEC Project 2012-27 (Uddin et al. 2016). This included the freight data on Mexican border ports and transportation infrastructure databases associated with NAFTA’s corridors. This data was used to generate geospatial maps of international bridges on US-Mexico border and road/rail infrastructure. Figure 41 shows the ports on both the north and south borders and the top border ports of commodity flow at the Canadian and Mexican borders.

NAFTA’s economy has a combined output of \$17 trillion. In 2008, the U.S. traded \$919.9 billion with NAFTA partners, and 25.1 million jobs have been created from 1993 to 2008 as a result of NAFTA (NAFTA 2012). Other freight mode data of US NAFTA related and north-south freight transportation corridors are, as follows (CEC 2011):

- Regarding modal shares, in 2008
 - Trucks transported a larger percentage of the tonnage of US land imports from Mexico (74%) than from Canada (25%).
 - Rail transported 24% of the tonnage of land imports from Mexico and 33% from Canada.
 - Pipelines accounted for 35% of total land imports

- For Mexico, 96% of its' total NAFTA trade was with the U.S. and was valued at \$572 billion in 2013. Canada traded 95% of its' total NAFTA trade with the U.S. and was valued at \$740 billion in 2013.
- States that have larger populations contain more border ports. The largest on the Mexican border was Texas, containing 13 border ports followed by California with 10. Along the Canadian border, Washington contains the most border ports at 26. From this map, it can be seen where freight is coming into the U.S. and where it is coming in large volumes.

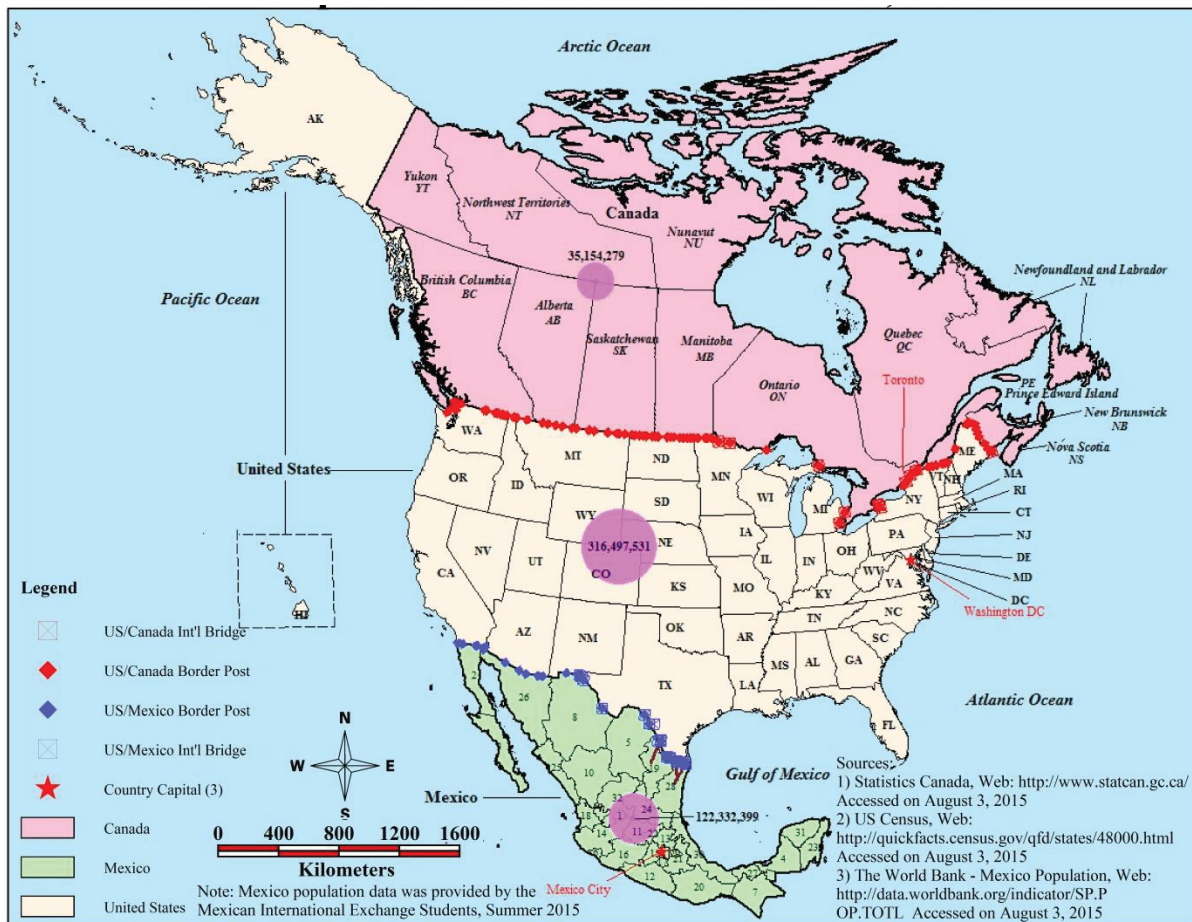


Figure 41. Spatial Map of NAFTA Countries showing Population and Border Posts

Figure 42 shows International NAFTA trade freight shipment value by mode on U.S. and Mexico borders for the top ten ports on the Mexican border passing through on truck or rail (BTS 2013). The figure also shows the percentage of total truck and rail freight that the port accounts for. From Figure 42, out of just over 50 million tons imported into the U.S. from Mexico, it can be seen that the Laredo, TX, border port accounted for a large majority of the freight imported on truck and rail at 39.2% in 2013.

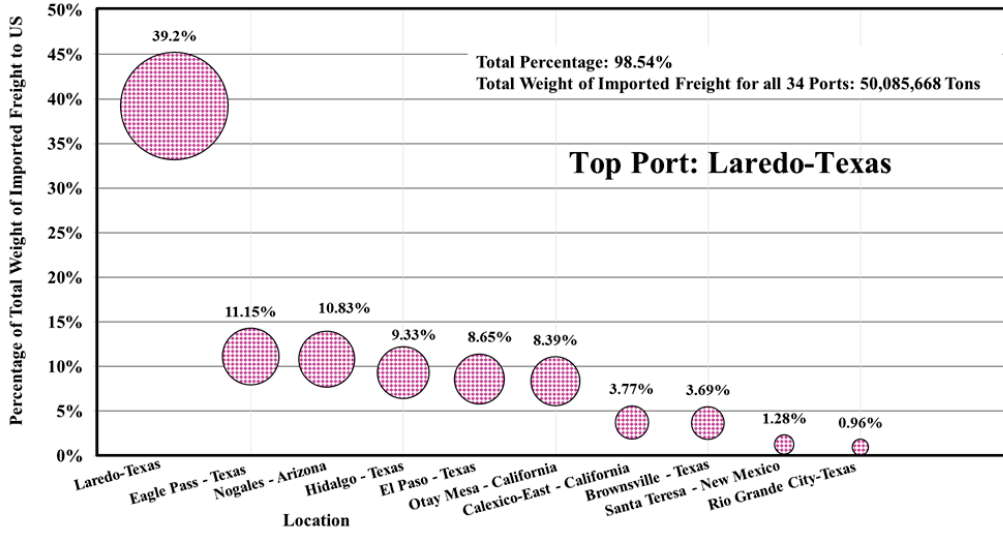


Figure 42. International NAFTA Trade Freight Shipment by Mode on U.S. and Mexico Border

Figure 43 shows the highlighted highway corridors that were chosen for the analysis. Once these corridors were selected, rail corridors that run parallel to each highway corridor were selected using the AAR freight rail network map. The highways and corresponding rail lines can be seen in Figure 44. Although routes only connect with two Mexican border ports, they split as they make their way through the U.S. and connect with four Canadian border ports and two major freight hubs that are not technically border ports. The Canadian Border ports that are connected are Blaines, WA, Sweetgrass, MT, Pembina, ND/Noyes, MN, and Detroit, MI. The two which are not Canadian border ports are Chicago, IL, and Duluth, MN.

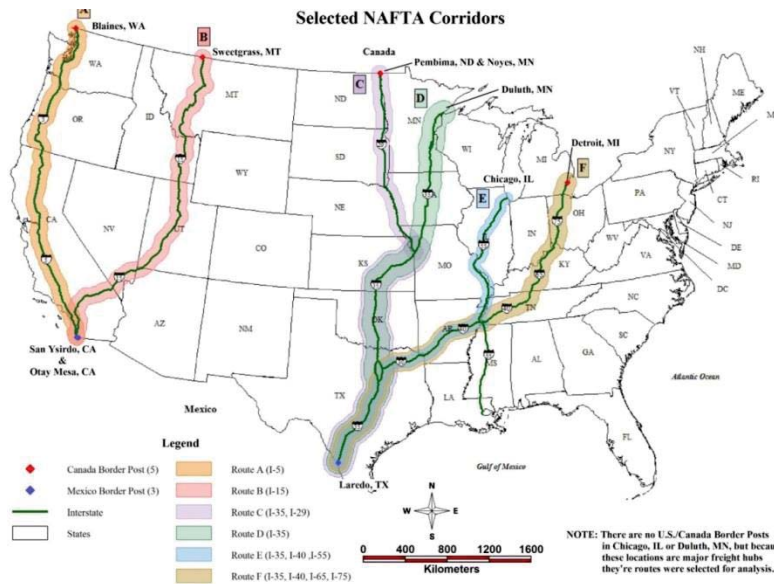


Figure 43. NAFTA Highway Corridors of Focus

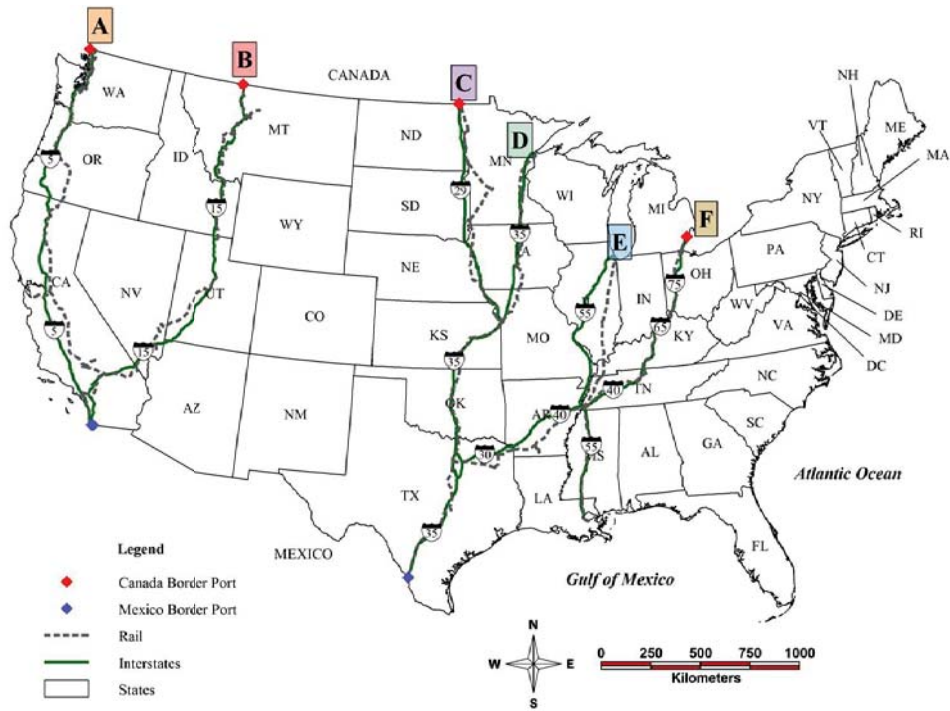


Figure 44. NAFTA Highway and Rail Corridors of Focus

Each of the highway and rail corridors shown in Figures 43 and 44 were analyzed to determine the benefits of moving freight from highway to rail. Each of the NAFTA highway corridors made up of the following interstates and the lengths of each corridor can be seen in Table 4.

Table 4. NAFTA Corridor Lengths

NAFTA Route from Mexican Border to the Final Destination	Mode	Length (miles)
A – Interstate 5 (to Blaines, WA)	Truck	1,359
	Rail	1,732
B – Interstate 15 (to Sweetgrass, MT)	Truck	1,436
	Rail	1,737
C – Interstate 35 and 29 (to Pembina, ND/Noyes, MN)	Truck	1,800
	Rail	1,833
D – Interstate 35 (to Deluth, MN)	Truck	1,677
	Rail	1,600
E – Interstate 35, 30, 40, and 55 (to Chicago, IL)	Truck	1,424
	Rail	1,481
F – Interstate 35, 30, 40, 65, and 75 (to Detroit, MI)	Truck	1,594
	Rail	1,777

Cost and Benefit Analysis for Intermodal integration of NAFTA Corridors

The following cost and benefit calculations were completed for each route: Travel Time Savings, Ton-Mile Costs and Savings, Fuel Savings, and CO₂ Emission Reduction. Complete analysis for base truck and intergrade highway-rail cases of each route are presented by Uddin et al. (2016). For brevity only the calculations were also completed for 20%, 40%, 60%, and 100% of total freight using the unit cost data (Table 1) and Equations 1, 2, 3 and freight data in Table 4. Only the final results of 20% truck freight diverted to rail case are presented in Table 5 and discussed but because it is the most conservative of the options. Table 6 shows percent reductions in travel time, shipping costs, and CO₂ emissions for NAFTA corridors in the case of diverting 20% truck freights entering the U.S. to rail for long haul trips.

Table 5. NAFTA Corridor Analysis of Costs and Benefits for 20% Trucks Diverted to Rail

NAFTA Route from Mexican Border to the Final Destination	2013 Truck Freight Entering U.S. (Tons)	Mode	Length (miles)	Total Ton-Mile Cost per Year (\$ Millions)	Total CO ₂ Emissions (Short Tons per Year)	Total Fuel Cost Savings (20% Truck to Rail)
A – Interstate 5 (to Blaines, WA)	4,201,887	Truck	1,359	\$393	81,787	\$19,357,168
		Rail	1,732	\$57	39,120	
B –Interstate 15 (to Sweetgrass, MT)	4,201,887	Truck	1,436	\$415	86,421	\$20,453,931
		Rail	1,737	\$58	39,233	
C – Interstate 35 and 29 (to Pembina, ND/Noyes, MN)	15,693,635	Truck	1,800	\$1,943	404,592	\$95,757,773
		Rail	1,833	\$227	154,628	
D – Interstate 35 (to Deluth, MN)	15,693,635	Truck	1,677	\$1,810	376,945	\$89,214,325
		Rail	1,600	\$198	134,973	
E – Interstate 35, 30, 40, and 55 (to Chicago, IL)	15,693,635	Truck	1,424	\$1,537	320,077	\$75,755,038
		Rail	1,481	\$184	124,934	
F – Interstate 35, 30, 40, 65, and 75 (to Detroit, MI)	15,693,635	Truck	1,594	\$1,720	358,289	\$84,798,828
		Rail	1,777	\$220	149,904	

Benefit for Moving 20% Freight from Highway to Rail						
NAFTA Route	Reduction in Travel Time (hrs)	Percent Change	Reduction in CO ₂ Emissions (Tons per Year)	Percent Change	Reduction in Ton-Mile Cost (\$ Millions)	Percent Change
A - Interstate 5	1,085,141	98.7%	42,667	52.2%	\$335	85.4%
B -Interstate 15	1,132,164	98.7%	47,189	54.6%	\$357	86.1%
C - Interstate 35 & 29	5,056,689	98.9%	249,964	61.8%	\$1,715	88.3%
D - Interstate 35	4,782,564	99.0%	241,972	64.2%	\$1,612	89.0%
E - Interstate 35, 30, 40, and 55 (Chicago)	4,208,434	98.9%	195,143	61.0%	\$1,353	88.1%
F - Interstate 35, 30, 40, 65, and 75 (Detroit)	4,588,048	98.8%	208,384	58.2%	\$1,500	87.2%

Optimization Analysis of NAFTA Freight Corridor, from Laredo, TX to Detroit, MI

Out of the six corridors A through F shown in Figures 43 and 44, corridors E and F (Figure 45) were selected for optimization to minimize shipping costs from Laredo, TX, to Michigan (Uddin et al. 2016). In 2008 Laredo, Texas had the highest amount of truck traffic (1,555,000) at the US-Mexico border of NAFTA corridor in the United States and it transported merchandise worth 115,759 million dollars (Kong and Wroth 2015). In 2013, the total amount freight entering the U.S from Laredo, TX on truck and rail was 19,652,674 tons. The following data shows how much freight flows from Laredo, TX, to Michigan.

- Total Freight Entering U.S. through Laredo, TX: 19,652,674 Tons
- Percentage of Laredo Freight that goes to Michigan by Truck: 5.51%
- Percentage of Laredo Freight that goes to Michigan by Rail: 7.21%
- Truck (5.51%): 19,652,674 Tons x 0.0551 = 1,082,862 Tons
- Rail (7.21%): 19,652,674 Tons x 0.0721 = 1,416,957 Tons
- Total Freight to Michigan: 2,499,819 Tons

Percentage entering Michigan from Laredo on Truck = $(1,082,862 / 2,499,819) \times 100 = 43.3\%$

Percentage Entering Michigan from Laredo on Rail = $(1,416,957 / 2,499,819) \times 100 = 56.7\%$

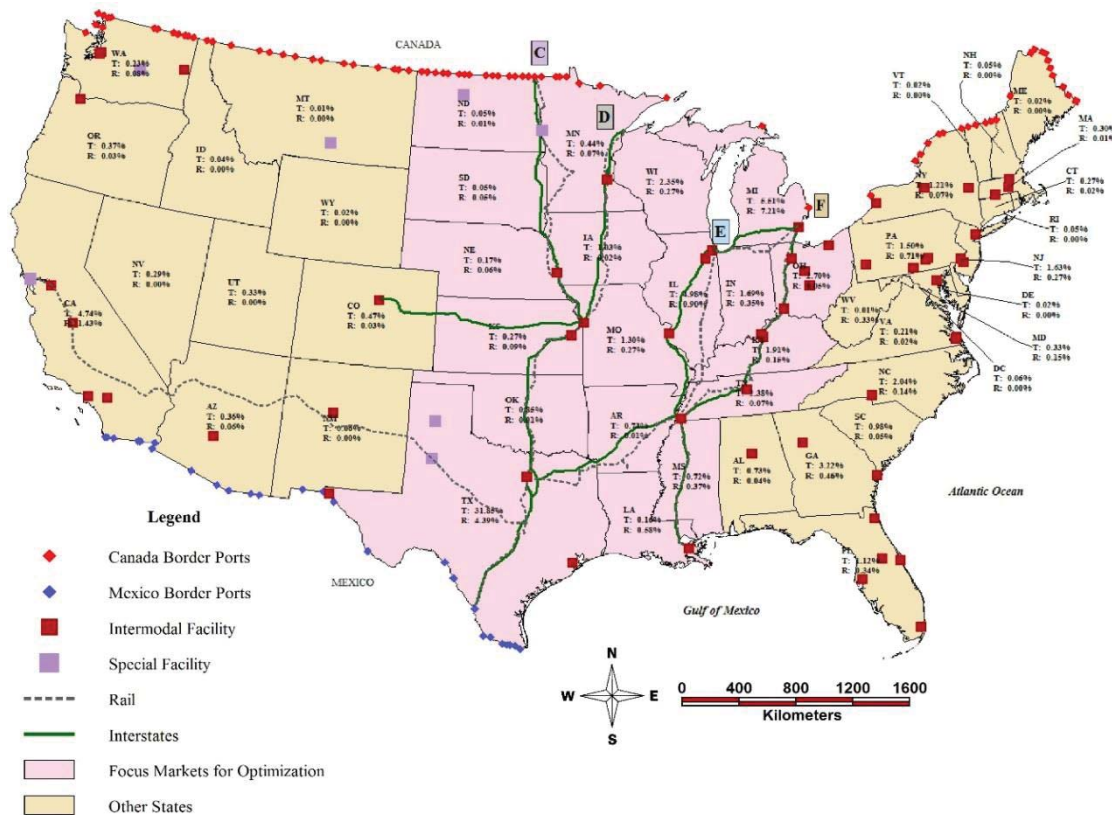


Figure 45. Spatial Map Showing Routes Chosen for Optimization

The geospatial analysis helped to identify and discard all unfeasible routes considering only interstate highway segments and major rail lines with intermodal terminals in the corridors. The routes, E and F, selected to optimize the minimum shipping cost share the same corridor segment from Laredo, TX, via Dallas to Memphis, TN. Memphis has a large rail-truck intermodal facility. The corridor then splits at Memphis into two segments (East and West), and each run separately to Michigan. The East corridor segment goes from Memphis to Detroit via Cleveland, OH, and the West corridor segment goes from Memphis to Detroit via Chicago, IL.

The following objective function was used to optimize the shipping cost for the corridors. Equation 4 shows the objective function used for this optimization.

$$\text{Minimize TC} = \sum_{i=1}^I \sum_{m=1}^2 \sum_{j=1}^J [D_{i,m} \times C_m \times \{ (T_{m=1} \times (1 - j)) + (T_{m=2} \times (1 + j)) \}] \quad \text{Eq. 4}$$

Where,

TC = Total Cost to ship freight from Memphis to Detroit, \$

m = Mode of Shipping Freight (1 = Truck, 2 = Rail)

$D_{i,m}$ = Distance from Memphis to Detroit for corridor i and mode m

C_m = Shipping Unit Cost, \$ per ton-mile for mode m

Truck shipping cost (m = 1) is \$0.3439 per ton-mile

Rail shipping cost (m = 2) is \$0.0395 per ton-mile 3.95

T_m = Total Freight from Memphis to Detroit, tons for mode m,

$T_{m=1}$ for Truck, $T_{m=2}$ for Rail

i = Corridor 1, 2, ..., to I (For this case study: 1 = East Corridor, 2 = West Corridor)

j = 1, 2, ..., to J; Reduction in Proportion of Freight Shipped (0, 0.05, 0.1, 0.15, 0.2) on Highway for m =1 and addition in Proportion Diverted to Rail for m =2

For the objective function, the term T is the total freight going from Memphis to Detroit and is a function of the mode it is being transported by, m. The corridor distance (D) is a function of the corridor (i) and the mode (m). The unit cost C is determined by which mode (m) is transporting the freight based on unit cost data shown in Table 1. The total shipping cost (TC) for each corridor is a function of the reduction (j) in freight being shipped on the highway (m=1) and corresponding increase in freight on rail (m=2).

The objective function is subject to the following constraints:

$$\sum_{m=1}^2 T_m \leq 2,499,818 \text{ Tons} \quad \text{Eq. 5}$$

$$j \leq 20\% \quad \text{Eq. 6}$$

Also, a non-negative constraint is applied to ensure that tonnage values shipped by each mode always stay positive for the optimization.

The linear programming optimization was then completed using Excel Solver for the base scenario ($j = 0\%$) and for diverting 5%, 10%, 15%, and 20% freight from the highway to rail. The spatial features of the two candidate corridors and the optimization results are shown in Table 6. The East corridor is slightly shorter than the West. Based on the results from the optimization, the East corridor shows minimum shipping costs for all values of j (Figure 46). Reduction in CO₂ emissions by using rail for shipping 20% truck freight is 208,384 short tons per year or 58.2% compared to 100% freight shipped by long-haul trucks.

Table 6. Shipping Costs for East and West Corridor

1 - East Corridor	Distance (mile)		Shipping Cost (\$Millions) for % Trucks Diverted to Train				
	Highway	Rail	0%	5%	10%	15%	20%
Laredo, TX - Dallas, TX	415.3	432.5	\$372	\$340	\$308	\$276	\$243
Dallas, TX - Memphis, TN	443.2	509.9					
Memphis, TN - Detroit, MI	695.3	714.2	\$299	\$272	\$246	\$220	\$193
Total	1,553.8	1,656.6	\$671	\$612	\$554	\$496	\$436

2 - West Corridor	Distance (mile)		Shipping Cost (\$Millions) for % Trucks Diverted to Train				
	Highway	Rail	0%	5%	10%	15%	20%
Laredo, TX - Dallas, TX	415.3	432.5	\$372	\$340	\$308	\$276	\$243
Dallas, TX - Memphis, TN	443.2	509.9					
Memphis, TN - Detroit, MI	810.9	732.1	\$343	\$312	\$280	\$249	\$218
Total	1,669.4	1,674.5	\$715	\$652	\$588	\$525	\$461

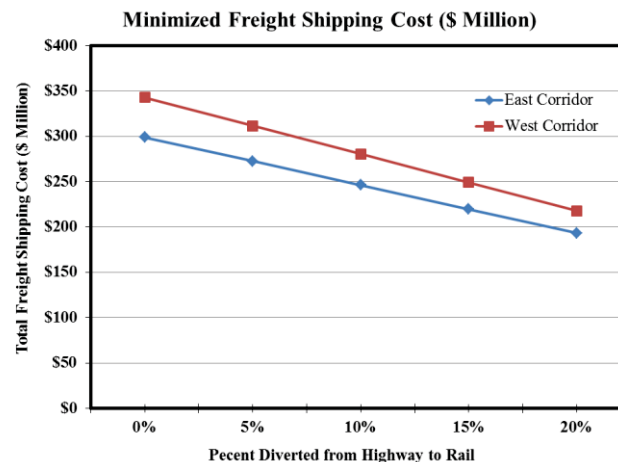


Figure 46. Minimized Freight Shipping Cost (\$ Million) from Memphis to Detroit Segment

Key Results of NAFTA Freight Integration Study from Mexico via Laredo to Detroit

The NAFTA intermodal integration and optimization studies involved candidate freight highway and rail corridor segments within NAFTA corridors from Mexico City to Canada through

Laredo. Laredo, TX border port and Detroit, MI border port were chosen because Laredo manages a volume large enough to justify diverting truck freight to rail. Geospatial analysis was useful to reduce numbers possible routes to just a few feasible corridors. Using the base scenario of freight distribution by highway trucks (43.3%) and rail (56.7%), optimization analysis was performed for truck-rail integration study by diverting 5%, 10%, 15%, and 20% truck loads to rail.

By diverting 20% truck freight to rail corridor connecting Laredo and Detroit, the annual benefits of the integration of highway and rail corridors include the following (Uddin et al. 2016):

- Saving in travel time = 4.6 million hours = 98.8%
- Saving in ton-mile cost = \$1,500 million = 87.2%
- Reduction in CO₂ produced = 208,384 tons = 58.2%
- Saving in fuel cost = \$84,798,828 or 85 million dollars
- About 80% part of truck freight will still be transported by long-haul trucks

2.3 Freight Flow Study of Highway and Mississippi River Corridor Integration

Inland Waterway Freight Flow and Data on Barge Fuel Efficiency and Unit Costs

Efficient and safe freight transportation along and across Mississippi River is essential to support millions of people and all businesses. Bridges on Mississippi River are critical to the mobility of people and freight transportation. For example, the I-40 highway bridge at Memphis serves typically 55,000 vehicles daily including 10,000 trucks traveling in East-West direction across Mississippi River. Additionally, the I-55 highway bridge on Mississippi River also carries traffic North to Chicago and South to Mississippi and Louisiana. It is estimated that it will cost billions of dollars to the economy if the I-40 or I-55 bridge on Mississippi river is out of service due to a catastrophic disaster. In the NCITEC project on flood risk vulnerability, a methodology has been presented for using the flood simulation results to assess the potential damage to transportation infrastructure (Durmus et al. 2015, Durmus 2016, Uddin and Altinakar 2015). Therefore, diverting truck freight from highways to barges through the Mississippi River provides a viable strategy for enhancing supply chain resilience to natural disasters (Uddin et al. 2016).

Spatial maps of barge freight data for the states bordering with Mississippi River and Ohio River for 2009 and associated CO₂ are shown in Figure 47. Figure 48 shows a spatial map of barge shipment data of commodity flow freight processed through major ports in states bordering Mississippi River and Ohio River.

Two case studies were analyzed for highway-rail integration: (1) From Gulfport Port to Vicksburg, MS by short-haul trucks for barge terminal then upbound Mississippi River by barges to St. Louis, MO. (2) Downbound Mississippi River from St. Paul, MN to St. Louis, MO.

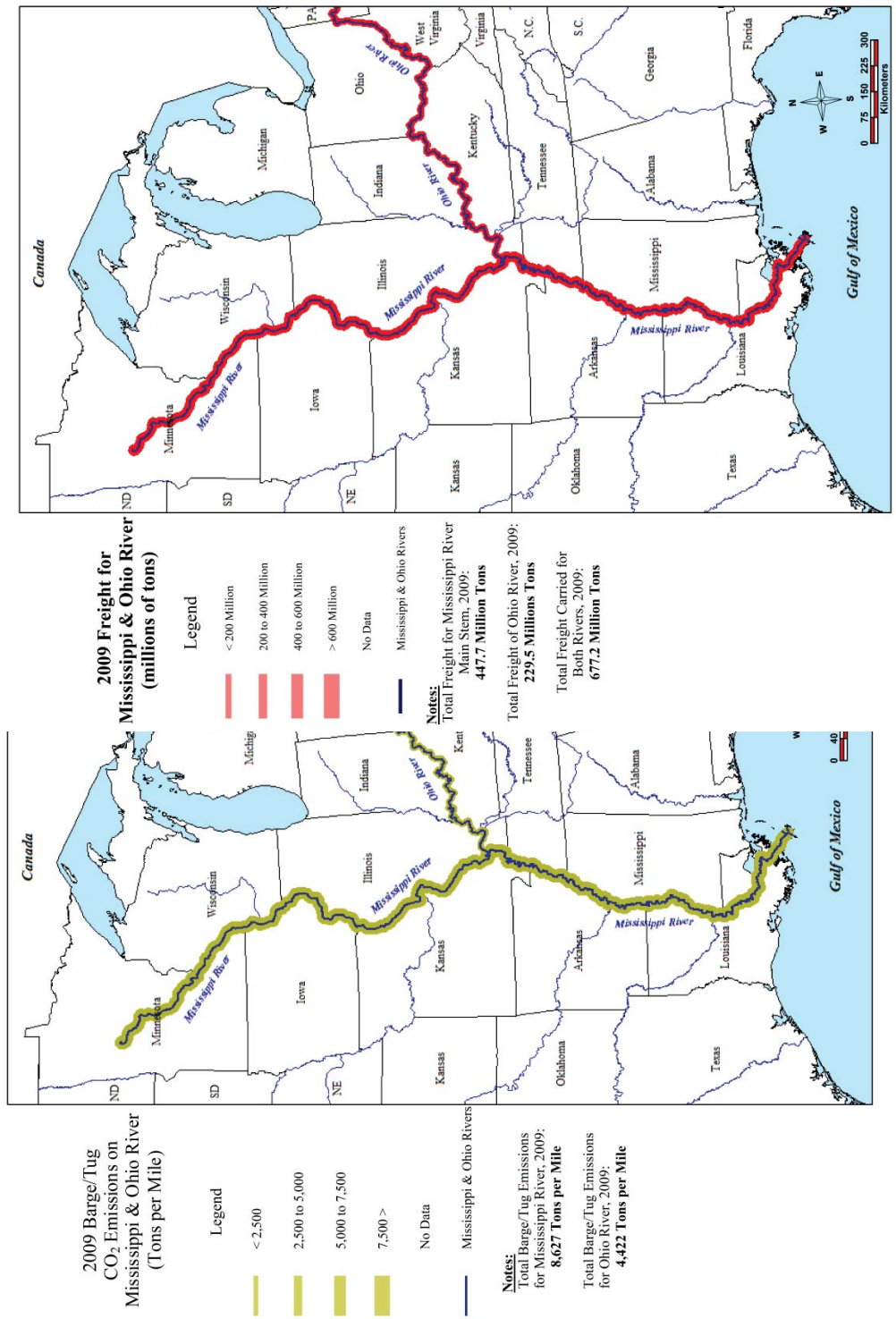
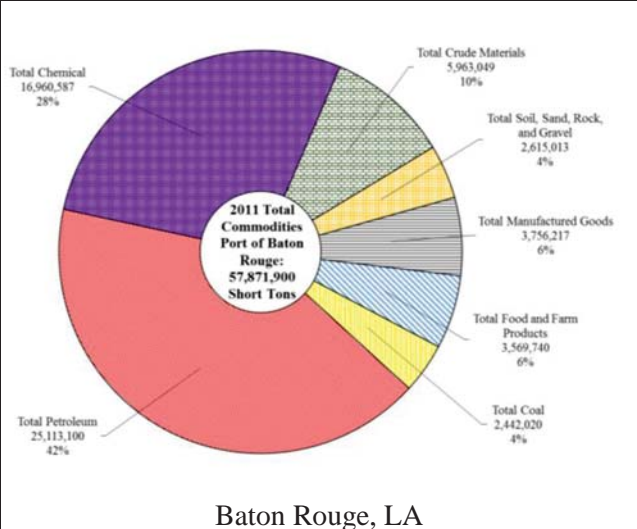
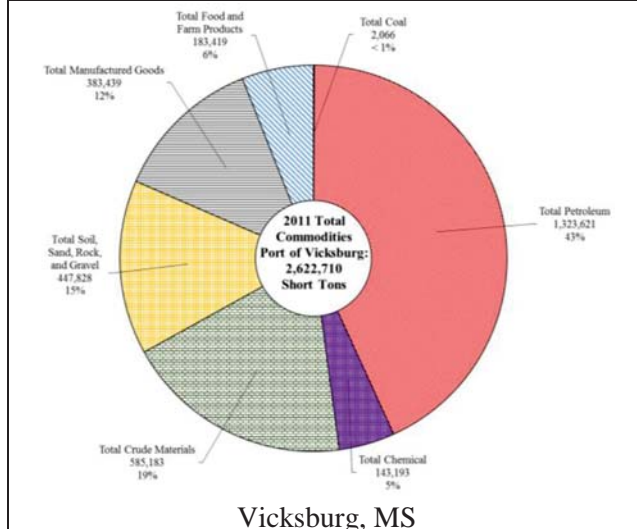
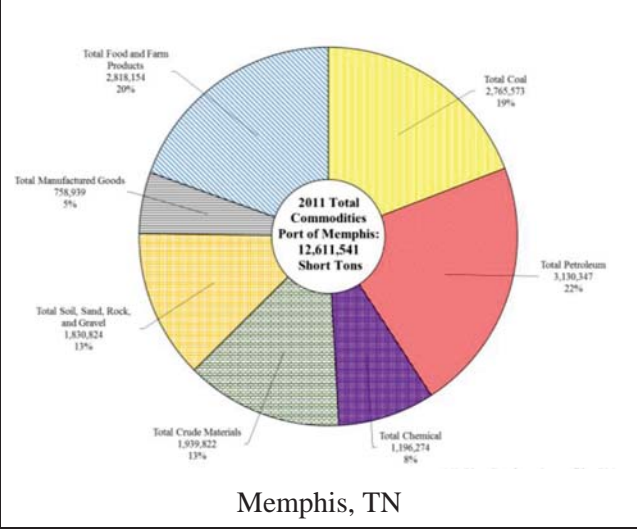
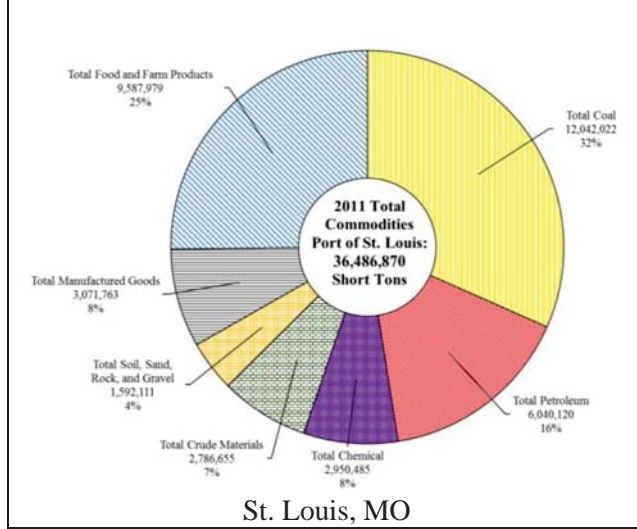
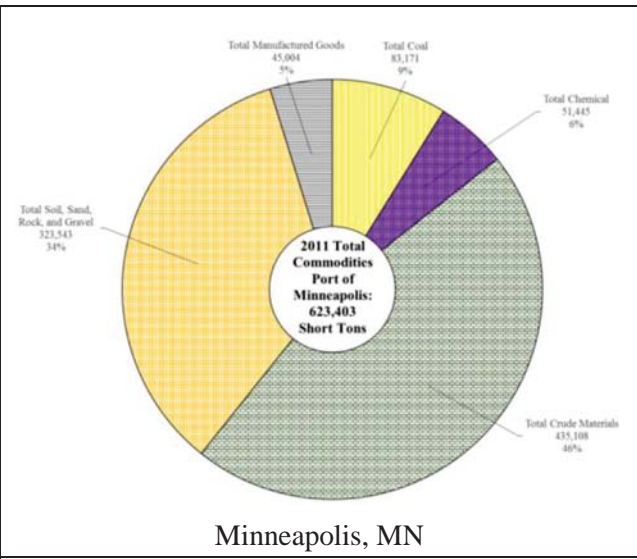
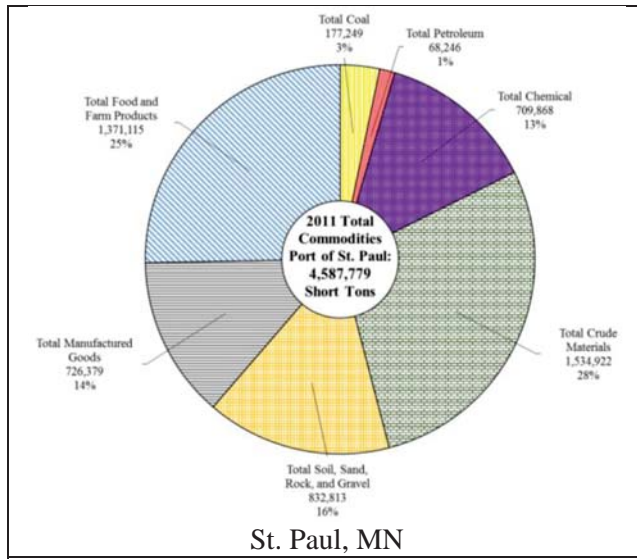


Figure 47. Barge freight data an associated CO for Mississippi River and Ohio River, 2009

All rivers can be seen in the blue color in Figure 48. The Mississippi and Ohio Rivers were displayed in a thicker line width to provide more emphasis on those rivers. The surrounding tributaries are shown in thinner line width.



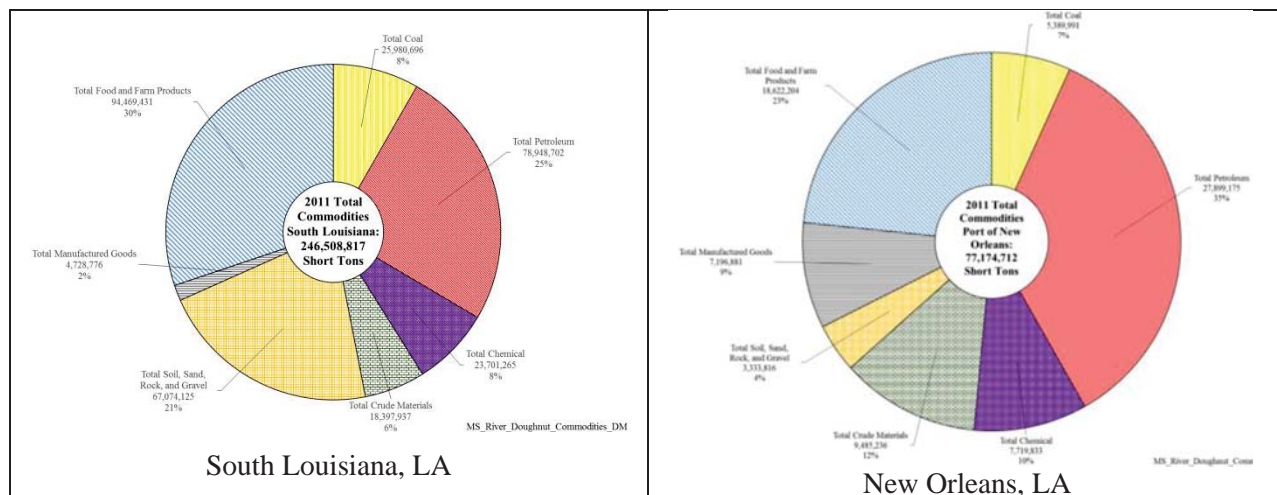


Figure 49. Commodity Flow by Barges Through Ports on Mississippi River

One of the largest ports in the state of Mississippi is the Port of Gulfport, which is located in the central part of the Mississippi Gulf Coast. The port is a major hub for international trade, primarily from South America, but also handles some domestic shipments throughout the U.S. With its' centralized location along the Mississippi Gulf Coast, the Port of Gulfport is a major contributor to truck traffic along the southern portion of the state and along the major interstates passing through Mississippi.

Upbound Highway-Waterway Freight Integration Study

Spatial Features of Selected Routes

This case study analyzes costs and benefits of moving domestic shipments from the Port of Gulfport to the Mississippi River. The integration of highway freight transport with inland waterway system from the Port of Gulfport to the Port of St. Louis is described in Section. The results of this upbound study of highway-waterway freight integration are based on Cobb's M.S. thesis (Cobb 2015) and the final report of NCITEC Project 2012-27 (Uddin et al. 2016). The freight corridor from Gulfport, MS to St. Louis, MO was chosen to assess the benefits of diverting a part of freight truck traffic from I-55 highway to upbound barges on Mississippi River. The Port of Gulfport is the second largest importer of green fruit in the United States and the third busiest container port on the US-side of the Gulf of Mexico. Located right in the center of the Mississippi Gulf Coast, the Port of Gulfport is in close proximity to inland locations along the Mississippi River.

The Port of St. Louis is a major freight hub centered on the Mississippi River corridor. For this reason, a base scenario corridor was chosen for 100% freight only being moved by truck to the Port of St. Louis. Figure 50 is a spatial map developed using GeoMedia Professional that shows the base scenario of the probable route taken for commodities shipped by truck to St. Louis, MO, from Gulfport, MS. The proposed base route would be to take US-49 North 96.1 miles, then turn

onto US-84 West 56.5 miles. From US-84, the driver would turn onto I-55 North and travel 542.6 miles straight into St. Louis, MO.

The directions and distances for the base route are summarized and shown in Table R. The spatial map displays all existing highway infrastructure in the state of Mississippi, including U.S. and state highways, and all interstate highways for the rest of the United States. Interstate highways are shown as the green lines were used to analyze the base scenario and to find where there would be opportunity for moving bulk, non-perishable truck freight to barge. The Mississippi River and other waterway tributaries, ports, and effected states' features are also displayed to help find opportunities. The total length of the base interstate corridor scenario is 695.2 miles.

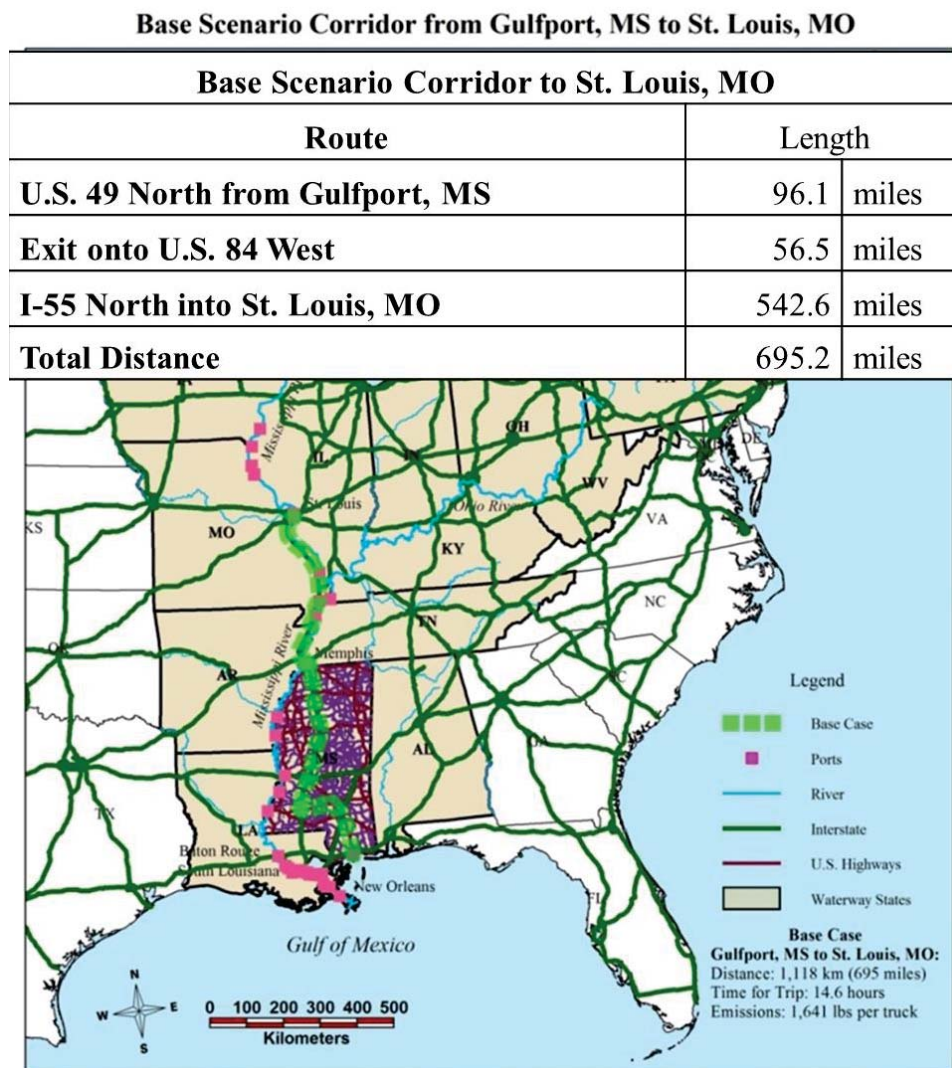


Figure 50. Base Scenario for Freight Shipped by Trucks from Gulfport, MS, to St. Louis, MO

Based on the 2012 commodity flow analysis, there were 25,588 tons of domestic outgoing freight leaving from the Port of Gulfport, all of which were iron and scrap metal. For this case study, the benefits were calculated for moving 30% of this freight from highway to the Mississippi River. The following benefits were calculated for this case study and will be discussed in the next section:

- Travel Time Savings
- Ton-Mile Cost Savings
- CO₂ Emission Reduction
- Fuel Savings

An alternative highway-waterway scenario was also developed for moving the same freight from Gulfport, MS, to St. Louis, MO, but utilizing the Mississippi River to develop a “multimodal corridor” to move the freight. Figure 51 shows the alternative integrated highway/waterway corridor from the Port of Gulfport in Gulfport, MS, to St. Louis, MO. This proposed route is displayed with an orange dashed line overlay.

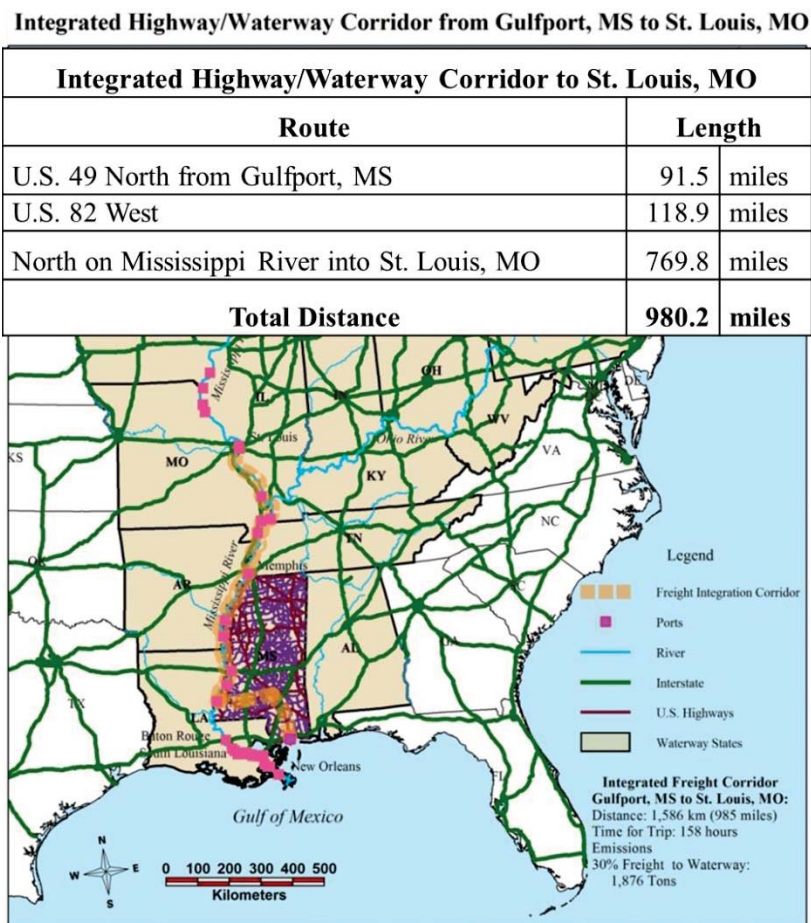


Figure 51. Integrated Highway/Waterway Corridor from Gulfport, MS, to St. Louis, MO

The directions and distances for the base route are summarized and shown in Figure 50 and Figure 51 shows the details of the alternative integrated route. The proposed freight integration corridor includes short haul truck trips from the Port of Gulfport to the Port of Natchez in Natchez, MS, where truck freight would be loaded onto a barge. This short haul truck trip includes travelling North on US-49 for 91.5 miles from the Port of Gulfport and then heading West on US-82 for 118.9 miles, which will run into Natchez, MS. From there, freight will be transferred from truck to barge and shipped 769.8 miles upstream via the Mississippi River, which would run directly into St. Louis, MO. From St. Louis, freight can be shipped by truck on a short haul route to surrounding cities.

This spatial map in Figure 51 shows the same highway infrastructure features as the base scenario map, which includes interstates for the U.S., U.S. and state highways in the state of Mississippi, and also inland waterways within the focus area of the case study. The focus states are shaded in beige color on the map. St. Louis' centralized location allows for easy short truck hauls to major freight hubs in the northern U.S. such as Detroit, MI, Chicago, IL, and Minneapolis, MN. The total distance for the integrated corridor is 980.2 miles from Gulfport to St. Louis. Due to the meandering nature of the Mississippi river, there is a significant difference in length between the two corridor scenarios. The integrated corridor length is 285 miles or 41% longer than the highway base scenario.

Economic Analysis of Costs and Benefits

(a) *Travel Time Savings:* Truck trips were calculated using Equation 7, and travel time per trip was calculated using Equation 8. Below are some of the known data and assumptions used for calculating total travel time for the Base Truck Scenario which is hauling all freight from Gulfport, MS, by truck to St. Louis, MO, on the route as shown previously in Table R. All calculations are made to determine the savings and benefits, assuming 30% of the total domestic freight (for illustration) is being removed from highway and onto barge to travel on the Mississippi River.

- Total Domestic Freight Amount for Port of Gulfport: 25,588 Tons
- 30% of Domestic Freight for Highway/Waterway Integration: 7,676 Tons
- Assumptions for Base Scenario Trucks (MODOT 2012)
 - 20-Ton Truck Capacity
 - 55 mph Average Speed
 - 4 hours of stops for rest, fuel, and food per trip

$$\text{Number of Trips} = \frac{\text{Total Freight (Tons)}}{\text{Capacity (Tons per Vehicle)}} \quad \text{Eq. 7}$$

$$\text{Travel Time per Trip (hrs)} = \frac{\text{Length (miles)}}{\text{Speed (mph)}} + \text{Time for Stops (hrs)} \quad \text{Eq. 8}$$

- Base Scenario Trucks: Travel Time Calculations
 - Total Number of Truck Trips for All Outbound Freight (Equation 7):
25,588 Tons/20 Tons per Truck = **1,280 Trips**
 - Total Time taken per Truck from Gulfport, MS, through US-49, US-82, and I-55 to St. Louis, MO, (Equation 8):
(695 Miles/55 mph) + 4 hours (stops, fuel, food) = **16.6 hours per Truck Trip**
 - Total Travel Time for 384 Truck Trips:
16.6 hours per trip x 1,280 trips = **21,248 hours**

The following calculations are for the short haul truck portions of the Integrated Highway/Waterway Scenario. The truck portion of the integrated scenario uses the same assumptions as that in the Base Truck Scenario for the trucks hauls. The only change is the length of the route being driven, which is now from Gulfport, MS, to Natchez, MS, and there are no stops for rest due to a significantly shorter trip.

- Integrated Highway/Waterway Corridor Travel Time Calculations for Truck Portion (using same truck assumptions as for base scenario):
 - Number of Short Haul Truck Trips to Move 30% of Outbound Freight (Equation 7):
7,676 Tons/20 Tons per Truck = **384 Truck Trips**
 - Total Time taken per Truck from Gulfport, MS up US-49 North, US-82 West into Natchez, MS (Equation 8):
216 Miles/55 mph = **4 hours per Truck Trip**
 - Total Travel Time for 384 Truck Trips to Natchez, MS:
4 hours x 384 Short Haul Trips = **1,536 hours**

Barge trips were calculated using Equation 7, and travel time per trip was calculated using Equation 8. The following are some assumptions used for the calculations of travel time and barge trips for the Mississippi River Corridor from Natchez, MS, to St. Louis, MO.

- Assumptions for Barge Freight on the Mississippi River from Port of Natchez to St. Louis, MO:
 - 1500 Tons per Barge (75 number of 20-Ton Truck Loads)
 - 4 knots (5 mph) upstream
 - Non-stop travel using multiple operators (no stoppage for fuel, food, rest, etc.)

The following calculations were made using the assumptions previously listed for barge:

- Integrated Highway/Waterway Corridor: Travel Time Calculations for Barge
 - Total Number of Barge Trips (Assuming slight overload) (Equation 7):
7,676 Tons/ 1500 Tons per Barge = **5 Barge Trips**

- Hours per Trip from Gulfport, MS, to Natchez, MS, by Truck and from Natchez, MS, to St. Louis, MO, by Barge (Equation 8):

$$(216 \text{ Miles}/55 \text{ mph}) (\text{Truck}) + (768 \text{ Miles}/5 \text{ mph}) (\text{Barge}) = 158 \text{ Hours per Trip}$$

$$4 \text{ Hours (Trucks)} + 154 \text{ Hours (Barge)} = \mathbf{158 \text{ Hours}}$$
- Total Travel Time:

$$(4 \text{ Hours} \times 384 \text{ Trips}) (\text{Truck}) + (158 \text{ Hours} \times 5 \text{ Barge Trips}) = 2,306 \text{ Hours}$$

$$1,536 \text{ Hours (Truck)} + 770 \text{ Hours (Barge)} = \mathbf{2,306 \text{ Hours}}$$
- Travel Time for Remaining 70% of Freight by Highway:

$$(1280 \text{ Trips} - 384 \text{ Short Haul Trips}) \times 16.6 \text{ hours per trip} = \mathbf{14,874 \text{ Hours}}$$
- Total Time to Move 100% of Freight Using Multimodal Integration:

$$14,874 \text{ Hours} + 2,306 \text{ Hours} = \mathbf{17,180 \text{ Hours}}$$

The following should be noted about the calculations made:

- Tug boat operators can move more than one barge of commodities and shipments, but assuming different trips to move total outgoing amount since freight will not ship at one time.
- The above analysis does not consider interruptions in freight truck travel due to highway incidents or barge travel interruptions due to draught and incidents.

(b) Ton-Mile Cost Savings: Total ton-mile cost was calculated using Equation 1. Also, the average ton-mile cost values from Table 13 were also used in these calculations.

- Base Scenario Corridor Long Haul Trucks Cost
 - Total Ton-Mile Cost for Trucks Carrying 30% of Total Freight (Equation 1):

$$(25,588 \text{ Tons} \times 695 \text{ Miles}) \times (34.39 \text{ cents}/100) = \mathbf{\$6.1 \text{ Million}}$$
- Integrated Highway/Waterway Corridor Cost
 - Total Ton-Mile Cost for 30% of Freight to Be Moved to New Integrated Highway/Waterway Corridor (Equation 14):

$$(7,676 \text{ Tons} \times 216 \text{ Miles}) \times (34.39 \text{ cents}/100) + (7,676 \text{ Tons} \times 768 \text{ Miles}) \times (2.17 \text{ cents}/100) = \mathbf{\$0.7 \text{ Million}}$$
 - Total Ton-Mile Cost to Ship Remaining 70% by Highway Corridor:

$$(17,912 \text{ Tons} \times 695 \text{ Miles}) \times (34.39 \text{ cents}/100) = \mathbf{\$4.3 \text{ Million}}$$
 - Total Ton-Mile Cost to Ship by Multimodal Corridor:

$$\mathbf{\$4.3 \text{ Million} + \$0.7 \text{ Million} = \$5.0 \text{ Million}}$$

(c) CO₂ Emission Reduction: CO₂ emissions were calculated in short tons using Equation 3 (Uddin 2012). Also, the net freight ton-miles per gallon values from Table 1 were used in these calculations. According to the EPA, the average CO₂ emissions per gallon of diesel fuel are 22.2 lbs/gal (EPA 2005).

- Base Scenario Long Haul Trucks:
 - CO₂ Emission for Trucks Carrying 30% of Total Freight (Equation 3):

$$(25,588 \text{ Tons} \times 695 \text{ Miles} \times 22.2 \text{ lbs/gal} / 155 \text{ Ton-Miles/gal}) / 2000 \text{ lbs} = \mathbf{1,274 \text{ Tons}}$$

- Integrated Highway/Waterway Corridor Short Haul Trucks
 - CO₂ Emissions for Trucks Carrying 30% of Total Freight on Short Haul Routes (Equation 3):
 $(7,676 \text{ Tons} \times 216 \text{ Miles} \times 22.2 \text{ lbs/gal} / 155 \text{ Ton-Miles/gal}) / 2000 \text{ lbs} = \mathbf{118 \text{ Tons}}$
- Integrated Highway/Waterway Corridor Barge from Natchez, MS, to St. Louis, MO:
 - CO₂ Emissions for Barge Carrying 30% of Total Freight on Mississippi River to St. Louis, MO (Equation 3):
 $(7,676 \text{ Tons} \times 768 \text{ Miles} \times 22.2 \text{ lbs/gal} / 576 \text{ Ton-Miles/gal}) / 2000 \text{ lbs} = \mathbf{114 \text{ Tons}}$
- Integrated Highway/Waterway Corridor Remaining 70% of Freight
 - CO₂ Emissions for Trucks Carrying 70% of Total Freight Highway (Equation 3):
 $(17,912 \text{ Tons} \times 695 \text{ Miles} \times 22.2 \text{ lbs/gal} / 155 \text{ Ton-Miles/gal}) / 2000 \text{ lbs} = \mathbf{891 \text{ Tons}}$
- Integrated Highway/Waterway Corridor Total CO₂ Emissions
 - Total CO₂ Emissions for Integrated Multimodal Corridor
 $118 \text{ Tons} + 114 \text{ Tons} + 891 \text{ Tons} = \mathbf{1,123 \text{ Tons}}$

(d) *Truck Fuel Cost Saving*: The fuel cost saving methodology used Equation 2 by reducing the number of long haul truck trips to ship 7,676 tons freight. The average fuel efficiency for a diesel engine heavy duty truck is 5.9 miles per gallon. The fuel cost for these calculations used \$2.50 per gallon at the general market price in 2015-2016.

Total Long Haul 20-ton Truck Trips in Base Case = 1,280 Trips (for 695.2 miles each trip)

30% Long Haul Truck Trips Eliminated in Integration Case = $0.3 \times 1,280 = 384$ Truck Trips

Fuel Saving per Truck = $(695.2 / 5.9) \times 2.5 = \294.5 ; For 384 Truck Trips = $384 \times 294.5 = \$113,088$

Additional Short Haul Truck Trips in Integration Case = 384 Truck Trips (91.5 plus 118.9 miles)

Total 1500-ton Barge Trips Added in Integration Case (freight of 75 Trucks) = $384 / 75 \sim 5$ Barges

Fuel Cost Saving per truck trip Diverted to Barge = Net Fuel Saved in Shipping

= $\{384 \text{ Truck trips} \times (695.2 - 210.4 \text{ miles}) / 5.9 \text{ miles per gallon}\} \times \$2.5 \text{ per gallon} = \$78,883$

For 20% Elimination of Long Haul Trucks, Fuel Saving per Truck = $(695.2 / 5.9) \times 2.5 = \294.5

For $0.2 \times 1,280$ or 256 Truck Trips Eliminated, Fuel Cost Saving = $256 \times 294.5 = \$75,392$

(e) *Summary of Highway-Waterway Upbound Intermodal Freight Results*: A summary of the results can be seen in Table 7. Based on the calculations, significant economic benefit can be found in moving just 30% of the total out going freight from the Port of Gulfport from the highway to barge on the Mississippi River. A summary of the results can be seen in 7. Although the base scenario provides a much shorter route, there is a 19% reduction in travel time dropping from 21,248 hours to move all freight by highway to 17,180 hours by integrating the Mississippi River. This is due to a significant drop in the number of trips due to barge having a much larger

capacity to haul freight. Using an integrated corridor also shows a reduction in CO₂ emissions by 11.8 % from 1,274 tons of CO₂ emitted to 1,124 tons. By removing 30% of the freight to waterway there was a savings of approximately \$1.1 million, which is a large amount of money for a relatively small amount of freight. There was an 18% decrease in total ton-mile cost to ship by the integrated route rather than the base scenario corridor. Figure 52 shows a visual comparison of the two corridors and the reduction in total travel time and CO₂ emissions.

Table 7. Summary of Benefit and Savings for 30% Freight Diverted from Truck Trips to Upbound Mississippi River

Route	Length (miles)		Total Travel Time (hours)	CO ₂ Emission (Short Tons)	Total Shipping Cost per Year, \$
	Highway	Barge			
Base Interstate Corridor Scenario	695	0	21,248	1,274	\$6.1 Million
Integrated Highway/Waterway – 30% Diverted to Water	216	768	17,180	1,124	\$5.0 Million
Savings from Integration Corridor			4,068 (19.1%)	150 (11.8%)	\$1.1 Million (18%)

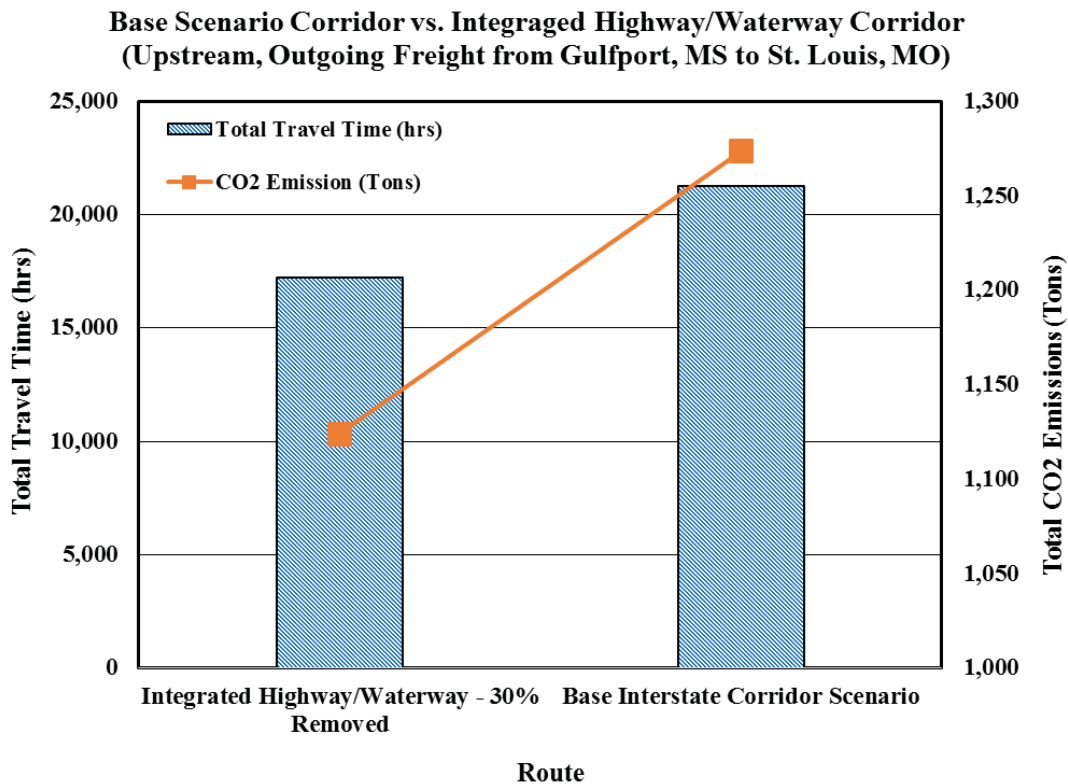


Figure 52. Base Scenario Highway Corridor vs. Integrated Highway/- and Upbound Waterway Corridor Results

By choosing to ship freight that is going to St. Louis, MO, by barge rather than by the base scenario highway route, there is a savings of \$294.50 per truck making the trip. Eliminating 30% of the truck freight from the highway, which is 384 truck trips, there is a fuel savings of \$113,088, using the 695-mile truck route for the calculations. The net truck fuel cost saving considering short haul truck trips is \$78,883.

The integrated corridor for diverting freight from truck trips to upbound Mississippi River reduces costs and provides more benefits compared to the base corridor scenario, as follows:

<u>% Truck Diverted</u>	<u>Travel Time Reduction</u>	<u>Ton-Mile Cost Savings</u>	<u>CO₂ Reduction</u>
10%	6.3%	6.2%	6.9%
20%	12.2%	12.4%	7.8%
30%	19.1%	18.0%	18.0%
100%	63.5%	61.9%	39.2%

Downbound Highway-Waterway Freight Integration Study

Study Features and Commodity Analysis

Further analysis was also conducted to assess the costs and benefits of diverting bulk commodity shipments from freight trucks to waterway barges downbound Mississippi River from the Port of St. Paul, Minnesota to the Port of St. Louis, Missouri. The results of downbound study of highway-waterway freight integration are based on an interim report on this NCITEC project 2013-32 by a PhD student (Jaafar 2016). This section discusses the example of intermodal integration of freight movement from Port of Saint Paul, Minnesota to Port of Metropolitan Saint Louis, Missouri. This freight corridor was chosen to assess the benefits of diverting a part of freight truck traffic from highway trucks to downbound barges on Mississippi River. Four different case studies were evaluated. The selected case studies were:

- 1) 100% of the commodity transported by freight truck
- 2) 20% of the commodity by barge (waterway) and 80% transported by truck
- 3) 40% of the commodity by barge (waterway) and 60% transported by truck
- 4) 60% of the commodity by barge (waterway) and 40% transported by truck.

The commodity was transferred exactly from Port of St. Paul, MN to Port of St. Louis, MO. No short-haul trucks were used in the downbound Mississippi River integration study. Other assumptions used in the analysis for freight movement using trucks and barges are as follows:

- Assumptions for freight movement using trucks (MODOT 2012)
 - 20-Ton Truck Capacity
 - Average 55 mph Speed
 - Average 4 hours of stops for rest, fuel, and food per trip
 - Average 34.39 Cents per ton-mile shipping cost
- Assumptions for freight movement using barge
 - 1,500-Ton Barge Capacity
 - Average 9.2 mph Downbound Average Speed
 - Non-stop travel using multiple operators (no stoppage for fuel, food, rest, etc.)
 - Average 21.7 Cents per ton-mile shipping cost

Prior to the freight shipping analysis, commodity research was conducted to determine bulk commodity transported mostly using truck from a few states in the northwest of the Port of St. Louis, MO. Those states are Idaho, Wyoming, South Dakota, North Dakota, and Minnesota. It was discovered that the nonmetal mineral products was almost 100% transported by trucks from Minnesota to Missouri at a total of approximately 2.3 million tons per year, as shown in Figure 53.

The nonmetal mineral product is 70% from the total of 3,220,195 tons of commodities transported from Minnesota to Missouri which is about 12 times higher than the percentages of the second highest commodity. The fact that 100% of the nonmetal mineral products was moved using trucks only provides a chance to move this commodity using barge. Therefore, further study was conducted to assess the benefits of integration of commodity between highway and waterway system in term of total travel time reduction, ton-mile cost savings, and CO₂ reduction.

Table 8 summarizes the highway routes and their distances for commodity shipment using trucks. The total highway lengths calculated was 863.3 km or 536.5 miles. The distances between the Port of St. Paul, MN to the Port of St. Louis, MO through Mississippi River Corridor are shown in Table 9. The total length of Mississippi River corridor in between those ports is 863.3 km or 536.5 miles.

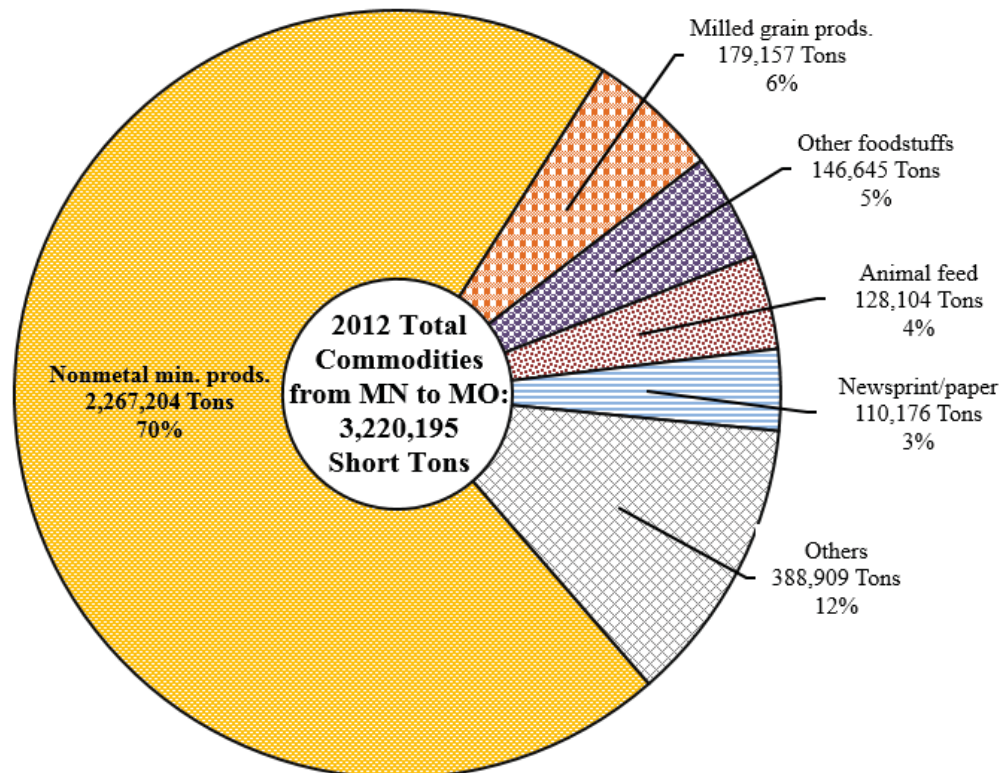


Figure 53. Top five commodities transported from Minnesota to Missouri, 2012

Table 8. Selected Highway Routes and Distances from Port of St. Paul, MN to Port of St. Louis, MO

No.	Freight Integration Corridor Lengths from Port of St. Paul, MN to Port of St. Louis, MO	
1	Saint Paul Port Authority to US-63 & I-90 Intersection at Stewartville, MN (through US-52)	138.1 km
2	US-63 & I-90 Intersection at Intersection at Stewartville, MN to US-63 & US-218 Intersection at Waterloo, IA (through US-63)	167 km
3	US-63 & US-218 Intersection at Waterloo, IA to US-218 & I-380 Intersection at Waterloo, IA (through US-218)	5.9 km
4	US-218 & I-380 Intersection at Waterloo, IA to I-380 & US-30 Intersection (through I-380)	88.3 km
5	I-380 & US-30 Intersection to I-380 & I-80 Intersection (through I-380)	26.3 km
6	I-380 & I-80 Intersection to US-218 & US-61 Intersection at Keokuk, IA (through US-218)	151.1 km
7	US-218 & US-61 Intersection at Keokuk, IA to US-61 & SR 27 Intersection at Kahoka, MO (through US-61)	20.2 km
8	US-61 & SR 27 Intersection at Kahoka, MO to US-61 & I-70 Intersection at Boone Township, MO (through US-61)	203.7 km
9	US-61 & I-70 Intersection at Boone Township, MO to Saint Louis Port River Terminal, MO (through I-70)	62.8 km
	Total Length	863.3 km

Table 9. Distances Between the Port of St. Paul, MN to the Port of St. Louis, MO

No.	Mississippi River Corridor from Port of St. Paul, MN to Port of St. Louis, MO	
1	Port of Saint Paul, MN to Port of Dubuque, IA	410 km
2	Port of Dubuque, IA to Port of Burlington, IA	278.8 km
3	Port of Burlington, IA to Port of Keokuk, IA	65.6 km
4	Port of Keokuk, IA to Port of Quincy, IL	58.6 km
5	Port of Quincy, IL to Port of Hannibal, MO	28.7 km
6	Port of Hannibal, MO to Port of Metropolitan Saint Louis, MO	201.8 km
	Total Length	1,043.5 km

The analysis for all case scenarios follows:

(1) *Base Scenario*

Base scenario considers 100% of the nonmetal mineral products transported using long haul trucks.

(a) *Travel Time Calculations:* Travel time is calculated for all 100% trucks.

- Total Number of Truck Trips for All Outbound Freight (Equation 7):
2,267,022.7 Tons/20 Tons per Truck = **113,351 Trips**
- Total Time taken per Truck from port of St. Paul, MN to Port of St. Louis, MO (Equation 8):
(536.5 Miles/55 mph) + 4 hours (stops, fuel, food) = **13.8 hours per Truck Trip**
- Total Travel Time for 113,351 Truck Trips:
13.8 hours per trip x 113,351 trips = **1,564,246 hours (65,177 Days)**
- (b) *Ton-Mile Cost Savings*: Base Scenario Corridor for 100% Long Haul Trucks Cost
 - Total Ton-Mile Cost per Year for Trucks Carrying 100% of Total Freight (Equation 1):
(2,267,022.7 Tons x 536.5 Miles) x (34.39 cents/100) = **\$418.2 Million**
- (c) *CO₂ Emission Reduction*: Base scenario's CO₂ emissions were calculated using Equation 3.
 - CO₂ Emission for Trucks Carrying 100% of Total Freight (Equation 1):
(2,267,022.7 Tons x 536.5 Miles x 22.2 lbs/gal / 155 Ton-Miles/gal)/2000 lbs = **87,099.7 Tons**

(2) *Integrated Scenario*

Assuming 80% of the commodity was transported using long haul trucks and the remaining 20% was shipped using barges through integrated downbound Mississippi River.

(a) *Travel Time*: Travel time is calculated for 80% trucks and 20% by barges.

- Total Number of Truck Trips for All 100% Outbound Freight (Equation 7):
1,813,618.2 Tons/20 Tons per Truck = **90,681 Trips**
- Total Time taken per Truck from port of St. Paul, MN to Port of St. Louis, MO (Equation 8):
(536.5 Miles/55 mph) + 4 hours (stops, fuel, food) = **13.8 hours per Truck Trip**
- Total Travel Time for 90,681 Truck Trips:
13.8 hours per trip x 90,681 trips = **1,251,396.5 hours**

Integrated Highway/Waterway Corridor: Travel Time Calculations for 20% Barge Freight

- Total Number of Barge Trips (Assuming slight overload) (Equation 7):
453,404.5 Tons/ 1,500 Tons per Barge = **302 Barge Trips**
- Total Travel Time for 302 Barge Trips:
70.5 Hours x 302 Barge Trips = **21,291 Hours**
- Total Time to Move 100% of Freight Using Multimodal Integration:
1,251,396.5 Hours + 21,291 Hours = **1,272,687.5 Hours**

(b) *Ton-Mile Cost Savings*: Costs are calculated for 80% Long Haul Trucks and 20% Barges in Integrated Highway/Waterway Corridor.

- Total Ton-Mile Cost for Trucks Carrying 80% of Total Freight (Equation 1):
(1,813,618.2 Tons x 536.5 Miles) x (34.39 cents/100) = **\$334.6 Million**
- Total Ton-Mile Cost to Ship Remaining 20% by Highway Corridor:
(453,404.5 Tons x 648.4 Miles) x (2.17 cents/100) = **\$6.4 Million**
- Total Ton-Mile Cost to Ship by Multimodal Corridor:
\$334.6 Million + \$6.4 Million = **\$341.0 Million**

(c) *CO₂ Emission Reduction*: Freight CO₂ emissions were calculated using Equation 3. Also, the net freight ton-miles per gallon values from Table 1 shown previously were used in these calculations. The average CO₂ emissions per gallon of diesel fuel are 22.2 lbs/gal (EPA 2005, Uddin 2012).

➤ CO₂ Emissions for Trucks Carrying 80% of Total Freight on Long Haul Routes (Equation 3):

$$(1,813,618.2 \text{ Tons} \times 536.5 \text{ Miles} \times 22.2 \text{ lbs/gal} / 155 \text{ Ton-Miles/gal}) / 2000 \text{ lbs} = \mathbf{69,679.8 \text{ Tons}}$$

➤ CO₂ Emissions for Barge Carrying 20% of Total Freight on Mississippi River to St. Louis, MO (Equation 3):

$$(453,404.5 \text{ Tons} \times 648.4 \text{ Miles} \times 22.2 \text{ lbs/gal} / 576 \text{ Ton-Miles/gal}) / 2000 \text{ lbs} = \mathbf{5,666.3 \text{ Tons}}$$

➤ Total CO₂ Emissions for Integrated highway and Waterway Intermodal Corridor
69,679.8 Tons + 5,666.3 Tons = **75,346 Tons**

(d) *Truck Fuel Cost Saving*: The fuel cost saving methodology used Equation 2 by reducing the number of long haul truck trips by 20% to ship 453,404.5 tons freight. The average fuel efficiency for a diesel engine heavy duty truck is 5.9 miles per gallon. The fuel cost for these calculations used \$2.50 per gallon at the general market price in 2015-2016.

Total Long Haul 20-ton Truck Trips in Base Case = 22,670 Trips (for 536.5 miles each trip)

(20% Long Haul Truck Trips Eliminated in Integration = 0.2 x 113,351 = 22,670 Truck Trips)

$$\text{Fuel Cost Saving per Truck} = (536.5 / 5.9) \times 2.5 = \$227.33$$

$$\text{Fuel Cost Saving for 22,670 Truck Trips} = 22,670 \times 227.33 = \$5,153,582.63$$

Table 10. Calculation Using Microsoft Excel for Diverting 20% of The Commodity by Barge to the Port of St. Louis, MO

Scenario: 20% of the commodity (nonmetal mineral products) moved by barge & 80% of the commodity was transported by trucks

A	B ₁	B ₂	C	D	E ₁	E ₂	F ₁	F ₂
Routes	Lengths (miles)		Total Freight (Tons)	20% of Total Freight (Tons)	No. of Trips		Time per Trip (Hours)	
	Highway	Barge			Highway	Barge	Travel	Rest/Food/Fuel
Base Interstate Corridor Scenario	536.5	0.0	2,267,023	453,405	22,670	0	9.8	4.0
Integrated Highway/Waterway - 20% Moved to Barge	0.0	648.4			22,670	302	4 Hours Truck + 70.5 Hours Barge	0.0

80% Truck 1,813,618.2 90,680.9
100% Truck 2,267,022.7 113,351.1

	G ₁	G ₂	H	I	J	K	L	M
Routes	Total Travel Time		Total Travel Time (Hours)	Total Days of Travel	CO ₂ Emissions (Tons)	CO ₂ Emissions per 100 Miles (Tons)	Total Ton-Mile Cost per Year (Million US\$)	Total Ton-Mile Cost per 100 Miles, (Million US\$)
	Travel	Rest/Food /Fuel						
Base Interstate Corridor Scenario	221,138	90,681	311,819	38,977	17,419.9	3,247.0	83.6	15,591,106.2
Integrated Highway/Waterway - 20% Moved to Barge	21,310	0	21,310	888	5,665.4	2,686.6	6.4	983,972.5
	1,251,396.5		1,251,396.5		75,345.2		341.0	
	1,564,245.7		1,564,245.7		87,099.7		418.2	

Table 10 shows the example of calculation the travel time, total mile-cost saving, and CO₂ emission reduction using Microsoft Excel for case scenario where 20% of the commodity was moved to waterway system. The remaining 80% of the commodity was transported by truck to the Port of St. Louis, MO.

The step-by-step calculations for other cases where 40% and 60% of the commodity shipped by barge are not shown in this section but the results are summarized in Table 11.

Table 11. Summary of Benefit and Savings Calculations

Routes	Length (miles)		Total Travel Time		CO ₂ Emission (Tons)	Total Ton-Mile Cost per Year, Million US\$
	Highway	Barge	Hours	Days		
Base Interstate Corridor Scenario, 100% Trucks	537	0	1,564,246	65,177	87,099.7	418.2
Integrated Highway/Waterway 20% Diverted to Barges	0	648	1,272,707	53,029	75,345.2	341.0
Integrated Highway/Waterway 40% Diverted to Barges	0	648	981,167	40,882	63,590.6	263.7
Integrated Highway/Waterway 60% Diverted to Barges	0	648	689,628	28,735	51,836.0	186.4

(e) *Summary of Highway-Waterway Downbound Intermodal Freight Results:* A summary of the results can be seen in Table 11. Although the base scenario provides a much shorter route, there are reductions in total travel time range from approximately 19 to 56%. The higher the percentage of commodity moved by barge results in lower total travel time to transport the nonmetal mineral products to the Port of St. Louis, MO. This is due to a significant drop in the number of trips due to barge having a much larger capacity to haul freight.

Using an integrated corridor also shows a reduction in CO₂ emissions by 13.5, 27.0 to 40.5% by moving 20, 40, and 60% of the commodity to the waterway system, respectively. By removing 20 to 60% of the freight to downbound waterway, the total savings based on the ton-mile cost per year range from 77.3 to 231.8 million US\$. The ton-mile cost per year saving range from approximately 19 to 55% compared to base scenario. Figure 53 (a) shows a comparison of reduction in total travel time and CO₂ emissions for all case studies. The reduction in travel time and total ton-mile cost per year (Million US\$) is shown in Figure 53(b). The integrated corridor reduces significant travel time, shipping cost, and CO₂ emission compared to only long haul truck freight shipment for the base corridor scenario. A summary of benefits and reduction in CO₂ emission is as follows:

% Truck Diverted	Travel Time Reduction	Ton-Mile Cost Savings	CO ₂ Reduction
20%	18.6%	13.5%	18.5%
40%	37.3%	27.0%	36.9%
60%	55.9%	40.5%	55.4%

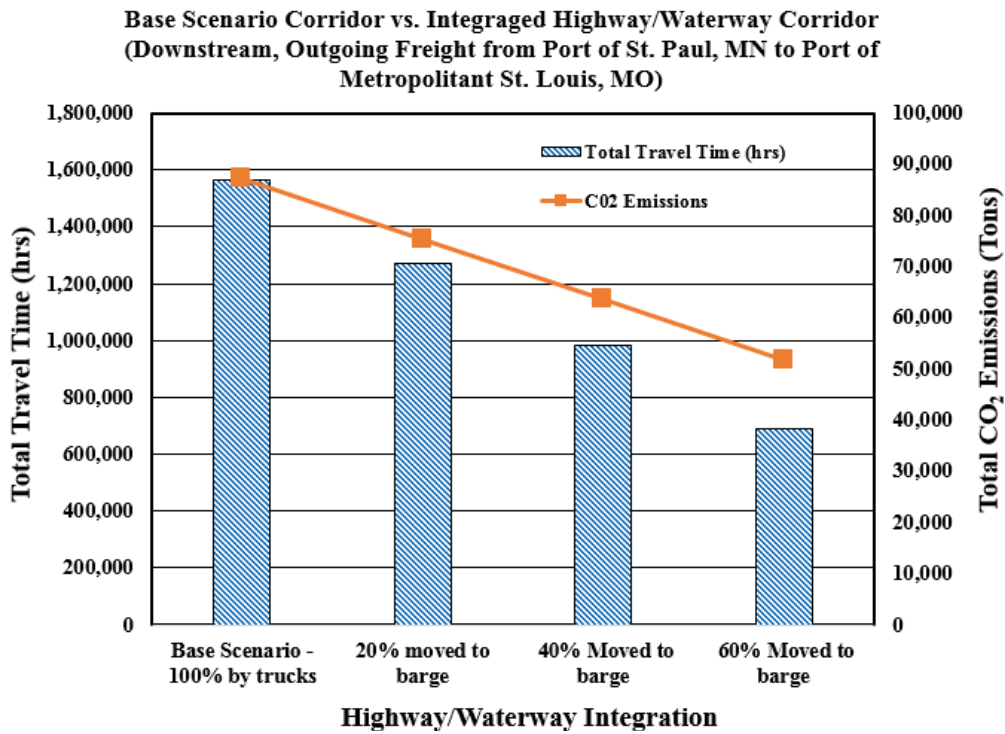


Figure 53(a). Base Scenario Corridor vs. Integrated Highway/Waterway Corridor Results to move commodity from the Port of St. Paul, MN to the Port of St. Louis, MO

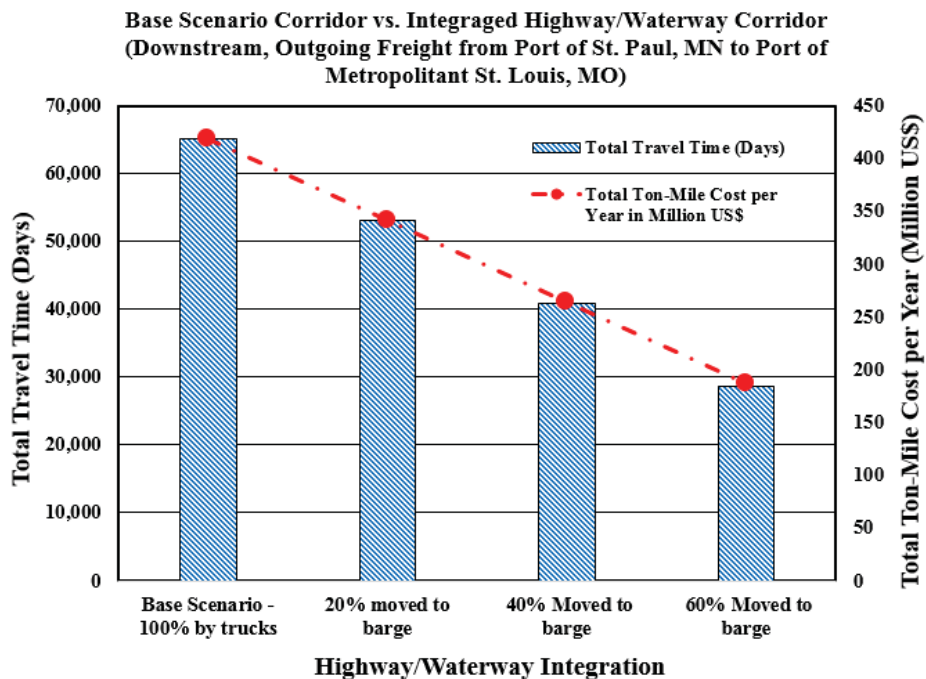


Figure 53(b). Base Scenario Corridor vs. Integrated Highway/Waterway Corridor Results to move commodity from the Port of St. Paul, MN to the Port of St. Louis, MO

Discussion of Freight Integration Study Results for Mississippi River Case Studies

Based on the calculations, significant economic benefit can be found in moving just 20 to 30% of the total freight shipping from the highway only mode to barge on the Mississippi River. The results also show that using an integrated corridor also reduces CO₂ emissions.

The following summary is for costs and benefits for diverting 20% of freight from truck trips to integrated Highway and Mississippi River:

Study	Travel Time Reduction	Ton-Mile Cost Savings	CO ₂ Reduction	Fuel Savings
Upbound	12.2%	12.4%	7.8%	\$75,392
Downbound	18.6%	13.5%	18.5%	\$5.15 Million

2.4 Optimization of Freight Corridor for Commodity Distribution

Freight Distribution Optimization Problem

Ports feature crucial intermodal terminals for processing commodity imports for shipment inland by highway trucks and freight rail, as well as commodity exports are shipped to the port for loading on ships to destinations abroad. A recent SHRP2 study evaluated integrating freight considerations for the highway capacity planning process (SHRP2 2014). This study was conducted to ensure more efficient freight movement which contributes to the economic well-being of the county at both the state and national level. Therefore, optimization of intermodal routes as part of the freight shipment planning is required to ensure a more efficient supply chain process, which directly involves port and highway authorities. This section presents a sample study of freight shipment distribution from the Ports of Los Angeles and Long Beach to neighboring states using linear optimization analysis.

An objective function and constraints were created to formulate a linear optimization problem involving a port from where freight tonnage to five separate state markets. Excel Solver was used to solve the problem (Jaafar 2016). The first step was to determine the annual port cargo in million tons at the ports of Los Angeles and Long Beach that needs to be distributed to state markets. The second step is to estimate shipping distances from the ports of Los Angeles and Long Beach to the top five state markets to which the freight from these ports is distributed. The linear distances were determined using Google Earth (GoogleEarth 2016). Figure 54 illustrates the coordinates for the ports and the origin and destination points for the linear distances between the ports and the five selected state market locations (Richardson 2016).

Table 12 shows the linear distances from the port to all five state markets. The maximum distance is from the ports to the state of Texas. The minimum distance is from the port to Nevada, which is about one-sixth of the distance from the ports to Texas.

The next step is to calculate the total shipping costs based on million tons of freight and miles traveled. The following unit costs were used (FLDOT 2016):

- Rail shipping unit cost = 3.70 cents per ton-mile
- Highway/road freight truck unit cost = 42.38 cents per ton-mile
- Unit cost in U.S. dollars per ton-mile = (cents per ton-mile) / 100

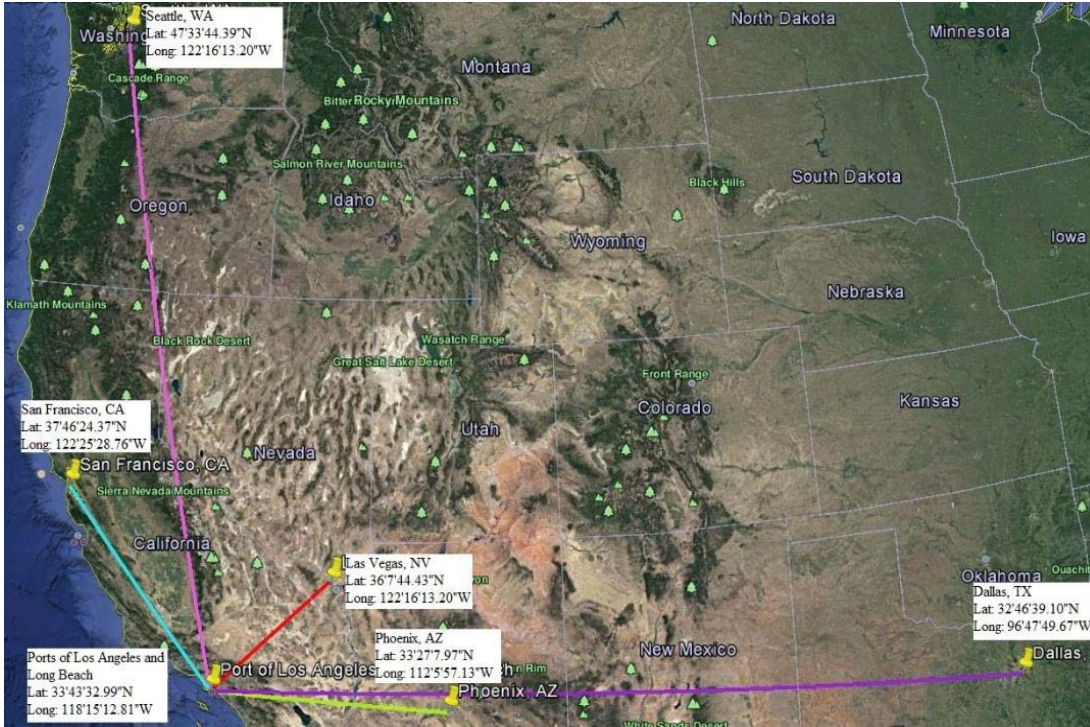


Figure 54. Linear Routes Between the Ports of Los Angeles and Long Beach to the Five State Markets (Richardson 2016)

Table 12. Estimated Linear Distance Between Ports of Los Angeles and Long Beach and Five State Markets

Ports	State Markets	Distance (Miles)
Ports of Los Angeles and Long Beach	California, CA	364.0
	Arizona, AZ	355.9
	Nevada, NV	243.6
	Texas, TX	1,241.7
	Washington, WA	981.3

The following optimization cases were analyzed in this research:

- 1) Base Scenario for shipping freights from the port to state markets by 100% truck.
- 2) Alternative Scenario of Intermodal Integration for shipping freights from the port to state markets by 70% truck and 30% rail.

The linear optimization of the Base Scenario was conducted for 100% truck freight from port (i) to state markets (j). The analysis calculates the optimum distributions of freight in million tons from origin port (i) to each state market (j) at the lowest shipping cost. The same freight distributions as in the Base Scenario are used in the analysis for an Alternative Scenario.

The basic unit cost for freight truck is 42.38 cents per ton-mile and freight rail unit cost is 3.70 cents per ton-mile. Table 13 shows the distance (d_{ij}) from port (i) to state markets (j) in miles, and unit cost per ton-mile (b_{ij}) for the Base Scenario and for the integrated Alternative Scenario. The unit cost for the Alternative Scenario is calculated using Equation 1 using the truck unit cost of 42.38 cents and rail unit cost of 3.70 cents per ton-mile.

$$0.7(42.38/100) + 0.3(3.70/100) = \text{US\$ } 0.3078 \quad \text{Eq. 9}$$

Table 13. Unit Costs in U.S. Dollars per Ton-Mile (100% Truck) for Base Scenario and (70% Trucks and 30% Rail) for Alternative Scenario

Linear Distance from the Ports to each State Market and Unit Cost per Ton-Mile				
Ports (i)	State Markets (j)	Distance (d_{ij}) (Miles)	U.S. Dollars Per Ton-Mile (b_{ij}) for 100% truck	U.S. Dollars Per Ton-Mile (b_{ij}) for 70% truck and 30% rail
Ports of Los Angeles and Long Beach	California, CA	364.0	0.4238	0.3078
	Arizona, AZ	355.9	0.4238	0.3078
	Nevada, NV	243.6	0.4238	0.3078
	Texas, TX	1,241.7	0.4238	0.3078
	Washington, WA	981.3	0.4238	0.3078

Objective Function and Formulation of Constraint Inequalities

Optimization analysis requires the formulation of an objective function and associated constraints as shown in Equations 10 through 13. The objective function minimizes the total shipping costs from the selected port (i) to each state market (j), as shown in Equation 10 for the Base Scenario. The same equations are applied for the Alternative Scenario except that the integrated freight b_{ij} values are used.

$$\text{Minimize: } C_{ij} = \sum_{i=1}^I \sum_{j=1}^J (y_{ij} \times b_{ij} \times d_{ij}) \quad \text{Eq. 10}$$

Where,

C_{ij} = Total cost (US\$) to ship from port (i) to each state market (j) for $i=1, \dots, I$ and $j=1, 2, 3, \dots, J$

y_{ij} = Quantity of the freight tonnage shipped from port (i) to state market (j)

d_{ij} = Distance from port (i) to state market (j)

b_{ij} = Unit cost in \$ per ton-mile of shipping freight from port (i) to state market (j) over distance d_{ij} . (The second column from right in Table 13 shows unit cost b_{ij} for the Base Scenario and right column in Table 13 shows b_{ij} for the Alternative Scenario.)

The next step is to formulate the constraints for this objective function. All constraint inequalities must be equal or more than certain values.

The first constraint deals with the summing of all commodity freight shipped from the port (i) to all state markets (j), which cannot exceed the total commodity freight available at the port (Equation 10).

$$\sum_{j=1}^J y_{ij} \geq -T \tag{Eq. 11}$$

Where, T= Total freight available at port (tons) for $i=1, \dots, I$ and $j=1, 2, 3, \dots, J$

The second constraint deals with the total amount sent to a state market, which cannot be less than the amount of the commodity required in that state market as shown in Equation 11.

$$\sum_{i=1}^I y_{ij} \geq r_j \tag{Eq. 12}$$

Where,

r_j = Freight (tons) required from each port (i) at the state market (j) for $i=1, \dots, I$ and $j=1, 2, 3, \dots, J$

Finally, the amount of freight from the port (i) to each state market (j) must be a positive value as shown in Equation 13. A non-negative constraint was applied to ensure that tonnage values shipped by each mode always remained positive (Cobb 2015, Jaafar 2015).

$$y_{ij} > 0 \tag{Eq. 13}$$

Where,

y_{ij} = Freight tonnage quantity shipped from port (i) to state market (j) for $i=1, \dots, I$ and $j=1, 2, 3, \dots, J$

The objective function C_{ij} is the summation of the freight volume multiplied by unit cost per ton-mile and distance for each state market as shown in Equation 10.

Table 14 shows the initial data set up for the optimization analysis to determine the optimum proportion of freight (million tons) from the port to each state market at the minimum total cost. Before the Solver is executed, the freight volume cells are left unfilled.

The following assumption applies:

- The total freight in million tons (T) shipped from the port (i) to all five state markets (j) cannot exceed the total commodity freight available at the port.
- The freight sent from the port (i) is the exact amount of freight required at the state market, r_j .

Table 14. Initial Set Up in Microsoft Excel Before Executing the Solver for Base Scenario of 100% Truck

	A	B	C	D	E	F	G	H
1								
2		Port of Los Angeles and Long Beach, CA						
3			y_{1-A} (to California)	y_{1-B} (to Arizona)	y_{1-C} (to Nevada)	y_{1-D} (to Texas)	y_{1-E} (to Washington)	Z
4		y_{ij} (Freight in million tons)						
5		b_{ij} (Unit cost per ton-mile in US\$)	0.4283	0.4283	0.4283	0.4283	0.5000	0.0
6		d_{ij} (Distance in miles)	364.0	355.9	243.6	1,241.7	981.3	
7			62.51	1	0	0	0	0.000
8			1.44	0	1	0	0	0.000
9		Constraint 1: $y_{ij} \geq -T_i$	1.42	0	0	1	0	0.000
10			0.83	0	0	0	1	0.000
11			0.56	0	0	0	1	0.000
12			62.51	1	0	0	0	0.000
13			1.44	0	1	0	0	0.000
14		Constraint 2: $y_{ij} \geq r_j$	1.42	0	0	1	0	0.000
15			0.83	0	0	0	1	0.000
16			0.56	0	0	0	1	0.000

The following equation represents the calculation for the objective function in the Solver data Table 14:

$$Z = C5 * C4 * C6 + D5 * D4 * D6 + E5 * E4 * E6 + F5 * F4 * F6 + G5 * G4 * G6 \quad \text{Eq. 14}$$

Figure 55 shows the Solver parameters set up before solving the linear programming problem.

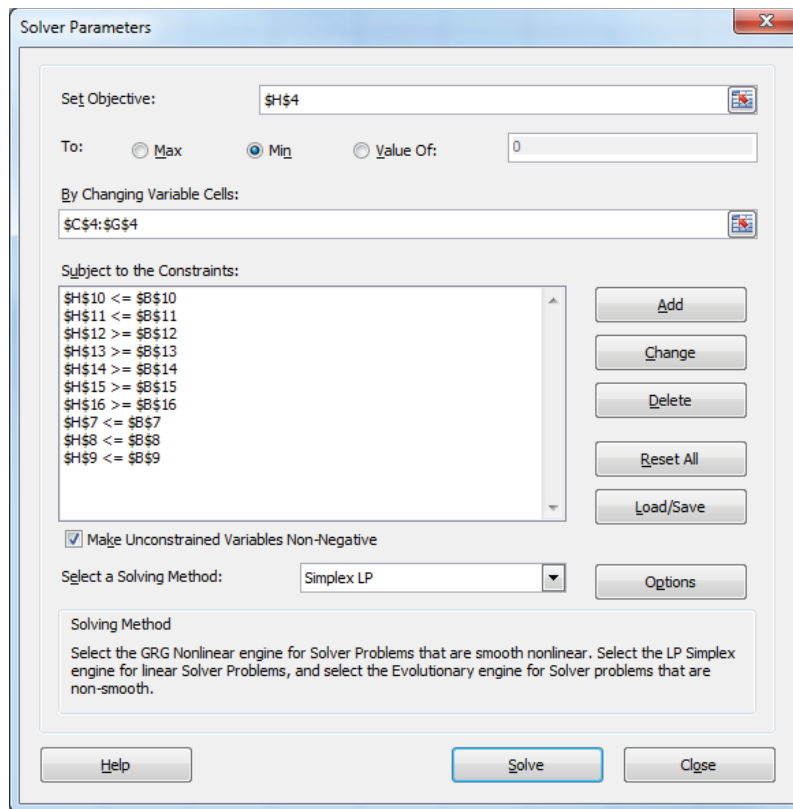


Figure 55. Solver Parameters before Solving for the Linear Optimization Problem

Table 15 shows the results for the Base Scenario of the distribution of the freight shipped using 100% truck. The optimized minimum cost of \$10.675 billion was calculated, as follows:

- 1) 62.5 million ton of the freight shipped to the California
- 2) 1.44 million tons of the freight shipped Arizona
- 3) 1.42 million tons transported to Nevada
- 4) 0.83 million tons transported to Texas
- 5) 0.56 million tons of freight shipped to Washington state

Table 15. Results from the Solver analysis for the Base Scenario of 100% truck

	A	B	C	D	E	F	G	H
1								
2	Port of Los Angeles and Long Beach, CA							
3		y_{1-A} (to California)	y_{1-B} (to Arizona)	y_{1-C} (to Nevada)	y_{1-D} (to Texas)	y_{1-E} (to Washington)	W	
4	y_{ij} (Freight in million tons)	62.51	1.44	1.42	0.83	0.56	10,676.4	
5	b_{ij} (Unit cost per ton-mile in US\$)	0.4238	0.4238	0.4238	0.4238	0.4238		
6	d_{ij} (Distance in miles)	364.0	355.9	243.6	1,241.7	981.3		
7		62.51	1	0	0	0	62.510	
8		1.44	0	1	0	0	1.440	
9	Constraint 1: $y_{ij} \geq T_i$	1.42	0	0	1	0	1.420	
10		0.83	0	0	0	1	0.830	
11		0.56	0	0	0	0	0.560	
12		62.51	1	0	0	0	62.510	
13		1.44	0	1	0	0	1.440	
14	Constraint 2: $y_{ij} \geq r_j$	1.42	0	0	1	0	1.420	
15		0.83	0	0	0	1	0.830	
16		0.56	0	0	0	0	0.560	

Table 16 summarizes percentages of freight distribution to each state market. Most of the commodities are shipped to within California which is about 94% out of 66.76 million tons of freight volume shipped.

Table 16. Distribution to Each State Market for Base Scenario

Ports Distribution to Each State Market fro Base Scenario, 100% Trucks		
State Market	Freight Distribution (Millions of Tons)	% Freight Distributed
California, CA	62.51	93.63%
Arizona, AZ	1.44	2.15%
Nevada, NV	1.42	2.14%
Texas, TX	0.83	1.24%
Washington, WA	0.56	0.84%
Total	66.76	100%

The subsequent linear optimization analysis was conducted for the Alternative Scenario which integrates 30% of the freight shipped by rail and the remaining 70% of the freight shipped by truck. The same freight tonnage distribution (%) from the Base Scenario was used in this analysis. The result for the Alternative Scenario of 70% truck and 30% rail is shown in Table 17.

Table 17. Results Produced by the Solver Analysis for the Alternative Scenario of 70% Truck and 30% Rail

	A	B	C	D	E	F	G	H	
1									
2	Port of Los Angeles and Long Beach, CA								
3		y_{1-A} (to California)	y_{1-B} (to Arizona)	y_{1-C} (to Nevada)	y_{1-D} (to Texas)	y_{1-E} (to Washington)		Z	
4	y_{ij} (Freight in million tons)	62.51	1.44	1.42	0.83	0.56		7,754.2	
5	b_{ij} (Unit cost per ton-mile in US\$)	0.3078	0.3078	0.3078	0.3078	0.3078			
6	d_{ij} (Distance in miles)	364.0	355.9	243.6	1,241.7	981.3			
7		62.51	1	0	0	0			62.510
8		1.44	0	1	0	0			1.440
9	Constraint 1: $y_{ij} \geq -T_i$	1.42	0	0	1	0			1.420
10		0.83	0	0	0	1		0.830	
11		0.56	0	0	0	0		0.560	
12		62.51	1	0	0	0		62.510	
13		1.44	0	1	0	0		1.440	
14	Constraint 2: $y_{ij} \geq r_j$	1.42	0	0	1	0		1.420	
15		0.83	0	0	0	1		0.830	
16		0.56	0	0	0	0		0.560	

For the Alternative Scenario, the optimized minimal cost is approximately \$7,753 billion. The lesser cost is due to lower unit cost per ton-mile as compared to Base Scenario.

Key Results and Discussion

The key results from the analysis follow:

- Freight shipment using 100% truck is 27.4% more costly compared to the Alternative Scenario of freight shipment using 70% truck and 30% rail.
- About \$2.922 billion is saved as a result of rail-road integration to ship 66.76 million tons of freight from the Port of Los Angeles and Long Beach to the five selected state markets.
- The shipping cost is lower as a result of high percentage of freight being distributed within the CA state due to shorter distance from the origin port to the destination state.

One major weakness in the traditional optimization analysis using a spreadsheet only approach is that the solution may not be accurate and practically feasible to implement. The main reason is the lack of representation of the actual transportation route in the field. This weakness limits the number of feasible routes that affects the numerical analysis because of the inaccuracies in actual route distances. It has been shown in the study of NAFTA route optimization (Uddin et al. 2016) that the geospatial mapping of feasible routes removes the assumption of linear distances from original to destinations, provides more accurate distances through linear feature's spatial analysis, and enhances the final results of the optimization. It is recommended to use geospatial mapping of surface freight shipping routes and conduct a more detailed optimization study of freight distributions from terminals at ports to destination state terminals and from the state terminals to the ports.

3. SHIPPING DEMAND MODELING AND ENVIRONMENTAL IMPACTS

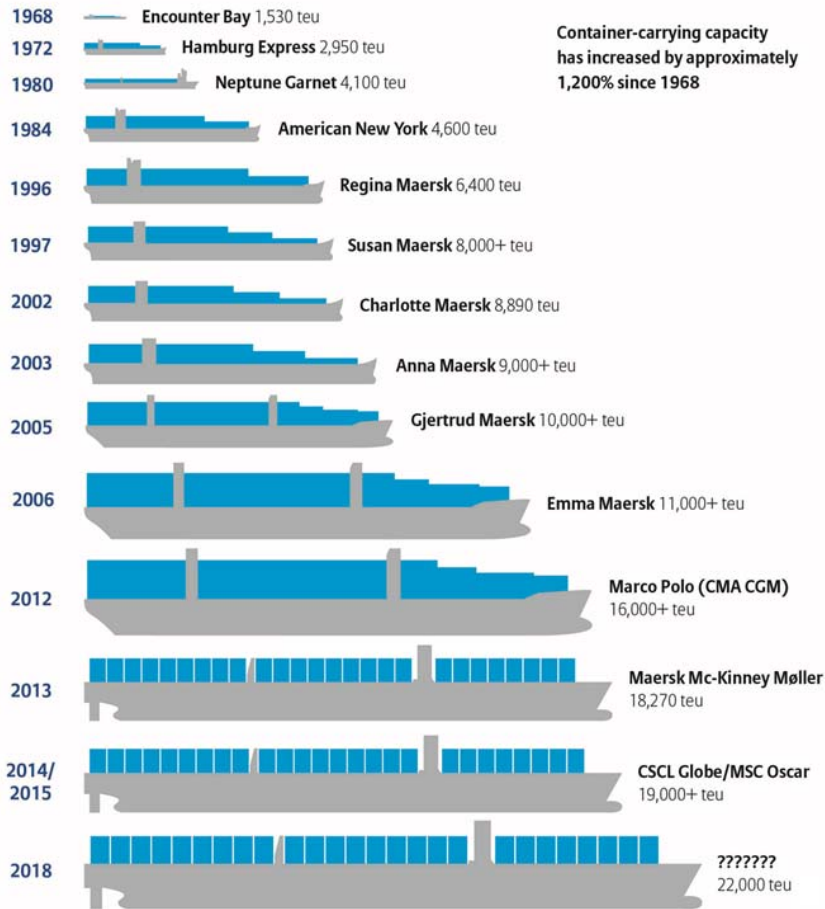
3.1 Methodologies and Applications of Shipping Demand Modeling

Trends in Cargo Vessel Inventory

Historically, ocean cargo shipping has been the backbone of the global economy to transport grains, raw materials, and finished products. In today’s global economy bulk and container ships got bigger and bigger as shipping and logistics companies face fierce competition in shipping industry, bigger ships reduce costs and Carbon footprint, and ports are ready to receive these ships. Container capacity of ships has increased by about 12.7 times since 1968. Figure 56 shows the milestones of container ship evolution (www.agcs.allianz.com/) and the world’s largest container ship MSC Oscar that entered the Panama Registry in 2015 (Bulletin 2015).

Intermodal Optimization for Economically Viable Integration of Surface and Waterborne Freight Transport I

50 years of Container Ship Growth



Graphic: Allianz Global Corporate & Specialty.
Approximate ship capacity data: Container-transportation.com

Figure 56. History of Container Ship Evolution (credit: Allianz)

The Mediterranean Shipping Company (MSC) owns the World's largest container ship MSC Oscar. Built in 2014, it has a length of 394 meters, a capacity of about 19,224 TEUs and its other specifications are: IMO No. 9703291, Gross Registered Tonnage 192,237, Net Tonnage 111,432. According to MSC's Aponte (Bulletin 2015), "the MSC Oscar is the most efficient ship in the world, that was built thinking about respecting the environment and not only can she carry 35% more cargo, but consume 35% less fuel, which will reduce the carbon dioxide emission by 35%."

Impacts of Panama Canal Expansion

A ship takes approximately 8 to 10 hours to transit through the Panama Canal (Panama 2014). The following history of Panama Canal is based upon a news report on the opening of Panama Canal expansion by Frank Townsend (Conversation 2016):

"Built Aug 15, 1914 vs. 2016 Explainer: how Panama Canal expansion will transform shipping once again..."

World shipping changed forever when the Panama Canal opened on August 15, 1914. It was an engineering marvel of its day, cutting the distance required to get from the Pacific Ocean to the Atlantic by as much as 8,000 nautical miles..... When the canal first opened, it was the size of U.S. Navy ships that dictated the width of the locks: 110 feet across and 42 feet deep. Before it opened, ships had to journey all the way down to the Strait of Magellan near the tip of South America to cross from New York to San Francisco. Ships enter the canal through a series of three chambers, which lift the vessels up to the higher level of Gatun lake through which they will glide, and subsequently lower them to sea level. In addition, tides on the Atlantic side are much lower than the Pacific.

The canal had to be expanded to allow for today's super-sized cargo ships.....

The shipping industry is changing once again as 70 heads of state gathered in Panama City recently to celebrate the canal's expansion to handle the super-sized ships that now dominate global trade. They were there to witness a Chinese container ship become the first commercial vessel to take advantage of the new, larger locks to pass from the Atlantic Ocean to the Pacific.... The upgrade, which cost \$5.25 billion and was built alongside the old locks, was designed to support the contemporary needs of global commerce from Asia. Modern so-called neo-Panamax ships can be more than 150 feet wide, extend three football fields in length and have a draft of 50 feet. (Draft is how deep into the water a ship goes below the surface.) Even though the new locks are 3.3 times larger than the 1914 ones, they use 7 percent less water..... Another enhancement is the expansion locks' use of rolling gates to close each lock, a significant upgrade from the old ones. The rolling gates allow maintenance to be performed without having to temporarily close the lock, saving lots of time and money." And whereas the 1914 locks used electric towing locomotives (known as mules) to guide ships through the locks, the expansion locks will rely on two positioning tugboats (fore and aft) to position vessels during transit, which is more efficient.

The impending arrival of new Panamax ships with a required draft of 50 feet has sent East Coast ports and businesses in the U.S. scrambling to benefit from this increased cargo. Currently, only Baltimore, Norfolk and Miami are ready to accommodate these larger ships and containers. Shipping channel deepening and widening dredging projects are underway in Savannah (which currently allows draft of up to 47 feet) and Charleston."

Container Ship Demand Models for Selected Ports

Recently, the state highway authorities and engineers reported that the growth rate of freight traffic was higher compared to passenger traffic growth rate on the highway network in the U.S. (SHRP2 2014). This condition possibly resulted in freight bottlenecks at various locations throughout the network, usually near ports and intermodal facilities. However, traffic bottlenecks are not the only issue that requires serious attention, but there is also a need to look into the effects of increasing freight traffic on highway and major roads in future years. The issues related to faster freight traffic growth leads to better estimating freight flow and forecasting freight demand for the highway capacity planning process. Rail freight lines operate on dedicated track corridors, but the rail infrastructure is aged and investment in maintenance and capacity enhancement requires prioritization of corridors based on freight demand. Intermodal container shipment by freight rail has become popular since coal demand has decreased in recent years (AREMA 2016). Accurate and reliable cargo ship demand modeling is important to achieve the goal of future expansion planning for major ports.

This section discusses the development of containership demand models for the Port of New Orleans, LA and the Port of New York and New Jersey. This research was conducted as a part of PhD dissertation (Nguyen 2017). These two ports are among the largest ports in the U.S. based on tons of freight handled every year at each port. The development of containership demand models are described for the Port of New Orleans using three different modeling approaches namely:

- (1) Multiple linear regression
- (2) Artificial Neural Network (ANN)
- (3) AutoRegressive Integrated Moving Average (ARIMA) time series modeling

For the Port of New York and New Jersey only ARIMA modeling technique is considered in the study as no other data was available.

Container Ship Demand Models for Port of New Orleans, Louisiana

Summary Statistics of Time Series

A total of 120 monthly total loaded export container volume data in Twenty-Foot Equivalent Unit (TEU) from 2005 to 2014 was used as historical time series to develop the demand model equations. Figure 57 shows the monthly time series in number of total loaded container monthly exported from the Port of New Orleans from 2005 to 2014. The average number of TEUs is 15,268 with standard deviation (SD) of 4,266 TEUs and coefficient of variation (COV) of 27.9%, respectively. The lowest container volume of 491 TEUs was recorded in September 2005, which is only about 3.5% from August 2005 value of 14,115 TEUs. The drastic reduction in the number of container volume was due to catastrophic disaster of Hurricane Katrina, which made landfall on August 29, 2005. The recorded monthly container volume steadily increased from October 2005 until May 2007. The number of TEUs from June 2007 until February 2009 gradually decreased as a result of the economic recession experienced in the U.S. and many other

countries worldwide. The industries started to recover as witnessed by the steady increase of container volume after the recession from March 2009 until December 2014.

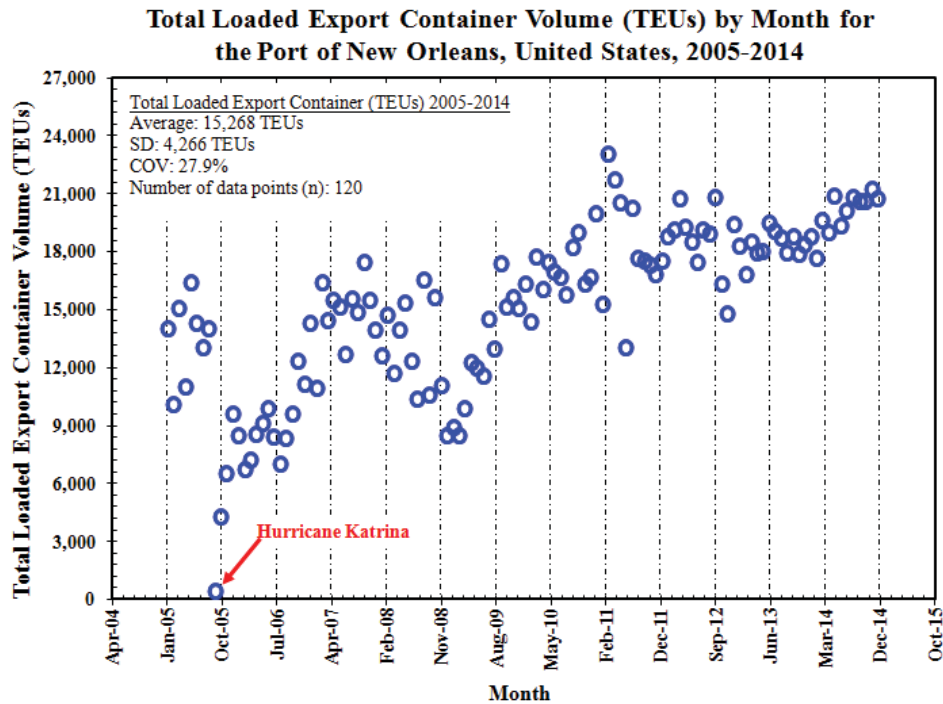


Figure 57. Total Loaded Export Container Volume of TEUs at the Port of New Orleans, LA, 2005-2014

Development of Multiple Regression Equation

For the development of TEU demand modeling equation, the total monthly loaded export container was used as the dependent variable (Y_{export}). The regression equation was developed to predict the dependent variable, and the predictions are depending on sets of independent variables that are highly correlated with the dependent variable. These data sets were obtained by personal communication (Nguyen 2015). Twelve different independent variables were used to develop the regression equation, denoted as X_1 until X_{12} . Equation 6 shows the developed regression equation with the coefficient of Pearson’s correlation (R) value of 0.963.

$$\begin{aligned}
 Y_{\text{export}} = & 52,222.83 + 219.04 (X_1) - 3.06 (X_2) + 153.03 (X_3) - 1099.27 (X_4) + \\
 & 82.63 (X_5) + 127.58 (X_6) + 1.22 (X_7) + 1.31 (X_8) + 0.61 (X_9) \\
 & + 1.83 (X_{10}) - 0.36 (X_{11}) + 0.95 (X_{12})
 \end{aligned}
 \tag{Eq. 15}$$

Where,

- X_1 = the cumulative months from 2005 to 2014 (January 2005 is the first month, December 2014 is the 120th month),
- X_2 = the U.S. Gross Domestic Product (GDP) in billion US dollars,
- X_3 = the U.S. inflation rate (%),
- X_4 = the U.S. unemployment rate (%),

- X₅ = the unemployment rate in Louisiana (%),
- X₆ = unemployment rate in New Orleans (%),
- X₇ = the export volume to Argentina (TEUs),
- X₈ = the export volume to Belgium (TEUs),
- X₉ = the export volume to Brazil (TEUs),
- X₁₀ = the export volume of forest product (TEUs),
- X₁₁ = the export volume of synthetic resins NSPF (TEUs),
- X₁₂ = the export volume of synthetic rubber (TEUs).

The independent variables X₅ to X₉ were selected because historical data showed that the total annual TEUs exported to those countries are among the highest commodities. Additionally, independent variables X₁₀ to X₁₂ were used since forest product, synthetic resins, and synthetic rubber were classified among the highest commodities exported from the Port of New Orleans, respectively. Figure 59 is a plot of prediction accuracy for export containerized cargo using the regression equation

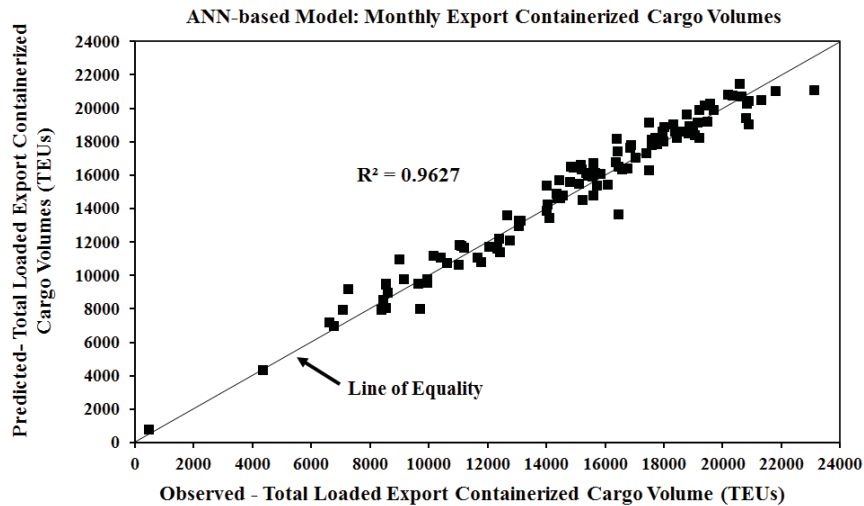


Figure 58. Graphical Prediction Accuracy for Export Containerized Cargo Using Regression Equation

Development of ANN Model of Loaded Export Container Volume, 2004-2015

The ANN is one of the predictive modeling techniques available and applicable for historical time series data if associated independent variable data are available. The ANN is a computing system established from several simple, highly interconnected elements that process information through dynamic response to input (independent variable). The neural network gains its knowledge through trained feed-forward network. During this process a set of training data sets consist of inputs and output (dependent variable) are presented to the network. The generated output is compared to the target values. Next, back-propagation process adjusts the connection weights to reduce the error between the actual and target values. Once trained, the network will provide an approximate functional mapping of any input pattern onto its corresponding output pattern. Subsequently, the validation process can be carried out using different data sets (Uddin

et al. 2013). The following key steps are used to develop ANN model for the total loaded TEU export container volume:

- Determine the dependent and independent variables to be used in the development of the ANN model.
- Classify data sets into training, testing, and validation groups.
- Select the best performing neural network after series of training, testing, and validation processes.
- Determine the best performing neural network based on the lowest mean absolute relative error (MARE) and sum of the squared prediction error (SSE), and the highest R value.
- Verify the model's prediction with the observed data. Predict dependent variable for future year, only if the data for all the independent variables are available for those years.

Data sets used to develop the multiple linear regression equation were also used to develop ANN-based model. The 120 data sets used for the model were classified into 68 training data sets, 26 testing data sets, and 26 validation data sets based on the principle of 50% for training, 25% for testing and 25% for validation processes. The results indicate that the neural network with 12 independent variables, 5 hidden nodes, and 1 dependent variable was the best performing network. Therefore, the final ANN model developed is shown in Equation 16. The independent variables X_1 to X_{12} were described previously in the multiple linear regression section.

$$Y = ANN_{12-5-1}[X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}] \quad \text{Eq. 16}$$

For the final ANN model:

R = 0.911 on Training all data

SSEN = 0.000869 on Training all data

MARE = 2.15% on Training all data

The Mean Absolute Relative Error (MARE) and Root Mean Square Error (RMSE) are two statistics used to determine the accuracy and reasonableness of the model (Riad et al, 2004, Dý'az-Robles et al. 2008). Equations 17 and 18 are used to calculate the MARE and RMSE statistics.

$$MARE = \frac{\sum_{i=1}^N \left| \frac{\hat{y}_i - y_i}{y_i} \right|}{N} \times 100 \quad \text{Eq. 17}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (y_i - \hat{y}_i)^2}{N}} \quad \text{Eq. 18}$$

Where, y_i and \hat{y}_i are the observed and predicted values of total loaded export containerized cargo volumes and N is total number of data points.

If the value of MARE is small, close to zero, it means that the model’s accuracy is good. The RMSE measures of the difference between values predicted by the model and measured values. The RMSE value should be as small as possible. Figure 59 is a plot of measured and predicted values. Figure 60 is a screen print of the Excel-based prediction application using ANN model for the total loaded export containerized cargo volumes.

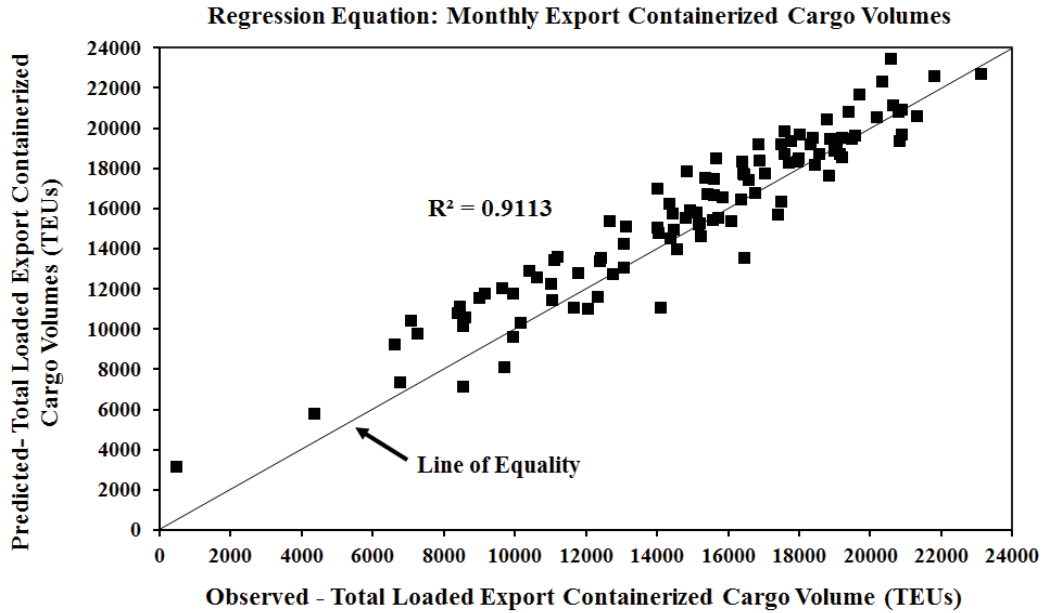
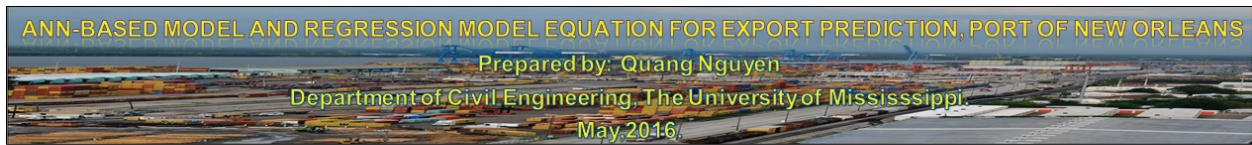


Figure 59. Graphical Prediction Accuracy for Export Containerized Cargo Using ANN Model



EXPORT INPUT			Applicable Range		OUTPUT	Model
			MAX	MIN	20,636	By ANN-Based Model
1.Season	118	Within the range	120	1	20,448	By Regression Model Equation
2.GDP_US (Billion Dollars)	17,704	Within the range	17,703.7	12,813.7		
3.InflationRate_US (%)	1.7	Within the range	5.6	-2.1	Verification Test using Input Data in October 2014:	
4.Unemployment_US (%)	5.8	Within the range	10.0	4.4	<ul style="list-style-type: none"> Total load export container volume in October 2014 by ANN- Based Model is 20,636 TEUs (-0.1% difference with actual data). Total load export container volume in October 2014 by Regression Model Equation is 20,448 TEUs (-1.0% difference with actual data). 	
5.Unemployment_Lou (%)	5.9	Within the range	11.0	3.2	Note: Actual total load export container volume in October 2014 is 20,657 TEUs	
6.Unemployment_NO (%)	7.2	Within the range	10.3	0.0		
7.Export_Argent (TEUs)	1,158.00	Within the range	1888.31	43.00		
8.Export_Belgium (TEUs)	2,375.25	Within the range	3705.31	0.00		
9.Export_Brazil (TEUs)	2,262.20	Within the range	3373.04	66.00		
10.Forest_products_EP (TEUs)	2,212.56	Within the range	5367.52	142.00		
11.SYNTHETIC_RESINS_NSPF_EP (TEUs)	549.11	Within the range	1400.72	0.00		
12.RUBBER_SYN_EP (TEUs)	1,128.31	Within the range	1293.38	0.00		

Figure 60. The desired excel-based prediction application using ANN-based model for the total loaded export containerized cargo volumes

Development of ARIMA Model of Loaded Export Container Volume, 2004-2015

A time series is an ordered sequence of values of a variable at equally spaced time intervals. The ARIMA modeling is able to consider nonlinearity and seasonal effects of any time series data. The ARIMA modeling approach was selected to better understand the data and also to make an appropriate forecasting of future months data. The “AR” stands for AutoRegressive, “I” describes Integration process or differencing order, and “MA” means Moving Average process. The general ARIMA model is denoted by ARIMA (p, d, q) where $p, d,$ and q are the orders of terms for autoregressive, differencing, and moving average processes, respectively (McCleary and Hay 1980). The ARIMA model equations for either seasonal or non-seasonal terms are used to model a time series. A previous study successfully analyzed time series data and predicted data for future year with a very small error (Uddin et al.1985). The ARIMA model has been successfully developed in the areas of port logistics (Echeverry et al. 2014) and maritime forecasting because the model can present real past patterns and deal with both stationary and non-stationary data series (Stopford 2009).

The observed monthly total loaded export containerized cargo volume time series data for ten years from 2005 to 2014 was provided by the Port of New Orleans (Nguyen 2005). A high sequential correlation R of 0.778 was evaluated between monthly data (y_i) and previous monthly data (y_{i-1}) at lag 1. This is a violation of linear regression approach for using time interval as an independent variable. So this data series is a good candidate of ARIMA modeling. For ARIMA time series analysis, it was recommended to have a minimum of 50 numbers of data points over the time period. With 120 data points, the numbers of loaded export container volume data are ideal for ARIMA modeling. The observed data from 2005 to 2013 was used for analyzing and evaluating the ARIMA model equations, and the observed data in 2014 was used for validating the model equations.

The results show high Pearson’s correlation between time and the total loaded export containerized cargo volumes. The observed loaded export container volume data as illustrated in Figure 57 indicated that there was no clear seasonal pattern. Therefore, only non-seasonal ARIMA models were tried. Figure 61 shows the schematic of ARIMA time series modeling process (Mc Cleary and Hay 1980).

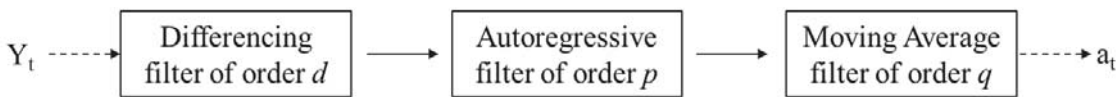


Figure 61. An input-output representation of the ARIMA modeling approach

The iterative ARIMA model building process involves the following steps (Mc Cleary and Hay 1980, Uddin et al. 1985):

- *Identification:* The identification of appropriate model for the time series requires using differencing, autocorrelation function (ACF) and partial autocorrelation function (PACF) of different orders.

- *Estimation:* The parameter estimates follows model identification using a standard ARIMA software such as SPSS for statistically significant terms (IBM 2016). The parameters are improved by going back to identification process.
- *Diagnosis:* After identifying a tentative ARIMA model, the model is diagnosed by analyzing (1) residuals of the model for independent at the first and second lags and (2) for statistical adequacy, the residuals must be distributed as white noise with zero value of ACF. This iterative process goes back to the identification and estimation step.
- *Metadiagnosis:* This step verifies that a tentative ARIMA model is statistically adequate with high R^2 value and it provides reasonably accurate results of model verification using estimate parameters.
- *Model implementation:* After a tentative model has been accepted, it may be used for forecasting and assessing impact of an intervention event.

The AR evaluates sequential correlation between the observed data of the number of total loaded export container volume for a single month (Y_t) and the value from previous month (Y_{t-1}), Lag 1, or the values at other lags. The differencing process was required to transform the data statistically stationary. A stationary time series explains that the properties of the total loaded export container volume data such as mean, variance and autocorrelation are all constant over time (Mc Cleary and Hay 1980). In the analysis, the data was differenced once, by subtracting the Y_t with Y_{t-1} data until 2014. The differencing process successfully transformed the data to a stationary series, as shown in Figure 62 (upward triangle).

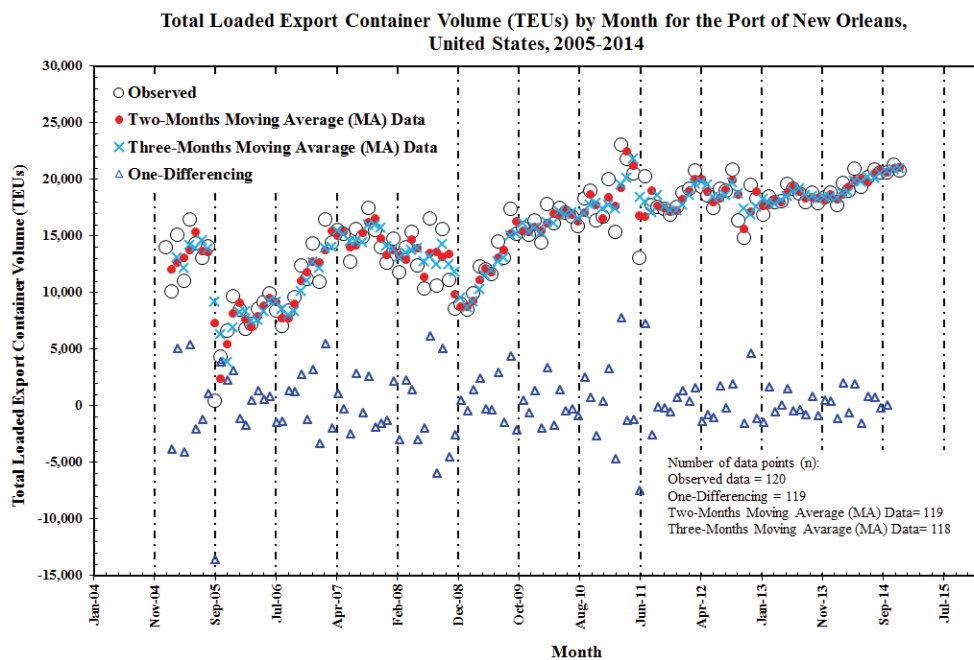


Figure 62. Differencing and Moving Average Process to Determine ARIMA Model Equation Terms for Port of New Orleans

The MA process was applied to smooth out the curve or line of the plotted time series data. The final term of MA for q equal to two and three was also applied in the series transformation process. The two months MA term was plotted in Figure 62 as shown by red “filled-circle” symbol. For the two months MA process, data from January and February in 2005 was the first averaged value (Y_t). The subsequent data (Y_{t+1}) was obtained by averaging data in February and March in 2005. The two month MA process continues until data in December 2014. Additionally, the three month MA term was also applied. The plot of the three months MA term is shown by blue “cross” symbol. The first three month MA data (Y_t) was obtained by averaging data in January, February, and March in 2005 and subsequent data (Y_{t+1}) was acquired by averaging data in February, March, and April in 2005. The three month MA process continues until the final data in December 2014.

Further analysis was conducted to evaluate sequential correlation or coefficient of correlation between the two values in a time series. This statistic is called the AutoCorrelation Function (ACF) with lag k . The example of ACF for a time series Y_t is shown in Equation 19.

$$\text{CORREL}(Y_t, Y_{t-k}) \tag{Eq. 19}$$

Where, k is the time lag. The ACF with lag one means the correlation between the data that are one time period (month) apart, to measure the linear relationship data at Y_t and data at Y_{t-1} . The plot in Figure 63 shows container volume vs. container volume for previous month with R of 0.778. A linear pattern suggests that the first order AR model could be useful. Therefore, the model with one AR term was considered in the analysis. Additionally, the final model without AR term was also included to study the effects of having no AR term to future data predictions.

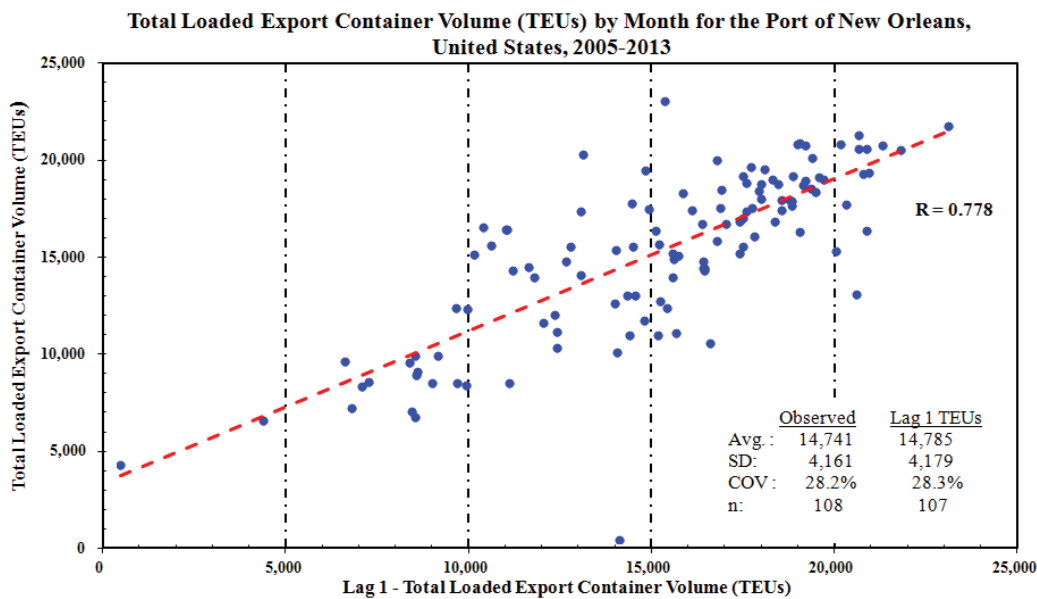


Figure 63. Scatter plot of container volume data versus container volume data in the previous year with lag one

The R value higher than 0.6 indicates that the ARIMA modeling approach is more desirable compared to the regression method. Table 18 shows high Pearson’s correlation R more than 0.6 between the cumulative months and the transformed data by using differencing and moving average terms. The differencing process shows close to zero value of Pearson’s correlation, which indicated that the transformed data was in a stationary condition. In contrast, the correlation between cumulative months with three months MA term was higher compared to two months MA term. Therefore, the differencing term (*d*) equal to one and three months MA term (*q*) was considered in the final ARIMA model equations, with AR term of 0 or 1.

Table 18. Sequential Correlation and Pearson’s Correlations of Container Volume Data With One Differencing and Different Moving Average Terms for Port of New Orleans

A	B	C	D	E
Sequential Correlation (Lag 1) R	Month vs. Total (TEUs) (Observed) R	Month vs. One-Differencing R	Month vs. Two Months Moving Average R	Month vs. Three Months Moving Average R
0.778	0.772	0.023	0.820	0.836

The following Equation 20 shows general ARIMA (0,1,3) model equation with one differencing and three moving average terms for the Port of New Orleans, LA.

$$\nabla^1 * Y_t = C + (1 - \theta_1 B - \theta_2 B^2 - \theta_3 B^3) * a_t \tag{Eq. 20}$$

Where,

Y_t = TEU at the end of the t^{th} month

∇^1 = Regular Differencing operator of order one

C = Constant = 402.395

$1 - \theta_1 B - \theta_2 B^2 - \theta_3 B^3$ = Regular Moving Average process of order three

a_t = random shock term; normally and independently distributed about the mean zero with constant variance equal to squared σ_a

The following Equation 21 shows general ARIMA (1,1,3) model equation with one AR, one differencing, and three moving average terms for the Port of New Orleans, LA.

$$\nabla^1 * Y_t = C + (1 - \phi_1 B) * (1 - \theta_1 B - \theta_2 B^2 - \theta_3 B^3) * a_t \tag{Eq. 21}$$

Where,

Y_t = TEU at the end of the t^{th} month

∇^1 = Regular Differencing operator of order one

C = Constant = 417.191

$1 - \phi_1 B$ = Regular Autoregressive process of order one

$1 - \theta_1 B - \theta_2 B^2 - \theta_3 B^3$ = Regular Moving Average process of order three

a_t = random shock term; normally and independently distributed about the mean zero with constant variance equal to squared σ_a

Both ARIMA (0,1,3) and ARIMA (1,1,3) model equations were developed and the results are shown in Figure 64. The estimations from 2005 to 2013 using ARIMA model equations were close to the observed TEU values despite nonlinearity and variations in the observed data sets. The average, standard deviation (SD), and coefficient of variation (COV) of the predicted data are relatively similar to the observed data values. An analysis of residuals of ACF and FACF plots supports for the correct model specification and estimation of the ARIMA (0,1,3) and ARIMA (1,1,3) models equations within the 95% confidence interval limits.

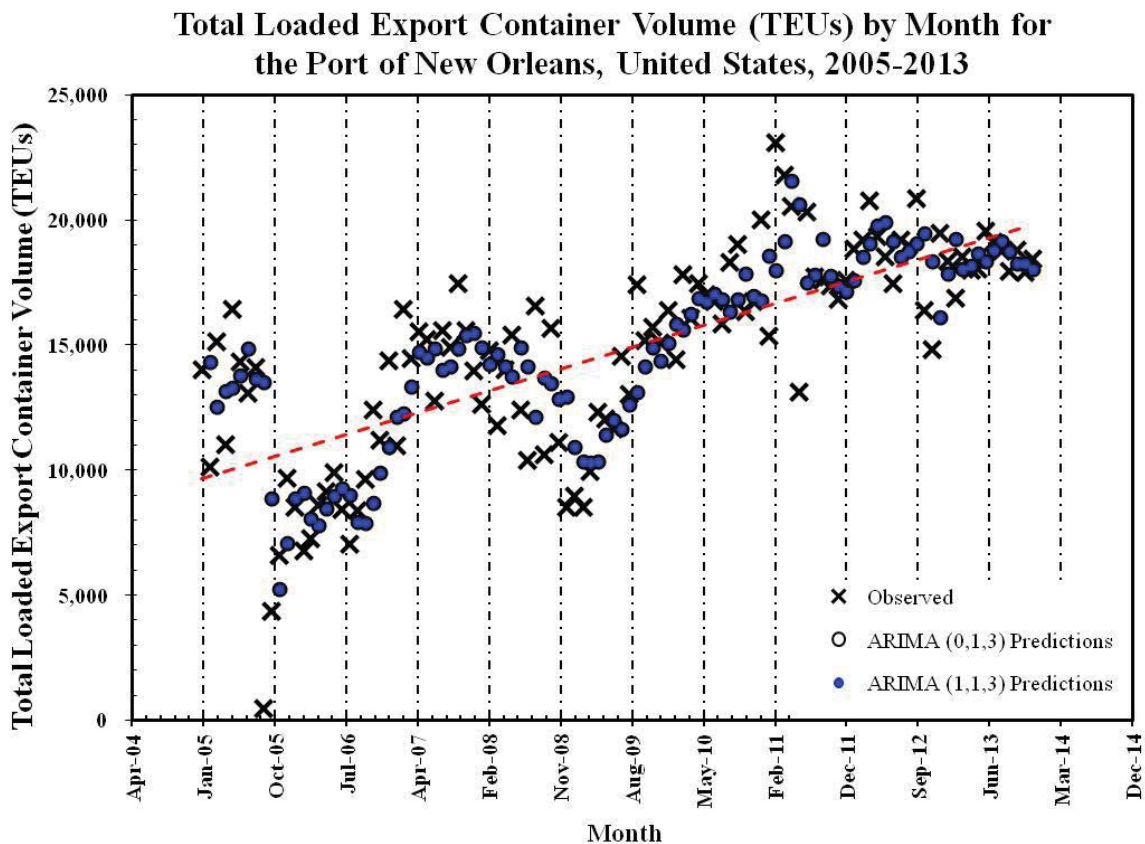


Figure 64. Observed and predicted loaded export container volume (TEUs) for Port of New Orleans, 2005-2013

The predicted vs. observed data plot for ARIMA (0,1,3) and ARIMA (1,1,3) model equations is shown in Figure 65. Both ARIMA model equations are equally good with high R of 0.83. The average values for ARIMA (0,1,3) model equation and ARIMA (1,1,3) model equation is a little less than the average observed value. The COV for both ARIMA model is approximately 25%, respectively. The average difference between observed and predicted values is less than 5% for both model equations. The MARE is 5.28% for the ARIMA (0,1,3) model equation and 5.34% for the ARIMA (1,1,3) model equation. The RMSE is 1,263.16 for the ARIMA (0,1,3) model equation and 1,276.74 for the ARIMA (1,1,3) model equation. This shows that the ARIMA (0,1,3) model equation is a better predictor compared to the ARIMA (1,1,3) model equation. Therefore, the ARIMA (0,1,3) model equation is recommended to use for future month predictions because even though the average percent difference is the same, the MARE, and the RMSE are smaller than those of the ARIMA (1,1,3) model equations.

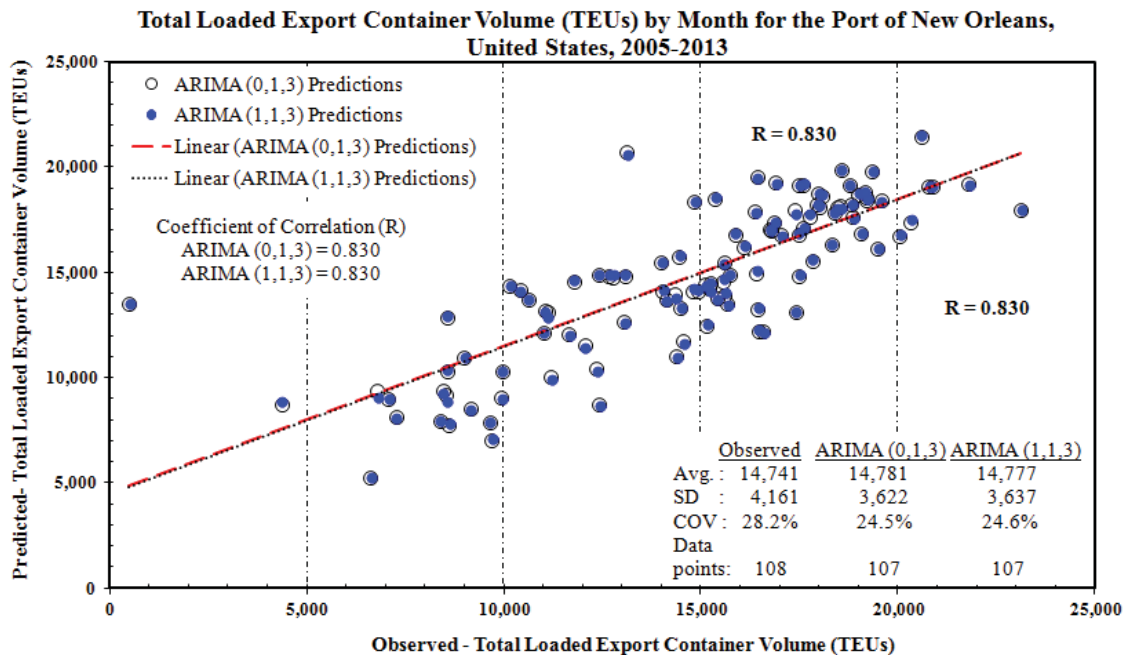


Figure 65. Predicted vs. Observed Plot for ARIMA (0,1,3) and ARIMA (1,1,3) Model Equations for Port of New Orleans

Table 19 shows the predicted annual total loaded export containerized cargo volumes from 2015 to 2020. The verifications from 2015 to 2020 were carried out using the selected ARIMA (0,1,3) model equation. Table 19 and Figures 66 and 67 show that the predicted annual total loaded export containerized cargo volumes steadily increase from 2016 to 2020. The predicted annual data was compared with the annual 2014 data. The predicted value in 2020 is 17.0% higher than the 2014 observed value. These future predictions were possible only for ARIMA model equation, which do not require any other independent variable data. Table 20 shows the prediction results for all 12 months of 2014 using both ARIMA model equations.

Table 19. Predicted annual total loaded export containerized cargo volumes from 2015 to 2020 by ARIMA (0,1,3) model equation

Year	Average Predicted Monthly Total Loaded Export Containerized Cargo Volumes	Predicted Annual Total Loaded Export Containerized Cargo Volumes	% Increase from Annual Total Loaded Export Containerized Cargo Volumes in 2014
	(TEUs)	(TEUs)	(%)
2015	19,872	238,460	-0.7
2016	20,580	246,955	2.8
2017	21,287	255,445	6.4
2018	21,995	263,937	9.9
2019	18,119	272,431	13.4
2020	23,410	280,924	17.0
Average	20,877	259,692	8.1

Annual total loaded export containerized cargo volumes in 2014 are 240,138 TEUs, which is 0.7% higher than the predicted value of 238,460 TEUs for 2015.

Figure 66 shows the plot with future month predictions until 2020 for ARIMA (0,1,3) which lower percent difference to the observed value compared with ARIMA (1,1,3) model equations. The dash-dash line indicates container volume data with one differencing and three moving average terms. The predictions for future months are illustrated by the solid lines, from 2005 until 2020. The ARIMA predictions are able to show increasing trend and seasonal cycle patterns, which is unable to be achieved using traditional regression approach.

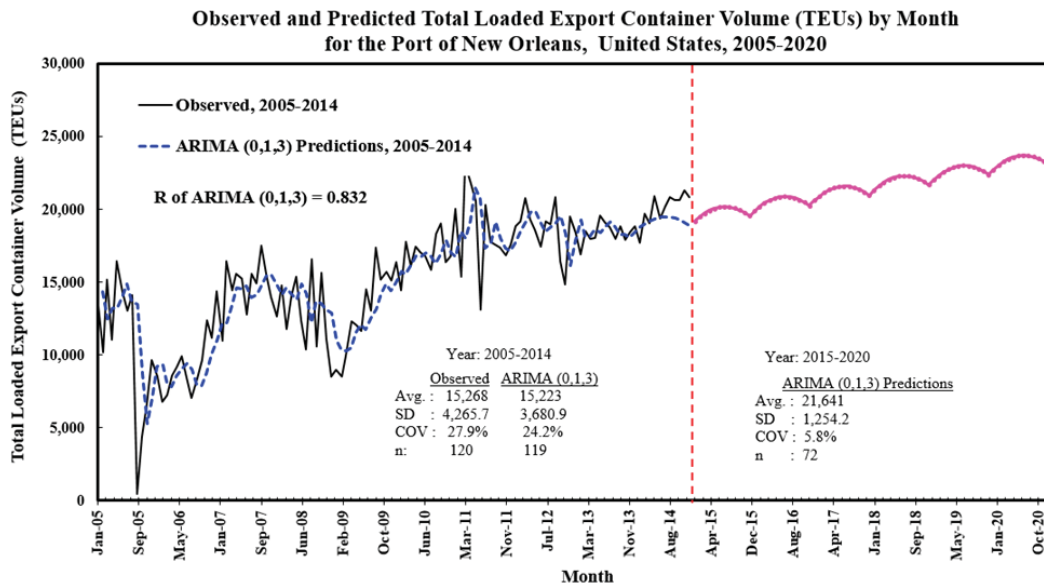


Figure 66. ARIMA (0,1,3) Predictions from 2005 to 2014 and Future Month Predictions until 2020

The annual data based on a total of 12 months data predicted using ARIMA (0,1,3) model equations were shown in Figure 67. The predicted container volume TEUs for 2015 is 238,460 TEUs with an average monthly of 19,872 TEUs. The ARIMA (0,1,3) model equation predicted constant annual growth rates ranging from 3.1 to 3.6% from 2015 until 2020. In 2020, it is expected that the total loaded export container volume to grow 17.8% from the container volume in 2015. The predicted 2020 container volume is 280,924 TEUs with monthly average of 23,410 TEUs.

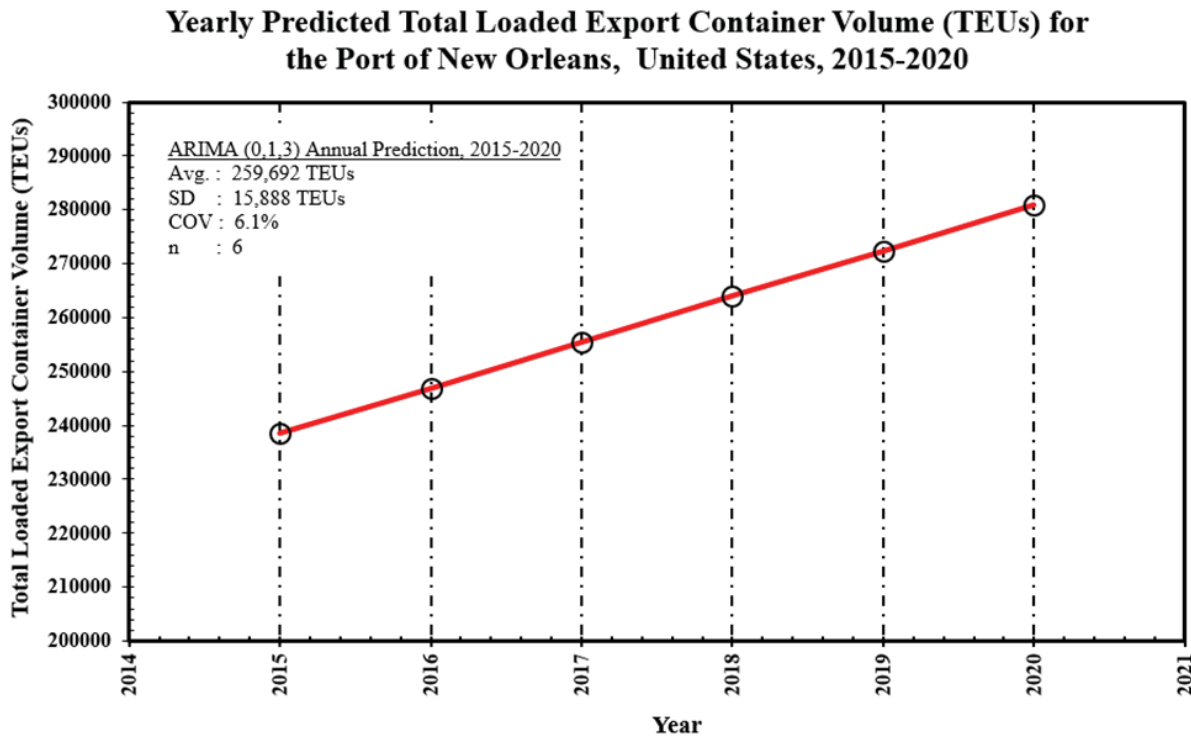


Figure 67. Annual Predictions of Total Loaded Export Container Volume from 2015 to 2020 for Port of New Orleans

Comparison of Regression Equation, ANN Model, and ARIMA Model Equation for 2014 Data

In order to evaluate the accuracy of the selected forecasting methods, the data of 12 months in 2014 were used for validation for the selected models and equations. Table 20 shows a comparison of results of 2014 data verification using the ARIMA model equation, the ANN-based model, and the regression equation for the Port of New Orleans. The average percent differences between the average observed and average predicted data for 2014 are -4.2% for the ARIMA (0,1,3) model equations, -0.2% for the ANN-base model, and 1.7% for the regression equation. MARE and RMSE values of the ANN model equation are smaller than those of ARIMA model equations and the regression equation. This indicates that the ANN-based model is better or more accurate than the regression equation and the ARIMA (0,1,3) model equation.

Although both the ANN-based model and regression equation give relatively better results for the 2014 time series database than the ARIMA (0,1,3) model equation, they are only recommended to apply to the port for short-term prediction when predicted values of input independent variables are available. The Port of New Orleans exports more than 30 commodities to more than 100 countries in the world. If predicted values of only the top three commodities and the top three trading countries are known together with predicted economic indicators, the ANN-based model can be applied to predict total loaded export containerized cargo volumes with highly accurate predicted results.

Table 20 compares the predictions from January to December 2014 using regression equation, ANN model, and ARIMA model equations. The cumulative months are required for prediction using linear regression and ANN model. On the other hand, time period of the month-year combinations are allowed to be used for ARIMA forecasting in SPSS (IBM 2016), instead of using the cumulative months.

Table 20. Comparison between the Observed and Predicted Values using Different Modeling Approaches for 2014 (Port of New Orleans)

Cumulative Month	Month	Total Loaded Export	ARIMA (0,1,3) Predictions	ARIMA (1,1,3) Predictions	Regression Equation Predictions	ANN Model Equation Predictions
		(TEUs)	(TEUs)	(TEUs)	(TEUs)	(TEUs)
109	Jan-14	18,840	18,462	18,425	19,570	19,342
110	Feb-14	17,715	18,851	18,854	18,287	18,243
111	Mar-14	19,688	19,041	19,028	21,689	19,868
112	Apr-14	19,056	19,232	19,241	19,266	18,412
113	May-14	20,934	19,370	19,378	21,437	20,135
114	Jun-14	19,394	19,456	19,464	20,790	20,181
115	Jul-14	20,175	19,488	19,493	20,521	20,810
116	Aug-14	20,879	19,468	19,468	20,932	20,449
117	Sep-14	20,655	19,395	19,387	21,122	20,704
118	Oct-14	20,657	19,269	19,251	20,448	20,641
119	Nov-14	21,318	19,090	19,060	20,580	20,475
120	Dec-14	20,827	18,859	18,813	19,333	20,274
	Total	240,138	229,981	229,862	243,974	239,532
	Average	20,012	19,165	19,155	20,331	19,961
	SD	1082.0	316.0	329.4	1011.9	861.2
	COV	5.4%	1.6%	1.7%	5.0%	4.3%
	Average % Difference		-4.2%	-4.3%	1.6%	-0.3%

The results show the ARIMA and ANN models under predicted the average container volume, while the regression equation shows otherwise. The predicted values using ARIMA models show less variation with lower COV compared to the regression equation and ANN model predictions. The percentage differences between the average predicted and observed values are less than 5% for all modeling approaches. Although the regression equation and ANN model predictions show lower percent differences, the following limitations are observed for these modeling approaches:

- Both regression equation and ANN model require all independent variable data for future year prediction. If the prediction in 2020 is required, then the predictions must include 2020 data for all independent variable, which is unlikely to be obtained in the recent year.
- The multiple linear regression equation assumed a linear trend in the data sets, which resulted in either over or under predicted data sets for future years.
- Similar to the regression approach, the ANN model requires data in future years for all independent variable before any prediction can be carried out.

The ARIMA predictions are able to show linear trend and seasonal cycle patterns Therefore, it is advisable to use the ARIMA modeling approach for time series data with high sequential correlation and for future predictions when other independent variable data are not available.

Container Ship Demand Modeling for Ports of Los Angeles and Long Beach, California

Further ARIMA model equations and dummy regression equations were developed for the TEUs of containerized cargo ship data collected for Ports of Los Angeles and Long Beach on the West Coast. Dummy regression equations were used because there was a statistically significant difference between the cargo demand in 2008 and pre-2008 years compared to the post 2008 data (Figure 68). This is attributed to the 2008 economic recession in the U.S. and other countries and dummy variable was used to model the intervention effect due to the 2008 recession (Richardson 2016). Detailed results are not presented for brevity.

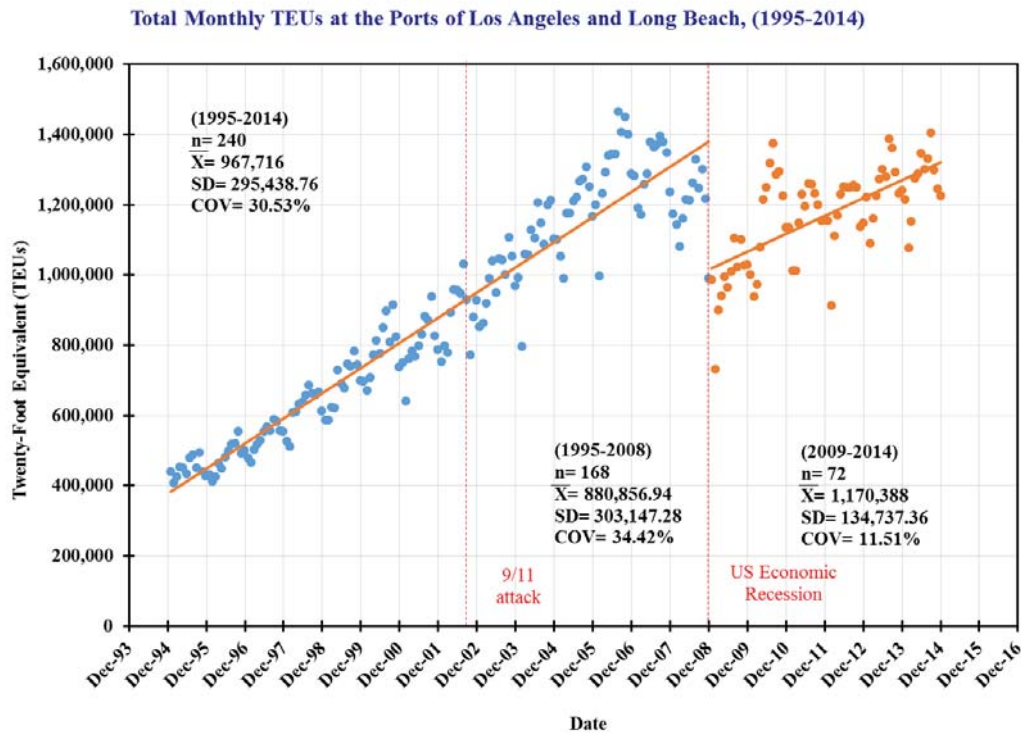


Figure 68. TEU data of the ports of Los Angeles and Long Beach

Container Ship Demand Models for Port Authority of New York and New Jersey

An analysis using container volume data for Port of New Orleans previously showed that the ARIMA model was a better predictor compared to the regression equation and ANN prediction model. Further analysis was conducted using container volume TEUs for Port Authority of New York and New Jersey on the East Coast using ARIMA modeling approach. Figure 69 shows the observed total loaded export container volume by month for Port of New York and New Jersey from 2005 to 2015 with R of 0.859. Generally, the number of TEUs gradually increased from January 2005 to October 2008, despite certain drops in TEUs at specific months. The economic recession affected the commodity shipment from this port, resulted in a sudden drop in TEUs from November 2008, and the container volume remained low until November 2010. The U.S economy started to recover from the effects of the recession in early 2011, as shown by higher container volume TEUs. However, the monthly container volume data from January 2011 to December 2015 varies greatly as shown by the scattered values in the plot.

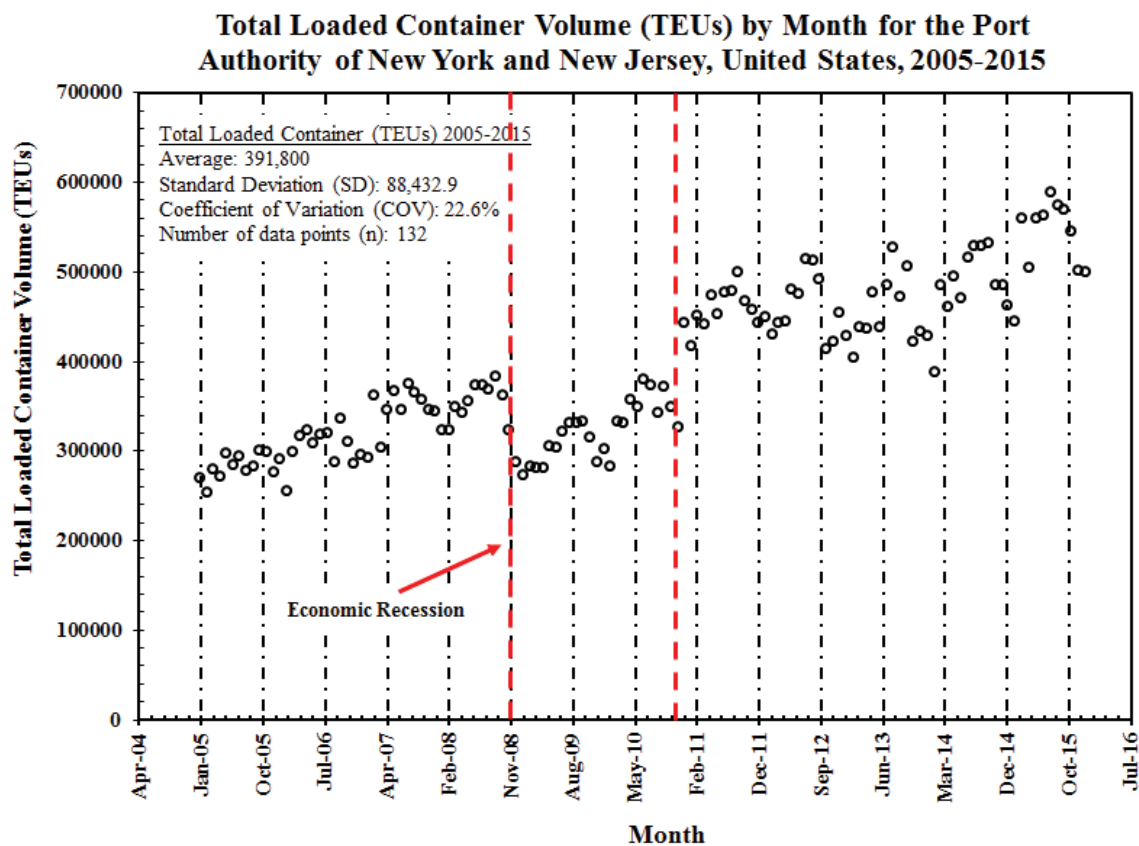


Figure 69. Observed Total Loaded Container Volume by Month for the Port of New York and New Jersey, 2005-2015

The sequential correlation between the data itself and the Pearson's correlations between the cumulative months and transformed data sets were determined and summarized in Table 21. High sequential correlation R of 0.935 between the observed volume and lag 1 container volume data showed that the time series data for Port of New York and New Jersey is suitable for

ARIMA modeling. The AR terms were decided by evaluating the month vs. observed TEUs (zero lag or AR equal to zero) and also month vs. lag 1 TEUs (AR equal to one). High correlation values of 0.885 and 0.883 suggested to try ARIMA models with AR terms equal to zero and one. Data transformation using one differencing term is adequate to ensure a statistically stationary data base on the correlation value reaching near to zero between month vs. one differencing data. Additionally, three differencing term was selected based on higher correlation between month vs. three months MA data compared to a two month MA term

Table 21. Sequential Correlation and Pearson’s Correlations of Container Volume Data With Different Differencing and Moving Average Terms for the Port of New York and New Jersey

A	B	C	D	E	F	G
Sequential Correlation (Lag 1), R	Month vs. Total TEUs (Observed), R	Month vs. Total TEUs (Lag 1), R	Month vs. Total TEUs (Lag 2), R	Month vs. One Differencing, R	Month vs. 2 Months Moving Average, R	Month vs. 3 Months Moving Average, R
0.935	0.885	0.883	0.881	-0.007	0.898	0.904

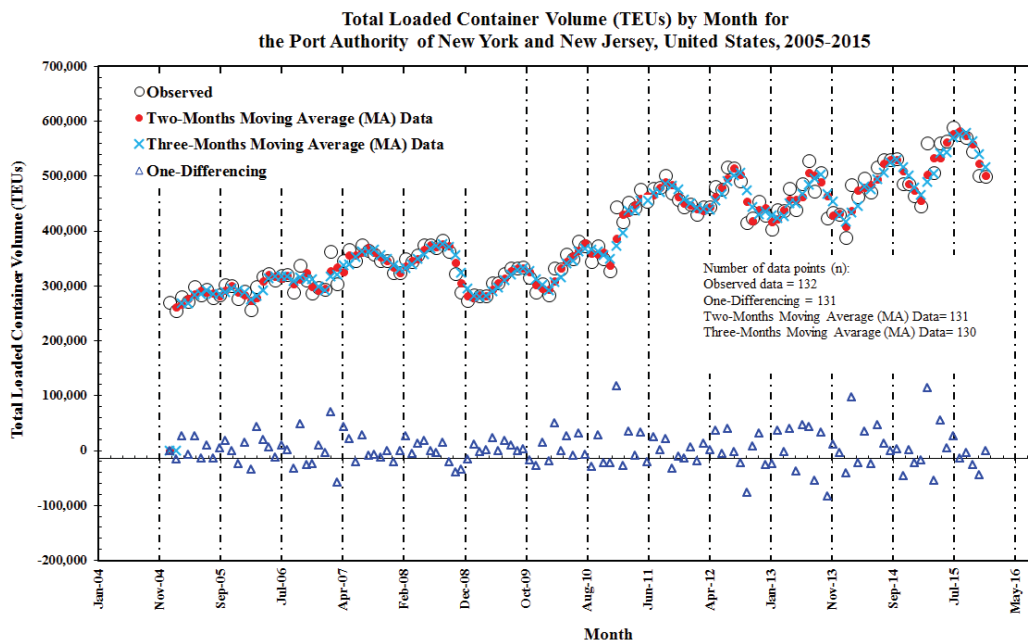


Figure 70. Differencing and Moving Average Process to Determine the ARIMA Model Equation Terms for the Port of New York and New Jersey

The data sets with one differencing and two and three month MA terms were plotted as shown in Figure 70. The differencing process removed the trend from the observed data. The non-stationary data was converted into a stationary condition, so that further analysis can be completed using the stationary time series. Therefore, the ARIMA (0,1,3) and ARIMA (1,1,3) model equations were evaluated using the monthly container volume data for the Port of New

York and New Jersey. The ARIMA models were developed using data sets from 2005 to 2014 and verified using monthly time series in 2015.

The prediction using both ARIMA (0,1,3) and ARIMA (1,1,3) model equations were made and the results are shown in Figure 71. The prediction from 2005 to 2014 using ARIMA model equations were close to the observed values despite nonlinearity and seasonal variations in the observed data sets. This implies that both ARIMA model equations are able to predict reasonable values in future months.

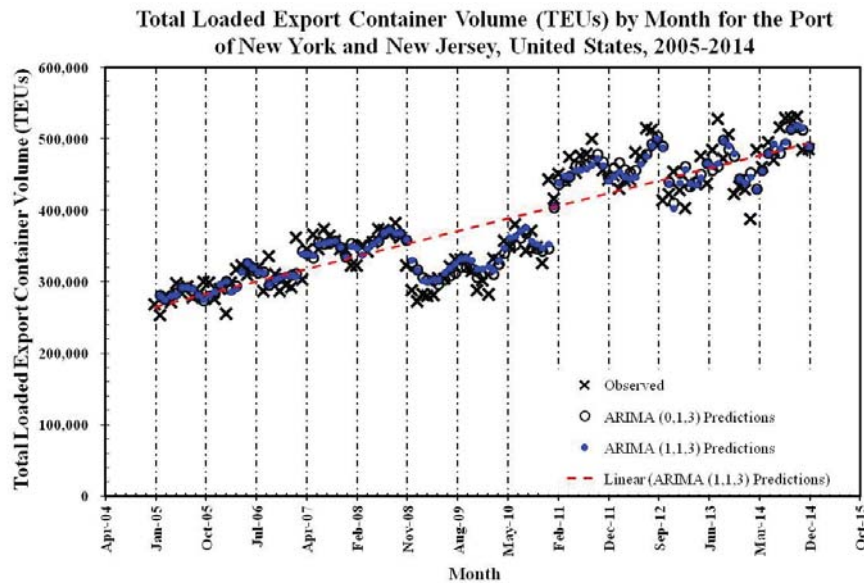


Figure 71. Observed and Predicted Loaded Export Container Volume (TEUs) for the Port of New York and New Jersey, 2005-2014

The predicted vs. observed data plots for ARIMA (0,1,3) and ARIMA (1,1,3) model equations are shown in Figure 72. In this particular example, ARIMA (0,1,3) model equation shows higher R of 0.938 compared to ARIMA (1,1,3) model equation R of 0.911. The average values for both ARIMA models are higher than the observed monthly average of 377,882 TEUs. The COV for both ARIMA model is approximately 20% which is lower compared to the COV of observed data.

Table 22 compares the predictions from January to December 2015 using the regression equation and the ARIMA model equations. The cumulative months of 121 to 132 represent the months of January to December 2015. The ARIMA (0,1,3) and ARIMA (1,1,3) model equations predicted container volumes of 6,295,092 and 6,120,206 TEUs, respectively which are lower compared to the observed total container volume of 6,371,720 TEUs. The monthly average volumes are 524,591 and 510,017 for ARIMA (0,1,3) and (1,1,3) model equations, respectively.

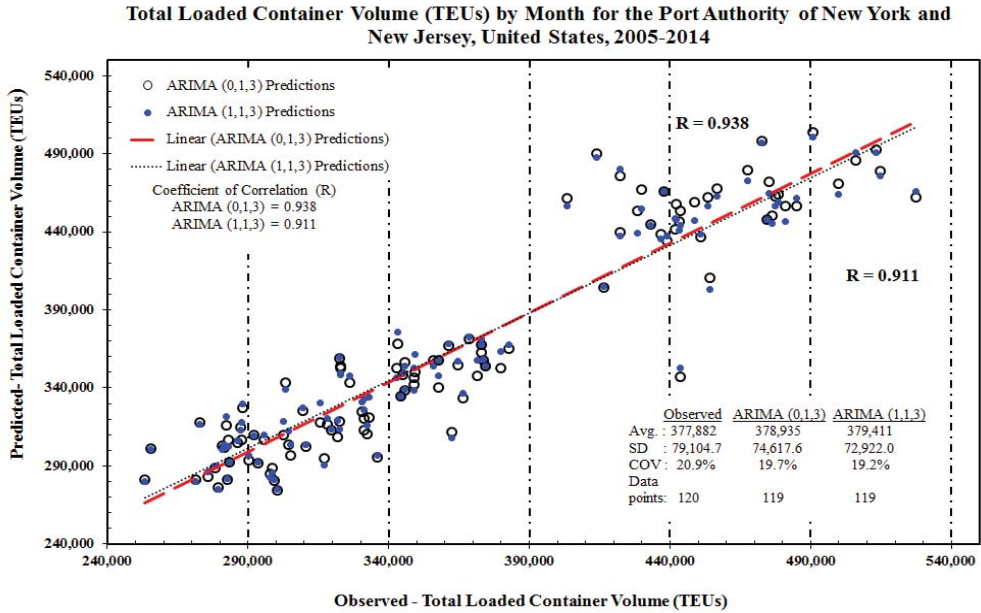


Figure 72. Predicted vs. Observed Plot for the ARIMA (0,1,3) and ARIMA (1,1,3) Model Equations for the Port of New York and New Jersey

Table 22. Comparison Between the Observed and Predicted Values Using Different Modeling Approaches (Port of New York and New Jersey)

Cumulative Month	Month	Total Loaded (Observed) (TEUs)	ARIMA (0,1,3) Predictions (TEUs)	ARIMA (1,1,3) Predictions (TEUs)
121	Jan-15	463,002	495,787	490,658
122	Feb-15	445,285	511,011	499,757
123	Mar-15	559,264	521,520	508,083
124	Apr-15	504,674	529,288	514,468
125	May-15	558,991	534,753	518,892
126	Jun-15	562,573	537,913	521,338
127	Jul-15	588,918	538,770	521,791
128	Aug-15	574,547	537,322	520,238
129	Sep-15	569,956	533,570	516,669
130	Oct-15	544,677	527,514	511,076
131	Nov-15	500,608	519,154	503,450
132	Dec-15	499,225	508,490	493,786
	Total	6,371,720	6,295,092	6,120,206
	Average	530,977	524,591	510,017
	SD	46,838	13,709	10,894
	COV	8.8%	2.6%	2.1%
	% Difference Average		- 0.6%	- 3.4%

The average percent differences between the predicted TEUs for both ARIMA model equations were compared with the observed value. The percent difference for the predictions using ARIMA (0,1,3) model equation is approximately three times lower compared to ARIMA (1,1,3) model's predictions. The predicted vs. observed plot for ARIMA (0,1,3) model equation also shows high R of 0.938. The results show that the ARIMA (0,1,3) model equation is a better predictor considering lower percent differences for annual and monthly average TEUs compared to the observed loaded export container volumes. The following Equation 23 shows general ARIMA (0,1,3) model equation with one differencing and three moving average terms for the Port of New York and New Jersey.

$$\nabla^1 * Y_t = C + (1 - \theta_1 B - \theta_2 B^2 - \theta_3 B^3) * a_t \quad \text{Eq. 23}$$

Where,

Y_t = TEU at the end of the t^{th} month

∇^1 = Regular Differencing operator of order one

C = Constant = 16,985.3

$1 - \theta_1 B - \theta_2 B^2 - \theta_3 B^3$ = Regular Moving Average process of order three

a_t = random shock term; normally and independently distributed about the mean zero with constant variance equal to squared σ_a

Further analysis was carried out to verify future year container volume predictions using ARIMA (0,1,3) model equation. The model equation was able to predict seasonal cycle patterns of the data as shown in Figure 73.

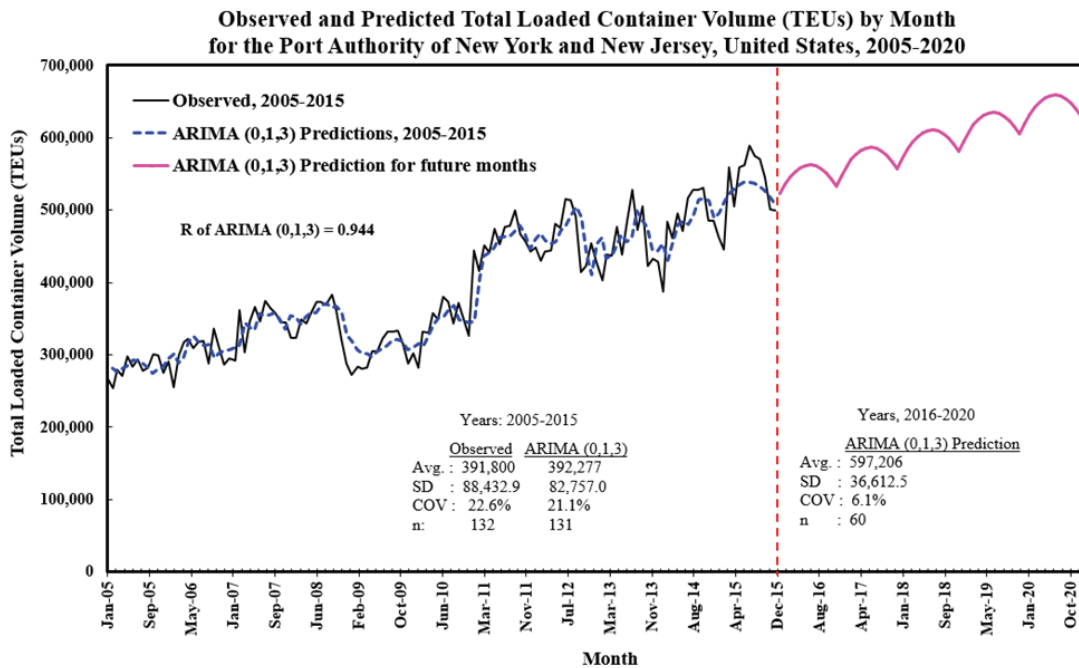


Figure 73. ARIMA (0,1,3) Predictions from 2005 to 2015 and Future Month Predictions until 2020 for the Port of New York and New Jersey

Figure 73 shows the observed and predicted TEUs from 2005 to 2015 and predictions for future months from January 2016 until December 2020. The dash-dash line indicates container volume data with one differencing and three moving average terms. The predictions for future months are illustrated by the solid lines with repeating cycle patterns. The ARIMA predictions are able to show increasing trends and seasonal cycle patterns, which is unable to be predicted using traditional regression approach.

The annual data based on a total of 12 months data predicted using ARIMA (0,1,3) model equations are shown in Figure 74. The predicted annual container volume for 2016 is 6,588,032 TEUs with an average monthly of 549,003 TEUs. The ARIMA (0,1,3) model equation predicted constant annual growth rates ranging from 3.9 to 4.4% from 2016 until 2020. In 2020, the total loaded export container volume was expected to grow to 17.6% from the container volume in 2016. The predicted 2020 container volume is 7,744,908 TEUs with monthly average of 645,409 TEUs.

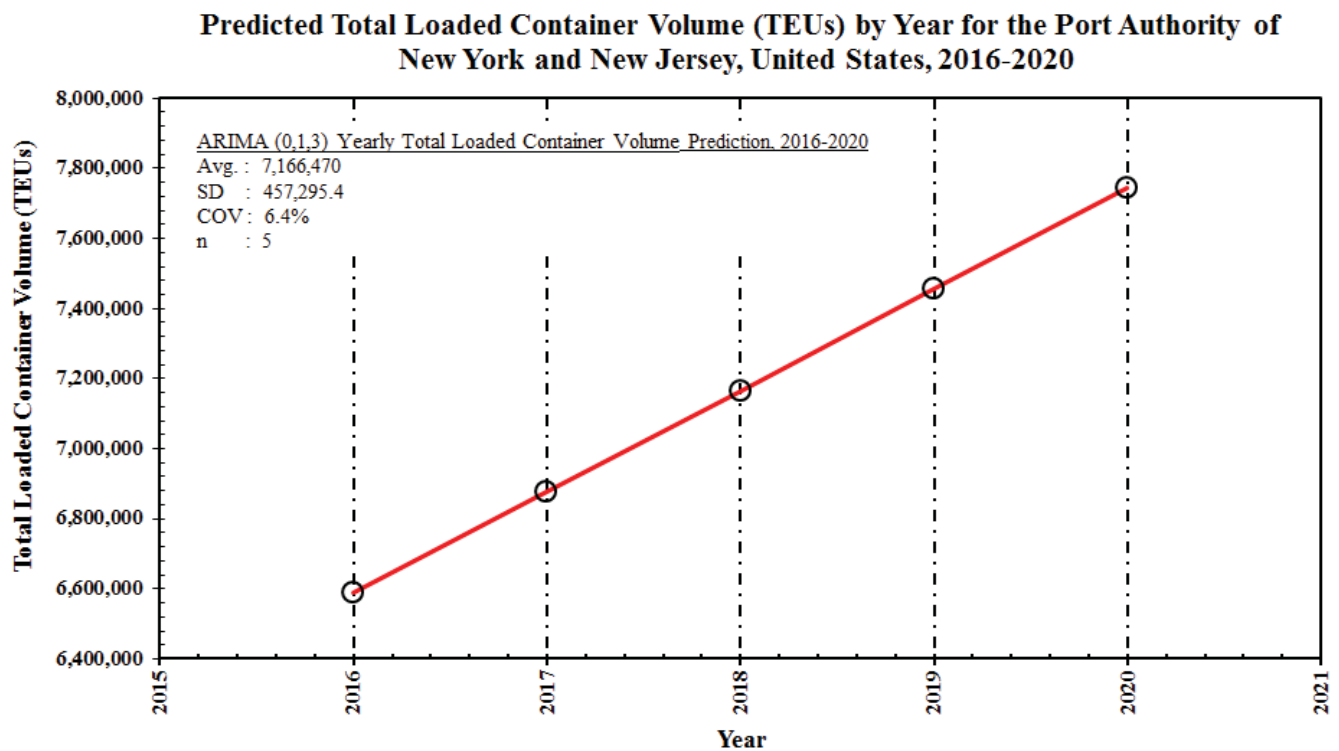


Figure 74. Annual Predictions of Total Loaded Export Container Volume from 2015 to 2020 for the Port of New York and New Jersey

3.2 AIS Marine Vessel Navigation Data Used for Global Shipping Impact Analysis

Historical Background

The AIS data has presented new opportunities in performance-based management of waterway infrastructure (Mitchell 2011). A review of AIS technology and by Scully and Mitchell (2013) is summarized, as follows: “It has been commercially available since 2001, and its use was mandated in 2002 for certain new classes of vessels (Calder and Schwehr, 2009). Technical characteristics are specified by the International Telecommunication Union, which describes the primary use of AIS for ship to ship communication and enhancement of navigation safety (ITU 2010). Primarily intended for real-time use, AIS expands operator awareness of the maritime domain. In the US, the Coast Guard (USCG) is charged with monitoring and recording AIS transmissions (USCG, 2012). . . . The utility of AIS data at a local scale has been investigated by several authors.”

Historically, starting from December 2004, the International Maritime Organization (IMO) requires all passenger vessels and all freight vessels over 299 gross tonnage to carry the AIS transponder, which submits and receives AIS data. This important requirement resulted from 2002 Safety of Life at Sea (SOLAS) agreement’s relative mandate (Marine Traffic 2015). AIS broadcast record transmits real-time vessel response on an assigned radio frequency to any condition, which provides a tracking record and helps in case of emergency or alerts any threat due to a disaster. These wireless remote sensing data are a part of growing Internet of Things (IoT) database, as discussed in the Marine Transportation Conference (Uddin et al. 2014).

Shipping Demand and Flow Mapping Based on AIS Marine Vessel Navigation Data

There are five major factors that influenced the demand for maritime transport on the maritime shipping market (Jugovic et al 2015). Those factors are (1) world economy, (2) international maritime trade, (3) average profit, (4) the influence of political disturbance on the shipping demand, and (5) transportation cost. Jugovis et al 2015 elaborated more on each factor through their study on the factors influencing the formation of freight rates on maritime shipping markets. For assessing shipping volume demand globally and local port locations AIS data provides a useful tool if available freely online.

For this purpose the project team registered and accessed the online web site of Marine Traffic (www.marinetraffic.com/) to collect cargo ship counts over a selected time period (Marine Traffic 2015). The “Live Map” feature on the Marine Traffic website provides near real time number of vessels passing through any major shipping channels worldwide including the number of vessels anchored at sea waiting for their turn to enter ports to deliver and receive bulk commodities. Figure 75 shows a screen capture of the online heat map of global AIS remote sensing data.

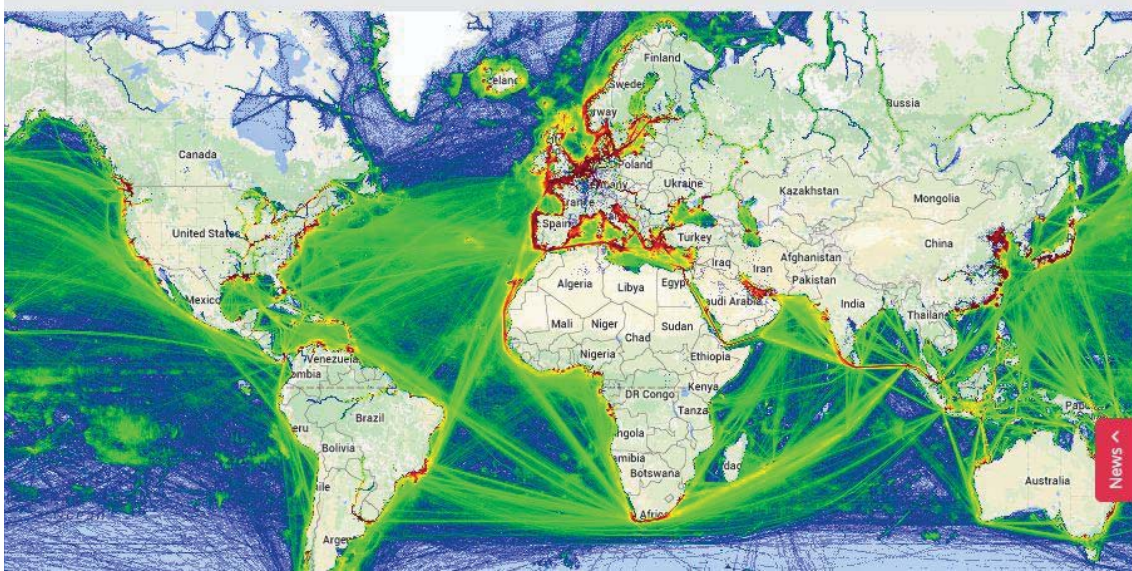


Figure 75. A Heat Map of Navigation Flow of Sea Vessels (www.marinetraffic.com/)

The availability of these historical spatial-temporal waterborne transport data was an important part of this research to map cargo ship traffic flow demand in selected channels. The commercial use of Automated Information System or AIS data from navigating vessels includes online surveillance of the vessels and mapping cargo shipping flow through selected navigation channels. It is reported that more than 140,000 vessels and 550,000 AIS events generated every day at 3,000 stations worldwide (Marine Traffic 2016a, 2016b). Figure 76 shows a screen capture of the online map for vessel counts.



Figure 76. Marine Traffic AIS Live Map Application Showing Number of Vessels at Specific Shipping Channels (www.marinetraffic.com/)

The AIS data and ship navigation flow maps have been extensively used in the maritime world. The AIS receiving stations record static and dynamic vessel information for live ship tracking and online mapping purposes. The live map provides near real-time number of vessels either passenger, cargo, tankers and other vessels. The numbers of the vessels are updated as soon as the latest data available via the AIS. The update time intervals may vary from a few minute to several hours. Further analysis was conducted on the number of cargo vessels to develop spatial maps of typical daily cargo vessel demand in the U.S and Mediterranean shipping routes (Richardson 2016, Nguyen 2017). The calculated number of vessels per hour for 24 hours was identified and the data was presented as a thematic or spatial map for better data visualization and analysis purposes.

The following key steps used to count the hourly cargo ship counts from the Marine Traffic AIS database, preparing daily summary of cargo ship volume in selected navigation channels:

- Determine the selected shipping channel areas. For the U.S. routes, the selected shipping channel areas are Europe-Atlantic (E), Gulf/Caribbean (G), East Coast Atlantic (EA), Pacific Ocean (P), and West Pacific Alaska (W).
- Create a spatial map using the GeoMedia Professional software which shows the shipping routes buffers where the number of cargo vessel will be counted as shown in Figure X. This spatial map was used to ensure that only cargo vessels in the selected shipping channel areas are counted.
- Count the total cargo vessels in the shipping channel areas at an hour interval for 24 hours. This step was carried out by summing up all cargo vessel counts from the AIS database, for example at 12.00 a.m and 1.00 a.m, 5.00 a.m and 6.00 a.m , 12.00 p.m and 1.00 p.m, and 5.00 p.m and 6.00 p.m.
- The vessel counts are not counted for 24 hours. Therefore, there will be missing total counts for a 24 hour time period. The missing number of vessel counts are interpolated or extrapolated from the observed data.
- Use the 24 hour vessel count data to create spatial maps for the selected shipping routes.

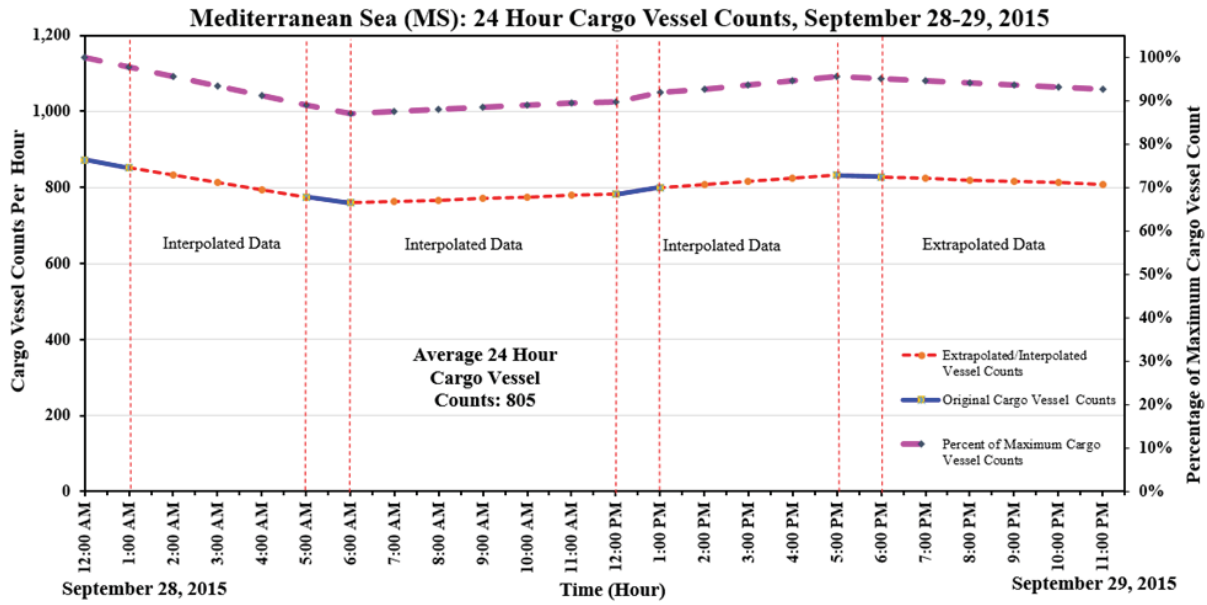
The major shipping corridors were identified from the Marine Traffic map. The selected shipping routes close to the U.S. are; Europe-Atlantic (E), Gulf/Carribbean (G), East Coast Atlantic (EA), Pacific Ocean (P), West Pacific Alaska (W). Other shipping routes are; Suez Canal (SC), Mediterranean Sea (MS), Red Sea (RS), Strait of Malacca (SM), and Panama Canal (PC).

Table 23 and Figure 77 show an example of vessel count data and interpolation/extrapolation methods used to determine 24-hour counts for East-West traffic in Mediterranean Sea. Table 23 shows typical daily observed cargo vessel counts and missing data interpolations and extrapolations for the Mediterranean Sea. The hourly vessel counts range from 759 to 872 with an average of 805 vessels per day. The COV of daily cargo vessel counts in the Mediterranean Sea is 3.6%, approximately 10 times less compared to the COV of the Suez Canal.

Table 23. Typical daily original and missing data interpolations and extrapolations for the Mediterranean Sea

Typical Daily Original and Missing Data Interpolations and Extrapolations in Mediterranean Sea (MS)				
	1	2	3	4 3/(Largest Value in 3)*100
Hour	Original Cargo Vessel Counts	Extrapolated/Interpolated Vessel Counts for Missing Cells	Hourly Cargo Vessel Counts	Percent (Normalized to Maximum Cargo Vessel Count)
12:00 AM	872		872	100.0%
1:00 AM	852		852	97.7%
2:00 AM		833	833	95.5%
3:00 AM		814	814	93.3%
4:00 AM		795	795	91.1%
5:00 AM	775		775	88.9%
6:00 AM	759		759	87.0%
7:00 AM		763	763	87.5%
8:00 AM		767	767	88.0%
9:00 AM		771	771	88.4%
10:00 AM		775	775	88.9%
11:00 AM		779	779	89.3%
12:00 PM	782		782	89.7%
1:00 PM	800		800	91.7%
2:00 PM		808	808	92.7%
3:00 PM		816	816	93.6%
4:00 PM		824	824	94.5%
5:00 PM	832		832	95.4%
6:00 PM	828		828	95.0%
7:00 PM		824	824	94.5%
8:00 PM		820	820	94.0%
9:00 PM		816	816	93.6%
10:00 PM		812	812	93.1%
11:00 PM		808	808	92.7%
Average			805	92.3%
Standard Deviation (SD)			29	
Coefficient of Variation (COV)			3.6%	
Number of data points (n)			24	

Table 23 shows that the 24 hour cargo vessel counts and the percentage of the number cargo vessel per peak count range from 87 to 100%. These percentages indicate more consistent cargo vessel counts observed every hour from 12.00 a.m. on September 28, 2016 to 11.00 p.m. on September 29, 2016. The same data set was used to create the typical 24 hour cargo vessel counts for the Mediterranean Sea as shown in Figure 77.



Source: MarineTraffic, 2015. <http://www.marinetraffic.com/en/ais/home/centrix:-20/centery:20/zoom:3> Accessed June 30, 2015

Figure 77. Typical Daily Cargo Vessel Counts for Mediterranean Sea Shipping Route

Figure 78 shows a spatial map of all navigation routes for the typical daily cargo vessel demand map analyzed in this study for shipping routes based on 2015-2016 cargo ship counts database. Table 24 is a summary of the data for all analyzed shipping routes and CO2 emission estimated using average daily vessel counts on hourly basis and Equation 24 (Nguyen 2017).

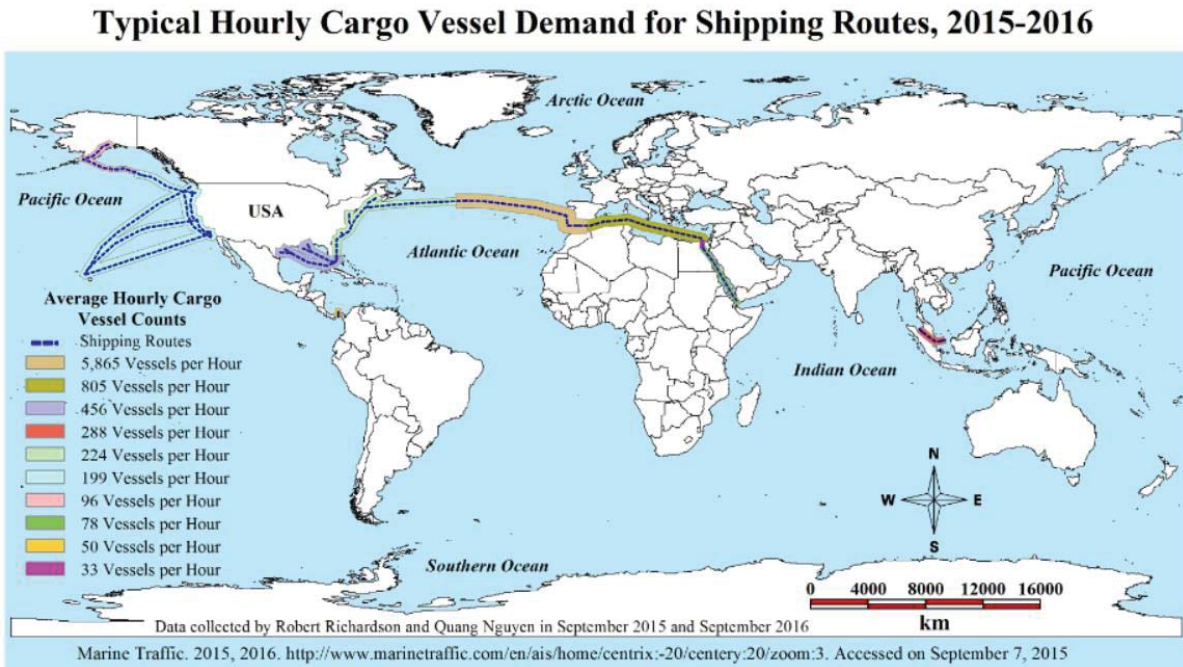


Figure 78. Spatial Map of Typical Hourly Cargo Vessel Demand for Selected Shipping Routes

Table 24. Summary of Daily Cargo Vessel Counts and Anthropogenic CO₂ Emissions In Selected Shipping Routes

Shipping Routes	Date Data Collected	Average Cargo Vessel Counts Per Day	Total Cargo Vessels Per Day	Route Length	Daily Shipping CO ₂ Emissions
	(mm/dd/yyyy)	(vessels/hour)	(vessels/day)	(km)	(tons/day)
Strait of Malacca (SM)	09/08/2016	288	6,921	790	4,171
Red Sea (RS)	09/28/2015	78	1,860	1,900	12,188
Suez Canal (SC)	09/28/2015	33	787	190	638
Mediterranean Sea (MS)	09/28/2015	805	19,324	3,500	12,188
Europe Atlantic (E)	09/07/2015	5,865	140,748	4,000	18,282
East Coast Atlantic (EA)	09/07/2015	224	5,372	5,093	12,188
Gulf/Caribbean (G)	09/07/2015	456	10,943	1,968	12,188
Panama Canal (PC)	09/08/2016	50	1,207	78	168
Pacific Ocean (P)	09/07/2015	199	4,776	4,788	12,188
West Pacific Alaska (W)	09/07/2015	96	2,310	3,149	12,188
Total				25,456	96,389

Total cargo vessels counted per hour in a day in selected shipping routes: 8,094 vessels

Total anthropogenic CO₂ emissions per day in selected shipping routes: 96,389 metric tons/day

Equation 24 was used to calculate Anthropogenic CO₂ emissions for each route for a typical single day trip by a container cargo ship.

CO₂ Emissions Per Day =

$$[\text{Vessel Counts} \times \text{TEU per Vessel} \times \text{Weight per TEU} \times \text{Distance km} \times 10\text{grams}] / 1000,000\text{grams} \quad \text{Eq. 24}$$

Where, CO₂ Emissions rate per ton-km = 10 grams for assumed 8,000 TEU ship.

For example, in Mediterranean Sea, we assumed average weight of TEU equal to 30 tons.

Average distance traveled per day in Mediterranean Sea= 24h x 46 km/h (Speed) = 1,104 km/day (Except for the Strait of Malacca, Red Sea, Suez Canal, and Panama Canal where the distance traveled per day was assumed as the length of each of these channels.)

So, Average Anthropogenic CO₂ Emissions per Day per Route =

$$[805 \text{ Vessels} \times 8,000 \text{ TEUs} \times 30 \text{ tons} \times 10 \text{ grams} \times 1,104\text{km}] / 1000,000 = 12,188 \text{ metric tons/day}$$

Total anthropogenic CO₂ emission per day in selected shipping routes is 96,389 metric tons/day during the sampling period of 2015-2106. Note this number does not include numerous other ships traveling other navigation routes. Depending upon the volume of worldwide ships traveling in a typical day the total CO₂ emission per day may be twice the above estimate. Europe Atlantic

(E) route has the highest number of ships (5,865) and produced the highest amount of 18,282 metric tons CO₂ emission per day.

Spatial maps were created for selected navigation routes together with the screenshot of AIS vessel count maps to ensure that the vessel counts belong to the correct the shipping channel buffer. Different color codes were used to identify different shipping routes buffer. By using the “attribute query” command in the GeoMedia Pro software, the polygon buffers of shipping channels and routes buffer were identified and mapped.

Further research is in progress on using AIS data to calculate processing time at ports and evaluate dock service performance of cargo vessels based on processing delay data using the port specific AIS data. Figure 79 shows an example of Miami port (Mitchell 2016).

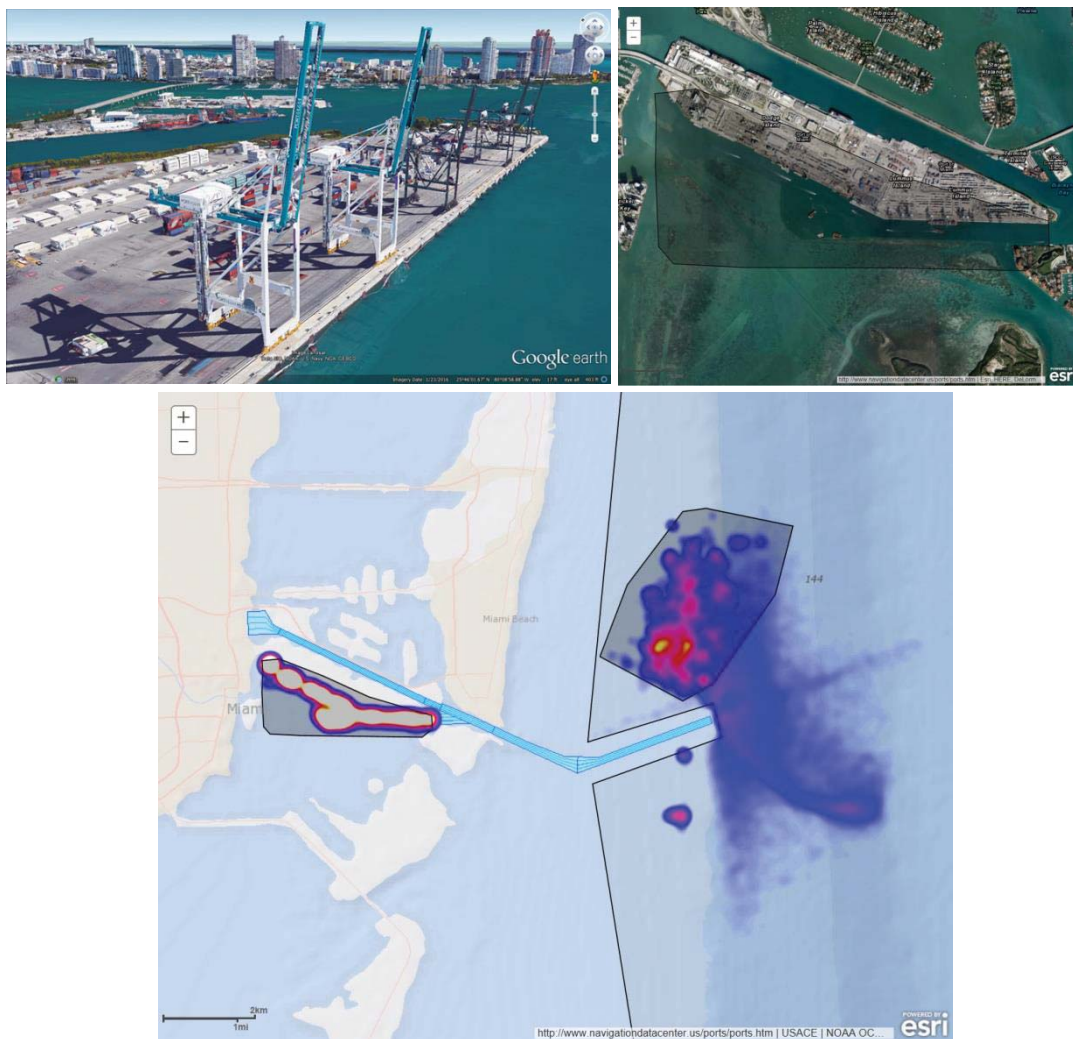


Figure 79. Miami Port, Florida: (Top Left) Google Earth Image, (Top Right) Navigation Data Center ESRI Image, (Bottom) Heat Map of AIS Data
(Credit: Dr. K. Ned Mitchell, ERDC Coastal and Hydraulics Lab, Vicksburg, Mississippi)

3.3 Impacts of Cargo Shipping on the Environment and CO₂ Emissions

Global Shipping Impacts

Detailed discussion on health and environmental impacts of harmful fossil fuel emissions and CO₂ emissions are available in the final report of NCITEC Project 2012-27 (Uddin et al. 2016). Due to diesel burning freight vessels, high amounts of unhealthy and harmful emissions are produced by the global shipping sector although it is still less than aviation emissions. Similarly, it produces less CO₂ per ton-km freight, as follows (data credit: AP Møller - Maersk www.maersk.com/):

- Large Container Ship (18,000 TEU) : 3.0 grams CO₂ per ton-km
- Large Oil Tanker (80,000 – 119,999 dwt) : 5.9 grams CO₂ per ton-km
- Large Bulk Carrier (10,000 – 34,999 dwt) : 7.9 grams CO₂ per ton-km
- Freight Trucks on Highways (> 40 tons) : 80.0 grams CO₂ per ton-km
- Air Freight (Boeing 747, Capacity 113 tons) : 435.0 grams CO₂ per ton-km

However, shipping is a major CO₂ emission producer worldwide due to the volume of ships sailing at any given time. New generation of very large container ships and bulk carrier vessels are designed to ship more load to longer distances while producing less emissions (Figure 56).

Additional Societal Benefits and Concerns Related to Freight Intermodal Integration

Major findings from geospatial analysis and intermodal freight traffic integration studies have been discussed in the above sections and illustrated by sample figures and tables for reductions in travel, time, shipping costs, fuel consumption, and CO₂ emissions. Table 25 presents key results.

Table 25. Summary of Benefit and Savings Calculations

Integrated Intermodal Routes	Length (miles)			Total Travel Time Reduction	Total Ton-Mile Cost per Year, Saving	CO ₂ Emission Reduction	Fuel Saving per Year, US\$
	Highway	Rail	Barge				
Integrated Highway/ Rail, CO - CA, 30% Trucks Diverted	1,201	1,353	--	98.9%	87%	57.7%	3.74 million
Integrated Highway/ Rail, Laredo-Detroit 20% Diverted to Barges	1,669	1,674.5	--	98.8%	87.2%	58.2%	84.8 million
Integrated Highway/ Waterway Upbound 20% Diverted to Barges	695	--	984	12.2%	12.4%	7.8%	75,392
Integrated Highway/ Waterway Downbound 20% Diverted to Barges	863	--	1,044	18.6%	13.5%	18.5%	5.15 million

Recent rail industry's AAR data shows (Candee & Co 2015) that 13.5M containers and trailers were moved by intermodal in 2014, which is up 5.2% or 666K units over 2013 record. This trend in rail intermodal freight is expected to grow (AREMA 2016) as rail intermodal shipment of containers to and from inland terminals and sea ports become a major part of freight rail business. More rail intermodal operations will reduce long haul truck trips and highway congestion, surge more short haul truck trips, and increase overall benefits to both truck and rail businesses.

There are many other societal benefits associated with diverting truck traffic from the nation's major freight corridors, which are discussed in the following sections.

Avoidance of Truck Driver Fatigue and Crashes: Cobb outlined and discussed the benefits of reduction in truck driver fatigue and crashes to improve safety (Cobb 2015). One of the top issues surrounding freight transportation is operator fatigue (Vector 2009). According to Advocates for Highway & Auto Safety, each year truck crashes kill over 5,000 people and injure 150,000 more, and heavy duty trucks are involved in multiple-vehicle fatal crashes at twice the rate of passenger vehicles (Advocates 2015). Truck driver fatigue contributes to as many as 30-40% of all heavy truck crashes. Even though many rules and regulations have been developed in recent years to limit truck drivers' hours behind the wheel, many drivers resist rules on sleep, despite the risks, due to strict time constraints on freight arrival (NYT 2014). By diverting freight to alternative modes, the possibility for driver fatigue related crashes is being reduced. Modes such as rail and barge do not have a constant encounter with passenger traffic like that of trucks on the highway. Fewer trucks making long haul routes on the highway reduce the chances of these crashes to occur. Moreover, driver fatigue and stress will be less for short-haul trucking jobs.

Fear of Losses of Trucking Jobs and Employment of Truck Drivers: Many see the diversion of truck freight from the highway as an issue due to the elimination of trucking jobs, but this is not necessarily the case. When diverting freight trucks to waterway and rail, there will still be a need for short haul trucking to reach intermodal terminals of rail and waterway ports. The same number of trips will be made just not the same distance drivers were originally travelling. This makes highways less congested as well as reduces driver fatigue on the highways. When utilizing rail corridors, the development of more intermodal facilities and the heavier operation and maintenance of the rail will develop many jobs. Where there is a possibility for long-haul truck driver job reduction by utilizing rail, there will be a huge increase in short haul trucks in the supply chain logistics industry. Due to these reasons, there should be no decline in jobs and business demand due to short haul trucking operations.

Energy Conservation, CO₂ Reduction, and Climate Impacts: According to the latest Energy Information Administration (EIA) report, the CO₂ emissions from energy production is decreasing as coal is being used less and natural gas more for generating electric power (EIA

2015). However, CO₂ emissions from petroleum fuel used in transportation fleets is on the rise. The impacts of U.S. and global CO₂ emissions are grave for our future generation, as follows (Durmus et al. 2015, IPCC 2014, Melillo et al. 2014, White House 2014):

- Climate is being affected and more weather related disasters are on the rise.
- Disruptions in transportation networks are happening due to extreme weather events.
- Communities are being uprooted due to extreme weather events resulting in more traffic congestion and emissions in urban areas.
- Long-term impacts on the planet are severe as polar ice masses and glaciers are melting and sea level may rise in future by the end of this century.

The fossil fuel based economy and transportation technologies have to face depletion of these natural resources in future so energy conservation is important in all economic sectors. Every economic sector has to contribute to the reduction of greenhouse gases (GHG) in which anthropogenic CO₂ is the largest contributor (Uddin 2012). So the CO₂ emissions from transportation sector must be reduced by having more fuel efficient and electric vehicle technologies.

3.4 Risk Assessment and Natural Disaster Resilience Management of Critical Infrastructure

In the United States, more than 95% of federal disaster declarations are related to floods, and annual flood losses average nearly \$8 billion per year. Floods are commonly caused by torrential rainfall in coastal areas and inland floodplains.. However, in coastal areas floods can also be caused by hurricanes, sea-level rise or a tsunami. From 2005 to 2014, flood disasters caused 3,816 deaths and \$545 billion of economic loss in the United States (Durmus et al. 2015, Nguyen 2016). Coastal cities are increasingly prone to the threats of destruction by natural disasters, especially floods. Most cities in the Southeast and Atlantic Coast of the United States with populated coastal areas are vulnerable to extreme weather events of hurricane and flood disasters.

Billions of dollars in repair and replacement costs of transportation and other public infrastructure assets were needed after the disasters of 2005 Hurricane Katrina, 2011 Hurricane Irene and 2012 Hurricane Sandy in the United States, as well as most recent 2016 flooding in West Virginia and Southern Louisiana. Natural disasters are increasingly becoming more frequent and pose destruction threats to economic and social well-being, human lives, and industrial and commercial supply chains worldwide. This has been evident during after 2011 Japan's Fukushima tsunami disaster, 2011 megaflood of Bangkok, and after typhoon devastations in other Southeast Asian countries by in recent years. Additionally, disruptions in transportation services lead to social harms and huge economic losses. Higher frequency and ferocity of rainfall and coastal disasters due to climate impacts have increased the risk of flood

hazards and sea level rise (White House 2014). Ports and municipal public infrastructure assets are essential to sustain the economy and society.

Significant research has been conducted in NCITEC Project 2012-25 (Uddin and Altinakar 2015, Durmus et al. 2015) and doctoral dissertations (Durmus 2016, Nguyen 2017) for disaster resilience management associated with rainfall floods, coastal hurricanes, tsunamis, and climate impacts of sea level rise by year 2100 (NOAA 2012). The approach is based on the application of computational modeling and geospatial mapping for disaster resilience management of public infrastructure assets in cities and the urban environment to prevent and minimize adverse impacts. Case studies of Port of Miami in the U.S. and in Vietnam were analyzed to identify potential threats and opportunities in order to enhance disaster resilience by hardening public infrastructure assets and communicating with communities. Additionally, value engineering (VE) application (Uddin 2013) was made to enhance flood disaster resilience of bridge structures subjected to extreme flood water forces (Durmus 2016, Uddin 2015). Detailed results are not presented here for brevity. It was demonstrated that floods from extreme rainfall may be the most devastating natural disaster endangering infrastructure and public depending upon the terrain topography and urban planning. Figure 80 shows the flood simulation results of Miami, Florida. Computer simulations estimated that 1.4 million of population may be affected due to flood inundation or from submerged land (Nguyen 2017). It is recommended that these coastal risks should be assessed for port cities in order to plan for “hardening” of port infrastructure assets to enhance disaster resilience (Touzinsky 2016, Uddin et al. 2013, Uddin 2016a, Uddin 2016b).

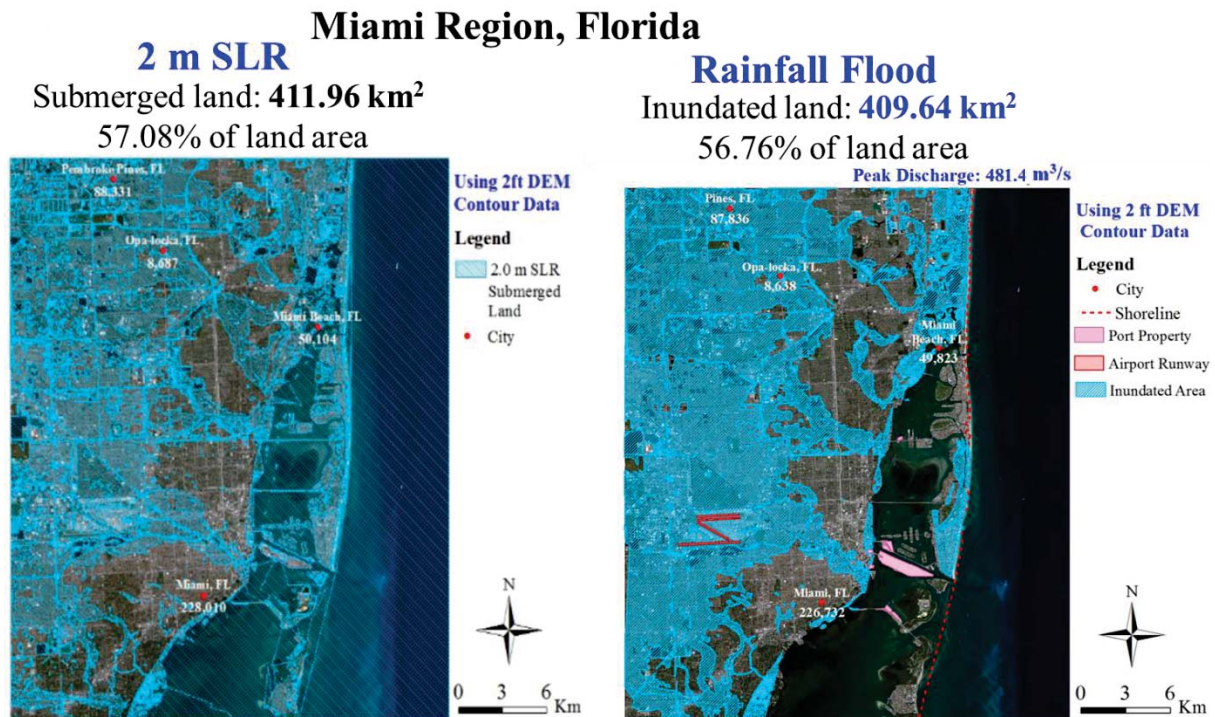


Figure 80. Results of Computational Modeling and Geospatial Mapping for Rainfall Flood and 2m Sea Level Rise for Miami Region, Florida

4. RESEARCH PRODUCTS AND IMPLEMENTATION STATEMENT

4.1 Publications and Presentations

A paper on traffic microsimulation conducted for the Mississippi DOT project, based on the thesis of a former M.S. student, was published in an international peer-reviewed ATS journal.

(This Miss DOT project won the 2014 AASHTO award of Sweet Sixteen projects.)

Graduate M.S. Report/Thesis and PhD Dissertation (3 M.S. and 3Ph.D.)

Ahlan, Muhammad. (2014). Geospatial Applications for Mobility, Travel Demand, Transport Infrastructure, and Associated Impacts on the Environment. M.S. Graduate Report, University of Mississippi, December 2014. (Advisor: Dr. W. Uddin)

Cobb, Seth. (2015). Economic Viability and Societal Benefits of Integrated Multimodal Freight Corridors and Sustainable Passenger Transportation. M.S. Thesis, University of Mississippi, August 2015. (Advisor: Dr. W. Uddin)

Richardson, Robert F. Jr. (2016). Cargo Shipping Demand Modeling, Infrastructure Mapping of Selected U.S. Ports, and Emission Impacts. M.S. Thesis, University of Mississippi, December 2016. (Expected)

Durmus, Alper. (2016). Flood Disaster Resilient Bridge Structures for Sustainable Bridge Management Systems. Ph.D. Dissertation. University of Mississippi, August 2016.

Nguyen, Quang. (2017). Extreme Weather Disaster Resilient Port and Waterway Infrastructure for Sustainable Global Supply Chain. Ph.D. Dissertation, University of Mississippi, May 2017. (In progress)

Jaafar, Zul Fahmi M. (2017). Computational Modeling and Simulations of Condition Deterioration to Enhance Asphalt Highway Pavement Design and Asset Management. Ph.D. Dissertation, University of Mississippi, May 2017. (In progress)

Additionally, the following publications/papers/conference presentations are related to the goals of NCITEC projects:

(One book, one book chapter, four journal paper and five papers in refereed published conference book/online proceedings, four papers in conference proceedings, and 14 other conference presentations)

Book Published

Uddin, W., W.R. Hudson, and Ralph Haas (2013). *Public Infrastructure Asset Management*. McGraw-Hill, ISBN 0071820116. (Book published, July 2013) This second revised and expanded edition of our 1997 *Infrastructure Management* book includes several new sections on flood disaster examples, rapid flood impact assessment

using remote sensing imagery and geospatial technologies, and examples of life cycle benefit cost analysis for flood disaster mitigation and protection of built infrastructure. Other new topics include supply chain management, use of remote sensing imagery and geospatial technologies, asset management practice for transportation and other lifeline public infrastructure, and value engineering applications for investment decision making. Book blog post. <http://infrastructureglobal.com/dr-robert-khayat-ole-miss-chancellor-emeritus-infrastructure-improvement-cannot-be-delayed-if-we-are-to-continue-as-a-vital-nation/>

YouTube video: <http://youtu.be/LiHqJInrFy0>

Book Chapter

Uddin, W. (2014). Chapter 23 “Mobile and Area Sources of Greenhouse Gases and Abatement Strategies,” in *Handbook of Climate Change Mitigation and Adaptation*, edited by Wei-Yin Chen, John M. Seiner, Toshio Suzuki and Maximilian Lackner, Springer. (Updated Chapter 23 of the 2012 Handbook in December 2014. The reference book is available in 2016).

<http://www.springer.com/energy/renewable+and+green+energy/book/978-3-319-14408-5>

Book In Progress

Uddin, W. (2016). *Disaster Resilience Management of Infrastructure Systems*. Taylor and Francis, UK. (In progress for publication in 2016-2017) This book addresses natural disaster vulnerability assessment and protection of lifeline infrastructure from natural disasters.

Journal and Refereed Conference Books/Online Proceedings

Mohamed Jaafar, Z.F., Y. Najjar, and W. Uddin. (2016). Asphalt Pavement Roughness Modeling using the Artificial Neural Network and Linear Regression Approaches for LTPP Southern U.S. States. *Compendium, 95th Annual Meeting of Transportation Research Board*, Washington, DC, January 11, 2016. (Peer reviewed)

Smith, Robert, and Waheed Uddin. (2016). A Rational Theory of Tire-Pavement Friction. Research Article 4858317, *Advances in Tribology*, Hindawi Publishing Corporation, Volume 2016. <http://www.hindawi.com/journals/at/2016/4858317/> Accessed April 7, 2106.

Nguyen, Quang and W. Uddin. (2016). Applications of Shuttle Radar Data and Landsat-8 Satellite Imagery for HEC-RAS Floodplain Modeling. The National Hydrologic Warning Council (NHWC), *The NHWC Transmission*, January 2016. <http://www.hydrologicwarning.org/docs.ashx?id=241424> Accessed February 10, 2016.

Durmus, Alper and W. Uddin. 2015. Extreme Flood Simulation and Inundation Impacts on Structural Integrity of Bridges. The National Hydrologic Warning Council (NHWC), *The NHWC Transmission*, September 2015. <http://bit.ly/23MAtdE> Accessed February 10, 2016.

Uddin, W., McCarty, T., and Sharma, J. (2015). Environmental Sustainability and Energy

Considerations for Life-Cycle Analysis of Transportation Infrastructure Systems. *ASCE Special Publication, International Symposium on Systematic Approaches to Environmental Sustainability in Transportation (ISSAEST)*, University of Alaska, Fairbanks, August 2015, pp. 227-240.

Durmus, A., Q. Nguyen, M.Z. McGrath, M.S. Altinakar, W. Uddin. (2015). Numerical Modeling and Simulation of Extreme Flood Inundation to Assess Vulnerability of Transportation Infrastructure Assets. *94th Annual Meeting of the Transportation Research Board*, The National Academies, Washington DC. TRB Online Proceedings, January 10-14, 2015. (published and presented by Uddin, international conference)

Uddin, W. (2014). Remote Sensing Laser Survey and Imagery Technologies for Expediting Airport Mapping and Asset Management Applications. *E-Proceedings, 2014 FAA Worldwide Airport Technology Transfer Conference*, Galloway, New Jersey, August 5-7, 2014.

Merighi, and W. Uddin. (2014). Study of Water Pools on Runways Considering The ICAO and Brazilian Civil Aviation Agency Recommendations For Large Aircraft. *E-Proceedings, 2014 FAA Worldwide Airport Technology Transfer Conference*, Galloway, New Jersey, August 5-7, 2014.

Headrick, Jessica and W. Uddin. (2014). Traffic Flow Microsimulation for Performance Evaluation of Roundabouts and Stop-controlled Intersections at Highway Overpass. *ATS - International Journal of Advances in Transportation Studies*, Issue, XXXIV, November 2014, pp. 7-18.

The above paper on traffic microsimulation is based on a former M.S. student on the Mississippi DOT project. (This Miss DOT project won the 2014 AASHTO award of Sweet Sixteen projects.)

Conference Proceedings and Presentations

Uddin, W., João Virgilio Merighi, and Rita Moura Fortes. (2016). Sustainable Asphalt Paving Technology for Haul Roads in Amazon Region of Brazil. *Proceedings, MAIREPAV8 International Conference*, Singapore, July 26-29, 2016. (Dr. Uddin served as a Welcome Speaker and Session Chair. He was presented International iSMARTi Achievement Award at the conference.)

Jaafar, Zul Fahmi Mohamed and W. Uddin. (2016). Modeling of Asphalt Pavement Rutting for LTPP Southern Region Using Multiple Linear Regression Method. *Proceedings, MAIREPAV8 International Conference*, Singapore, July 26-29, 2016.

Uddin, W. (2016c). Natural Disaster Resilience and Air Quality Management in Urban Environment. Invited seminar presentation at AIT Workshop “Disaster Resilience Education Capacity Building in South-East Asia,” Asian Institute of Technology (AIT), Bangkok, Thailand, July 21, 2016. (Invited lecture)

- Uddin, W. (2016d). Natural Disaster Resilience of Public Infrastructure Assets. Presentation, School of Engineering, Universiti Sains Malaysia (USM), Penang, Malaysia, August 1, 2016. (Invited lecture)
- Uddin, W. (2016). Managing Disaster Resilience of City Public Infrastructure Assets. Presentation, *2016 Critical Infrastructure Symposium, TISP, Tech Session 2B Infrastructure Protection and Resilience*, Society of Military Engineers, Charleston, South Carolina, April 3 - 5, 2016.
- Uddin, W. (2016). Pavement Design, Construction & Condition Management– Lessons Learned. *9th Airfield Engineering and Asset Maintenance Summit Conference*, Dubai, UAE, February 1-4, 2016. (Invited lecture, full travel support by the Organizers)
- Durmus, Alper and W. Uddin. (2016). Assessing Structural Integrity of Bridge Superstructure Subjected To Extreme Flood Simulation. Bridge Data Analysis Working Group (BDAWG) Forum on Pavement Data Analysis, *95th Annual Meeting of Transportation Research Board*, Washington, DC, January 9, 2016. (Peer reviewed)
- Mohamed Jaafar, Z.F. and W. Uddin. (2016). Development of Asphalt Pavement Roughness and Rutting Models by using LTPP Database and Considering Maintenance and Rehabilitation History. Data Analysis Working Group (DAWG) Forum on Pavement Data Analysis, *95th Annual Meeting of Transportation Research Board*, Washington, DC, January 9, 2016. (Peer reviewed)
- Uddin, W. (2015). Flood Modeling & Evaluation of Impact in Infrastructure. Panel on Innovated Technological Trends in Highways, *9th Congress and Exhibition, CBR&C 2015 and BRASVIAS 2015*, ABCR – The Brazilian Association of Highway Concessionaires, Brasília, Brazil, September 14 – 16, 2015. www.cbrbrasvias.com.br www.abcr.org.br (Invited lecture, full travel support by the Organizers)
- Uddin, W., McCarty, T., and Sharma, J. (2015). Environmental Sustainability and Energy Considerations for Life-Cycle Analysis of Transportation Infrastructure Systems. Presentation, *International Symposium on Systematic Approaches to Environmental Sustainability in Transportation (ISSAEST)*, University of Alaska Fairbanks, August 2-5, 2015, Fairbanks, Alaska.
- Uddin, W. (2015). Appraisal of Mechanistic-Empirical Pavement Design Guide for Highways Being Implemented in United States and Complimentary Needs for Pavement Asset Management. *6th ICONF BMP, 6th International Conference Bituminous Mixtures and Pavements*, Aristotle University of Thessaloniki (AUTH), June 10-12, 2015, Thessaloniki, Greece.
- Uddin, W, Altinakar, M.S. and Durmus, A. (2015). Extreme Flood Simulations to Assess Inundation Impacts and Structural Integrity of Transportation Infrastructure Assets. *The 2015 Critical Infrastructure Symposium*, The Infrastructure Security Partnership (TISP)

and the Society of American Military Engineers (SAME), April 20-21, 2015, Baltimore, Maryland.

Altinakar, M.S., M. McGrath, V.P. Ramalingam, and W. Uddin. (2015). Two-Dimensional Flood Modeling for the Assessment of Impacts on Critical Infrastructures. *University Transportation Center (UTC) Conference for the Southeastern Region*, University of Alabama at Birmingham. Birmingham, Alabama, March 26-27, 2015. (presented by Altinakar and Uddin, regional UTC conference)

Durmus, A., Nguyen, Q., McGrath, M.Z., Altinakar, M.S., and Uddin, W. (2015). Numerical Modeling And Simulation of Extreme Flood Inundation To Assess Vulnerability of Transportation Infrastructure Assets. *University Transportation Center (UTC) Conference for the Southeastern Region*, University of Alabama at Birmingham, March 26-27, 2015, Birmingham, Alabama.

Uddin, W., Cobb, S., Sherry, P. and Eksioglu, B. (2015). Economically Viable Intermodal Integration of Surface and Waterway Freight Transport for Sustainable Supply Chain. *University Transportation Center (UTC) Conference for the Southeastern Region*, University of Alabama at Birmingham, March 26-27, 2015, Birmingham, Alabama.

Uddin, W. (2015). Aircraft Safety on Airfield Pavements with Standing Water and Slush. Workshop 143- Influence of Airfield Surface Irregularity on Aircraft Life, *94th Annual Meeting of The Transportation Research Board*, Washington, DC, January 10-15, 2015.

Uddin, W., Seth Cobb, and David May. (2014). Environmental Sustainability Dimensions of Freight Transport Considering Highway and Waterway Intermodal Integration. *2014 TRB-CMTS Conference*, Transportation Research Board, Washington DC, June 24-26, 2014.

Uddin, W. (2014). An Overview of GPR Applications for Evaluation of Pavement Thickness and Cracking. *E-Proceedings, 15th International Conference on Ground Penetrating Radar (GPR 2014)*, Brussels, Belgium, June 30 - July 4, 2014.

Honors and Awards

Dr. W. Uddin:

- 2015 Senior Research Award, School of Engineering, University of Mississippi
- 2014 inductee of the University of Texas CAEE Academy of Distinguished Alumni
- 2014 Life member, American Society of Civil Engineers (ASCE)
- Mississippi Transportation Institute (MTI), member of Board of Directors since March 2014
- Gulf Region Intelligent Transportation Society (GRITS), member of Board of Directors, 2009-2012

- Invited member of European project COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar," coordinated by "Roma Tre" University, Rome, Italy, since 2012.

Students

- Holt, Elizabeth. (2015). Benefits of highway and Rail Intermodal Integration for NAFTA Supply Chain Corridors. Paper for 2015 ITE Paper Competition, Institute of Transportation Engineers District 5, March 2015. Best Undergraduate Paper 1st District Award (certificate and cash award)
- Sims, Haley. (2014). Impacts of Rapid Urbanization on Transport and Energy Demands along the Mississippi River Transportation Corridor. Paper for 2014 ITE Student Paper Competition, Institute of Transportation Engineers District 5, February 2014. Outstanding Undergraduate 1st Place District Award (certificate and cash award).

4.2 Research Products and Technologies

The project objective was accomplished by using spaceborne remote sensing and geospatial technologies for mapping and visualization of freight corridors and connecting major city hubs. Geospatial databases were created by CAIT research team for transportation networks in NAFTA countries and intermodal networks in the U.S. The intermodal freight corridor case studies were used to develop “best practice guide” examples. The following research products were created to accomplish project objectives, which can be used for future traffic flow, freight, supply chain, and natural disaster resilience related research projects:

- Geospatial mapping of Mississippi River barge freight, inland surface transportation integration, and highway and rail networks in NAFTA countries:
- Freight intermodal integration of highway truck traffic and barge traffic on the Mississippi River
- Commodity flow by barges for states along the Mississippi River
- Surface freight transportation by rail and highway integration and new intermodal rail routes
- United States-Canada-Mexico databases of highway and rail networks and border ports
- United States and NAFTA highway buffers for integration with freight rail
- Bridges of NAFTA corridors on U.S. and Mexico border and ports on U.S. and Canada border
- Comprehensive analysis of benefits of rail-highway integration and highway-waterway integration for travel time reduction, shipping cost, and lower CO₂ emission
- Shipping demand models using historical data at selected ports
- Global shipping flow estimates using AIS data and CO₂ emissions
- Computer simulations and spatial maps of extreme flood inundation and land submerged due to 2m Sea Level Rise expected by year 2100 by climate impacts
-

Other products include:

ACCESS Databases created for Intergraph's GeoMediaPro geospatial software:

- 2014 United States all (including Alaska and Hawaii), US-Mexico-Canada, 2014 World, Buffer-Mississippi-River-States. (These databases include the 2010 population data of states and counties; highway and rail inventory maps of US-Canada, and Mexico; river port inventory maps and commodity maps for 2014 United States.)
- Spatial maps and databases of major ports in the U.S., Canada, and Mexico.
- Spatial maps and AIS databases for global navigational routes.

4.3 Overall Benefits of Integrating Multimodal Freight Systems

The project is likely to make an impact on the public and society beyond the bounds of science, engineering, and the academic world on areas such as:

- Enhancing public understanding of freight transport impacts on urban communities and the environment through visualization products which are easy to understand and communicate with government stakeholders, businesses, media, and the general public.
- Adapting the developed approaches for freight shipping and logistics infrastructure, intermodal corridor integration, and logistics, and traffic demand management.
- Offering geospatial products for landuse planning, traffic management policies, and pavement safety evaluation for roads, airports, intermodal pavements, container parking, and ports.
- Computer simulations for risk assessment of extreme rainfall flood inundation and land submerged on coastal areas due to climate related expected sea level rise by year 2100.
- Implementing the developed methodologies and web-based social networking tools for public awareness of sustainable supply chain management and reducing degrading effects on the environment and communities

4.4 Recommendations and Future Work

In recent years freight truck-rail intermodal operations are gaining popularity inland and to/from ports. One reason is the decrease in coal transport by rail that has been replaced by intermodal transport of marine and highway containers. The freight mobility for economically competitive export and import commodities that can benefit tremendously from intermodal integration is the efficient freight transport through terminals/stations for seamless connectivity among surface (rail for long-haul and road for short-haul trucks), inland waterways, and marine ports.

The economic competitiveness, safety, security and disaster resilience of freight transport

can be significantly enhanced if owners, operators, and users of all transportation modes understand the importance of operational integration of these modes. Additional benefits include reduced wastage of millions of hours of travel time, cost avoidance of fuel wastage on congested highway corridors, and reduced transportation related CO₂ emissions of and other harmful pollutants.

It is recommended that transportation infrastructure agencies, shipping logistics companies, and supply chain stakeholders consider the research products developed in this project and benefits outlined to address the improve efficiency of intermodal operations and reductions in fuel wastage and transportation related anthropogenic CO₂ emissions.

Ports and municipal public infrastructure assets are essential to sustain the economy and society. The research shows that floods from extreme rainfall may be the most devastating natural disaster that can occur any year endangering infrastructure and public. Therefore, it is recommended that these coastal risks should be assessed for port cities in order to plan for “hardening” of port infrastructure assets to enhance disaster resilience.

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APPENDIX

Copy of e-news OleMiss Engineer, e-publication of School of Engineering, University of Mississippi, June 30, 2016.

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UM Engineering Partnership Producing Problem-Solving Research

National Center for Intermodal Transportation for Economic Competitiveness funds projects

JUNE 30, 2016 BY EDWIN SMITH

Engineers at the University of Mississippi are at the forefront of a research collaboration that is helping solve infrastructure problems near and far.

UM scientists have partnered with Mississippi State University-led University Consortium for a National Center for Intermodal Transportation for Economic Competitiveness grant of \$6.9 million from the U.S. Department of Transportation's Research and Innovative Technology Administration. Other consortium universities include the University of Denver, Louisiana State University and Hampton University.



"The theme of NCITEC is to promote the development of an integrated, economically competitive, efficient, safe, secure and sustainable national intermodal transportation network by integrating all transportation modes for both freight and passenger mobility," said Waheed Uddin, NCITEC associate director and UM professor of civil engineering. "Between 2012 and 2016, UM researchers conducted 13 research projects using a total grant of \$1.26 million from NCITEC."

Funded topics at UM include the global supply chain, NAFTA freight

Campus Briefs

Accreditation Assessment Team Invites Public Comment

OXFORD, Miss. – A team of assessors from the Mississippi Law Enforcement Accreditation Commission will conduct an on-site assessment June 27-28 at the University of Mississippi Police Department to ensure compliance with the Mississippi State Standards. Law enforcement agencies seeking to be accredited by the MSLEAC are required to comply with 140 professional standards to

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UM mechanical engineering professors Tyrus McCarty and Jagdish Sharman are the principal and co-principal investigators of the most innovative NCITEC project, “Energy Harvesting from Traffic Vibrations.” “This project used nanocoated PTZ sensors to enhance energy outputs from traffic vibrations,” McCarty said. “The implications are huge, once implemented in the field in rural areas. It can provide energy to illuminate dark areas on highways, including shoulder edges and rail-highway crossings, for increasing safety of auto and rail traffic and reducing carbon dioxide emissions.”

Uddin and Mustafa Altinakar are co-PIs on another NCITEC project, “Extreme flood simulations and flood impacts on structural integrity of transportation infrastructure assets.” Investigators of four other projects on structural assessment of bridges include civil engineering professors Elizabeth Ervin and Chris Mullen, Charles Swann of the Mississippi Mineral Resources Institute and researchers at the university’s National Center for Physical Acoustics.

“Dr. Altinakar’s computer flood simulations results were the backbone of new discoveries by my two Ph.D. students in civil engineering who advanced the knowledge of flood impacts on infrastructure and communities,” Uddin said. “Alper Durmus computed hydrodynamic forces using Dr. Altinakar’s computational flood modeling results.”

Durmus developed a detailed 3-D finite element computer model of a U.S. 51 concrete bridge subjected to the lateral extreme floodwater force and discovered the vulnerability of bridge superstructure (girders and deck). Uddin’s previous research showed that this failure mechanism was observed in the destruction of bridges during 2005 Hurricane Katrina on the Mississippi Gulf Coast and 2011 Hurricane Irene on the East Coast.

“Under my guidance, Alper is developing guidelines using National Bridge Inventory System database to identify such vulnerable bridges crossing over water bodies so that these can be prioritized for hardening to enhance flood resilience,” Uddin said.



The U.S. 90 and U.S. 49 at the Port of Gulfport.

Quang Ngyuen also used Altinakar’s two-dimensional flood modeling results to evaluate a one-dimensional flood simulation program developed by U.S. Army ERDC Hydraulics Lab using shuttle radar-based terrain elevation models available worldwide. Ngyuen implemented this framework for selected port cities in Mississippi and Vietnam.

“Quang has also formulated and implemented NOAA’s recommended sea-level rise predictions associated with climate impacts for inundation studies in Miami and Vietnam,” Uddin said. “He further developed a methodology under my guidance to simulate extreme tsunami using 2011 Fukushima tsunami wave surge data to evaluate the extent of submerged coastal land and impacts on affected population.”

Kristin Swain of the Meek School of Journalism and New Media conducted her project, “Risk framing of U.S. intermodal transportation toxic spills in news and social media.” Her research shows that 161,079 toxic spills in the U.S., reported between 2003 and 2012, involving air, rail and waterways exceeded \$701 billion in cleanup and mitigation costs.

Swain's news media analysis found that 99.48 percent of the 5,555 most serious spills during transportation of hazardous materials received no news coverage.

Uddin is PI for "Intermodal integration of highway-rail and highway-waterway corridors for economically viable supply chain." Other co-PIs from the University of Denver and Clemson University have their own NCITEC projects on this topic.



"This project demonstrated the use of geospatial analysis to identify feasible corridors on maps generated from highway and rail map database," Uddin said. "Using mathematical optimization for minimizing shipping costs, the least cost corridors were selected for several intermodal freight integration cases, including NAFTA routes. The research showed substantial reduction in transportation related-carbon dioxide emissions."

This U.S. 51 bridge is one of the study's subjects. Photo courtesy Mississippi DOT

The methodology developed in this project is timely because the current USDOT funding authorization of FAST Act recommends calculating carbon emissions as a part of transportation project planning. Uddin has partnered with two different University Transportation Center consortia that submitted new proposed projects on efficient freight mobility.

Two graduate students carried out most of the research tasks. Seth Cobb completed his master's thesis in August 2015. Doctoral student Zul Fahmi conducted comprehensive commodity research and geospatial mapping of carbon emissions on NAFTA corridors.

The white paper on another project, "Gulf Coast Rail Passenger Service Revival," is already being used as a reference in rail studies for connecting Dallas-Fort Worth with Atlanta through Mississippi.

Investigators represent the university's civil, electrical and mechanical engineering departments of the School of Engineering, National Center for Computational Hydroscience and Engineering, Mississippi Minerals Research Institute, National Center for Physical Acoustics, Meek School of Journalism and New Media, and Trent Lott Institute of Public Policy Leadership.

"The primary research accomplishments include brief fact sheets on key research results of each funded project for distribution and web access," Uddin said. "We've seen the development of transportation visualization products based on geospatial analysis and computational modeling."

Research funding has strengthened the workforce and enhanced undergraduate and graduate courses. Ten master's students and two doctoral students have completed their degrees thus far and two doctoral students will complete in 2016. One doctoral student on a CAIT/NCCHE project received the 2013 NCITEC Student of the Year award.

Key project investigators presented at regional and national conferences and published papers in journals and conference proceedings. Several YouTube videos and Slide Share posts disseminate the research results of the UM projects to the transportation community and agencies in the state, region and worldwide.

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