Great Lakes Maritime Research Institute October 2010-October 2011

Annual Report

UNIVERSITY of WISCONSIN Superior
Wisconsin's Leading Public Liberal Arts College

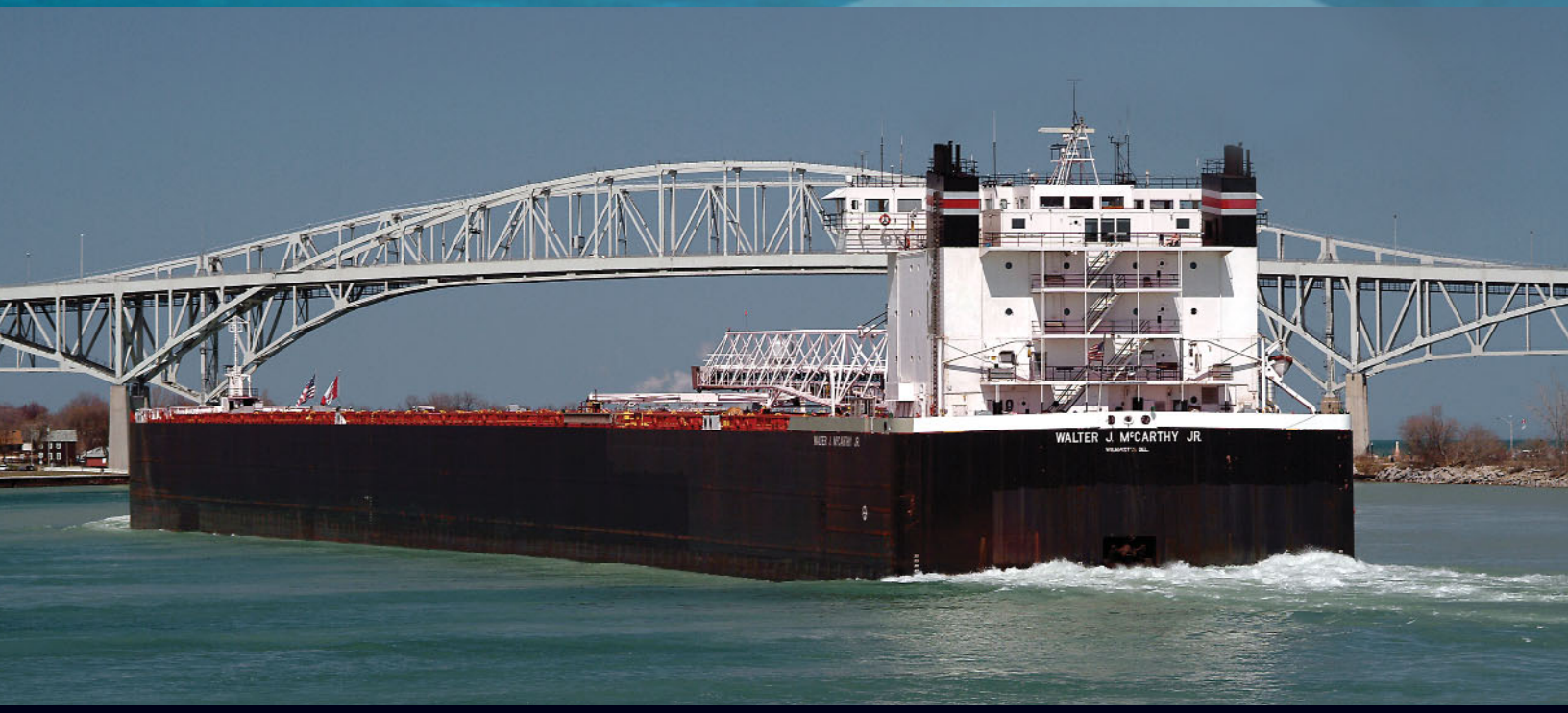
UMD DULUTH

Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

A NATIONAL MARITIME ENHANCEMENT INSTITUTE

Annual Report to Congress, the U.S. Department of Transportation and the U.S. Maritime Administration October 2010-October 2011



M/V Walter J McCarthy Jr.

GLMRI Staff

Richard D. Stewart
Co-Director

James P. Riehl
Co-Director

Carol J. Wolosz
Executive Director

Jeannie Hartwick
Program Executive Assistant

Terry Guggenbuehl
Technology Director

Kathy Derick, Contract Manager (not pictured)

The Great Lakes Maritime Research Institute is a National Maritime Enhancement Institute designated by the U.S. Department of Transportation Maritime Administration

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This study was supported by the U.S. Department of Transportation, Office of the Secretary and the Maritime Administration.

Grant Number DTMA1G10001

Prepared for the Great Lakes Maritime Research Institute by Harbor House Publishers, Inc., Boyne City, Michigan.

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Richard D. Stewart
Co-Director

James P. Riehl
Co-Director

Co-Directors' Statement

IN PAST YEARS, Great Lakes Maritime Research Institute (GLMRI) received funding in a format that allowed us to send out request for research proposals to our affiliate universities in areas defined by our federal authorization and recommended by our Advisory Board and other contacts. Currently this type of funding is not available, although we continue to make the case for permanent funding for the Institute to federal executive departments and legislative personnel when given the opportunity.

This year, however, we have been fortunate to receive targeted funding for selected projects. Several of the agencies and industry representatives on our Advisory Board have been instrumental in arranging for this project-based funding.

• During the summer of 2011, representatives from the U.S. Maritime Administration (MARAD) worked with GLMRI to set up a cooperative agreement to provide support for environmental research related to maritime commerce in the Great Lakes region. The five-year cooperative agreement can provide up to $1 million a year in project-based funding. Funding depends on MARAD's budget and performance in carrying out projects. MARAD and GLMRI will be working cooperatively with the maritime industry, the GLMRI Advisory Board and government agencies to establish a research agenda.

• In the fall of 2010, the American Bureau of Shipping Consulting asked GLMRI to be part of its research team when the Institute placed a successful proposal to undertake MARAD's Great Lakes Shipping Revitalization Study. The draft report was completed in November 2011.

• Working with the Duluth-Superior Port Authority, the U.S. Coast Guard and the State of Minnesota Homeland Security division, GLMRI was awarded a contract for a harbor security gap analysis study.

• The Lake Carriers' Association is funding GLMRI to sample and provide a biological analysis of the sediment in Great Lakes vessels' ballast tanks.

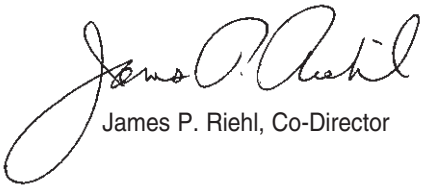
• Also, the U.S. Army Corps of Engineers has continued to support the GLMRI economic study and also work with the Great Lakes Maritime Data Clearinghouse.

Our focus has changed from hosting a research agenda and soliciting competitive research proposals to working on specific topics directed by the funding agencies. We strongly feel that our organization is effective because of our unique arrangement with the two host universities and having 10 affiliate universities that bring their research expertise and assets to support maritime research and education. We have been able to address a requested topic by reaching out to our affiliates to draw on their strengths and provide a regional multi-discipline team.

We plan to continue to serve the region while building the expertise in shipping and maritime commerce to affect positive changes for the economy and the environment.

Sincerely,

Richard D. Stewart, Co-Director



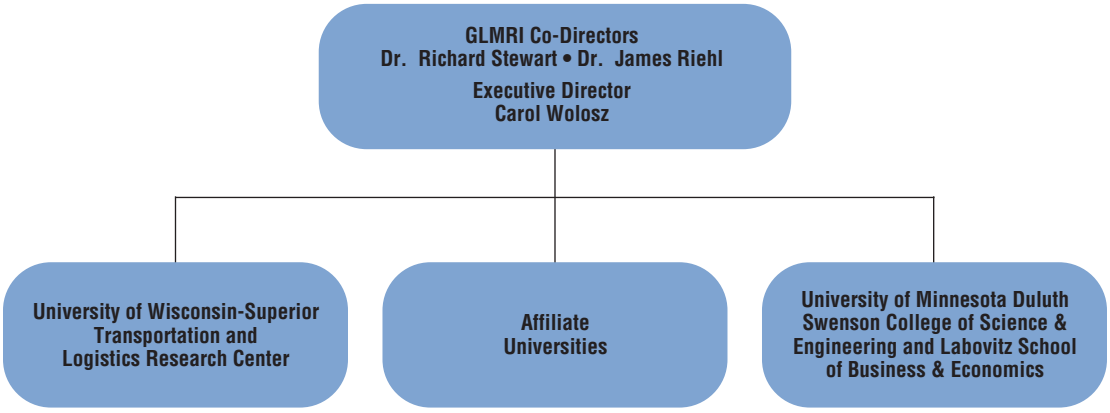
James P. Riehl, Co-Director

Mission Statement

The Great Lakes Maritime Research Institute is dedicated to developing and improving economically and environmentally sustainable maritime commerce on the Great Lakes through applied research.

Research Focus

Initial broad research focus areas for GLMRI were mandated by Congress and have been refined with input from the U.S. Maritime Administration and the GLMRI Advisory Board agencies. Each year at the GLMRI annual meetings, discussion is held with the Advisory Board and other stakeholders on current issues and opportunities for potential maritime research topics with impact for the Great Lakes.



THE GREAT LAKES MARITIME RESEARCH INSTITUTE (GLMRI) was established in 2004 to pursue research efforts in marine transportation, logistics, economics, engineering, environmental planning and port management. The U.S. Maritime Administration designated GLMRI as a National Maritime Enhancement Institute on June 1, 2005. Federal funding to support GLMRI was first received in May 2005. Since that first appropriation of $750,000, GLMRI has received $1,980,000 in 2006, $990,000 in 2008, $980,000 in 2009 and $450,000 in 2010.

This annual report summarizes the research performed under funding appropriated under the Federal Transportation Act for fiscal year 2010. Due to the late receipt of funding in 2009, several of the projects were also extended in to this time period. Previous annual reports are available on the GLMRI web page (www.glmri.org).

In March 2004, the University of Minnesota Duluth and the University of Wisconsin-Superior formed the GLMRI consortium to focus on Great Lakes maritime research. The two universities are located in the largest ports on the Great Lakes, the Twin Ports of Duluth, Minnesota and Superior, Wisconsin. The communities have been a transportation hub for more than 150 years. In addition to the maritime industry, the Twin Ports are serviced by four Class I railroads and is the terminus of the longest pipeline in North America. More than 30 trucking companies are headquartered in the area. The cities are serviced by an international airport and are the corporate headquarters for the largest single engine airplane manufacturer in the U.S. The Twin Ports has a U.S. Coast Guard (USCG) Marine Safety Unit and is the home port for the USCG Cutter *Alder*. The Twin Ports are also a Port of Entry with the U.S. Customs Office and The Immigration and Naturalization Service.

GLMRI represents a consortium of the University of Wisconsin-Superior Transportation and Logistics Research Center and the University of Minnesota Duluth Swenson College of Science and Engineering and Labovitz School of Business and Economics, combining the strengths of their academic and research expertise. Additionally, universities in the Great Lakes region with expertise in the research focus areas may be offered affiliation. This dynamic model provides a program with tremendous breadth as a National Maritime Enhancement Institute.

There are currently seven designated institutions throughout the U.S. as National Maritime Enhancement Institutes (NMEIs) by the Maritime Administration under Public Law 101-115. The purpose of the NMEIs is to create a research-oriented atmosphere that lends itself to providing effective input for addressing maritime issues. The institutes selected as NMEIs are capable of researching inter-disciplinary, intermodal issues and have access to a broad spectrum of resources enabling them to address National problems within the individual program areas.

GLMRI seeks input from experts in maritime shipping and commerce, ports and governmental agencies. The consortium is committed to improving the maritime system of the Great Lakes and the United States.

2011 Advisory Board

S.S. Badger.

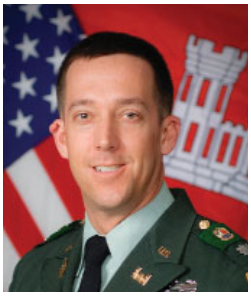
THE GLMRI'S ADVISORY Board consists of experts in maritime commerce, marine environmental issues or other segments of the Great Lakes marine transportation system. The membership was designed to bring together industry, academia and government leaders to advise the Co-Directors on the research agenda and to provide input on topical priorities. The Advisory Board can be expanded to include additional relevant stakeholders that agree to participate.

Saint Lawrence Seaway Development Corporation
Washington, D.C.
Mr. Craig Middlebrook
Deputy Administrator

U.S. DOT Maritime Administration
Chicago, IL
Mr. Floyd Miras
Director, Great Lakes Gateway

Lake Carriers' Association
Rocky River, OH
Mr. James H. I. Weakley
President

Tim Olson, Michael Carter, Craig Middlebrook at the GLMRI Annual Dinner.



U.S. Army Corps of Engineers,
Detroit District, Detroit, MI
Lieutenant Colonel Michael Derosier

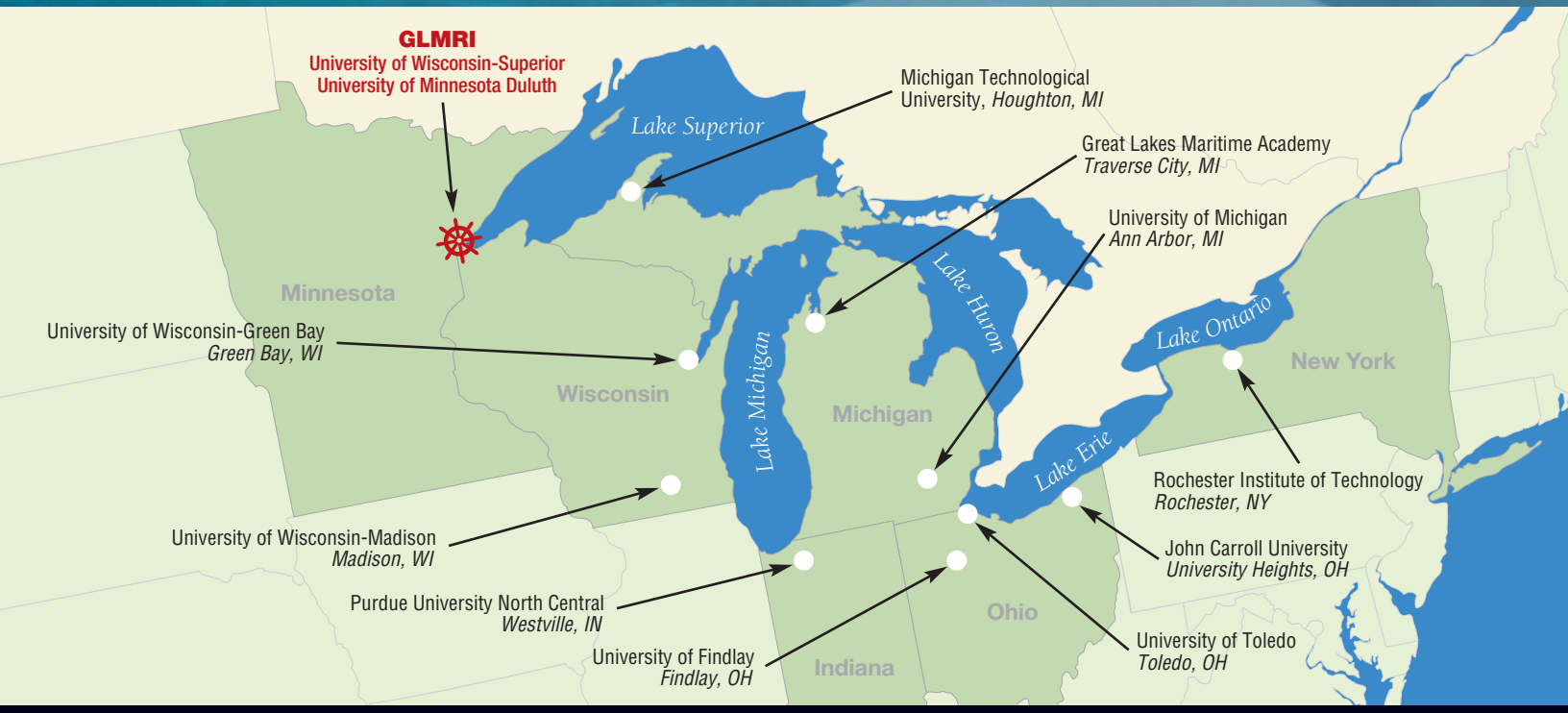
American Great Lakes Ports
Association, Duluth, MN
Mr. Adolph Ojard
Chairman

U.S. Coast Guard, Cleveland, OH
Commander Scott Anderson
Ninth District

Great Lakes Commission
Ann Arbor, MI
Mr. David Knight
Special Events Manager

The Society of Naval Architects and
Marine Engineers, Duluth, MN
Mr. James Sharrow
Great Lakes & Rivers Section

2011 Research Affiliates



Affiliate locations.

About Research Affiliates

Universities in the Great Lakes region (states bordered on the Great Lakes and in the Great Lakes watershed) with expertise in the research focus areas may be offered affiliations to partner in applicable areas. Researchers and other relevant assets from the affiliated universities are included as part of the research portfolio of GLMRI, and the affiliate may serve as project researchers based on submitted proposals in response to an annual request for proposals.

GLMRI is working with U.S. Maritime Administration personnel to advise other U.S. universities seeking status as National Maritime Enhancement Institutes to build a national platform for university maritime research. In addition to a collaboration with Finnish universities, we have initiated discussions with Canadian universities and academics.

Affiliate universities meet annually with the GLMRI Directors and the Advisory Board to provide input on future research topics and to discuss current research results and process. GLMRI maintains an open and continuous dialogue with affiliates to address evolving issues regarding maritime commerce. Research affiliates are encouraged to leverage GLMRI resources to secure independent and joint funding opportunities for Great Lakes maritime research. Matching funding is a significant consideration.

How to become an Affiliate

Universities seeking to obtain affiliate status should provide a request to the GLMRI Program Office with details on the capabilities and assets that they would bring to support the mission of GLMRI, along with an expected interest area for future research endeavors. Requests are evaluated by the Institute's co-directors for affiliate status in GLMRI. University affiliates are renewed annually.

GLMRI funding for research proposals is granted only to University Research Affiliates, and only proposals from GLMRI University Research Affiliates will be accepted for funding consideration.

GLMRI Program Office
229 Voss Kovach Hall
1305 Ordean Court
Duluth, MN 55812
(218) 726-7446
www.glmri.org

Great Lakes Maritime Academy
1701 East Front Street, Traverse City, MI 49686
RADM Jerry Achenbach, USMS, Superintendent

The Great Lakes Maritime Academy (GLMA) is a division of Northwestern Michigan College (NMC) and a partner of Ferris State University. The Academy trains men and women for service as licensed Officers in the U.S. Merchant Marine and as business professionals. GLMA's program is unique among the state maritime academies as it is the nation's only freshwater academy.

Upon successful completion of the program, graduates are qualified to sail as an Officer onboard a U.S. Merchant vessel sailing on either the oceans or the Great Lakes. Cadets who do not possess a four-year degree prior to being admitted complete both a Bachelor's Degree in Business Administration through our partnership with Ferris State University and an Associate's Degree in Maritime Technology. The education provided at GLMA ensures employers have a steady supply of the finest maritime personnel who are fully compliant with both US regulations and the Standards for Training, Certification and Watchkeeping Code (STCW).

As a condition of graduation, all deck cadets are required to sit for their unlimited tonnage Third Mate (ocean) license as well as Great Lakes Pilotage. All engineering cadets are required to sit for Third Assistant Engineer, Steam and Motor Vessels of any Horsepower.

University of Michigan
2600 Draper Drive, Ann Arbor, MI 48109
Prof. Steve Ceccio, Chair
Department of Naval Architecture and Marine Engineering

Students in the Department of Naval Architecture & Marine Engineering at the University of Michigan learn how to design/analyze ships and the other complex marine systems for a demanding and often harsh environment. In addition to the more traditional disciplines of naval architecture and marine engineering, the program offers courses and research opportunities in offshore engineering and coastal engineering. Graduates can be found in the U.S. Navy and other navies of the world, the U.S. Coast Guard, offshore companies, shipyards, marine laboratories, peer academic institutions and other maritime agencies.

Michigan Technological University
1400 Townsend Drive, Houghton, MI 49931-1295
William J. Sproule, Professor
870 Dow Environmental Sciences and Engineering Building
Department of Civil and Environmental Engineering

Michigan Technological University conducts an educational outreach program on Great Lakes Maritime Transportation for K-12 students, teachers and communities. From 2006 to 2011, program activities have included conducting one-day teacher workshops in MI, WI and MN; conducting six five-day summer teacher institutes in Door County (WI), Toledo (OH), Duluth (MN) and Michigan's eastern Upper Peninsula; conducting two five-day Navigation & Mathematics summer teacher institutes at Michigan Technological University; developing new classroom lessons on Great Lakes shipping; assembling and disseminating 38 Great Lakes Maritime Transportation education chests to maritime museums and K-12 education centers reaching every Great Lake state; developing an interactive web module titled *Great Lakes Shipping: Across the Country and Around the World* (http://techalive.mtu.edu/series.htm); presenting at conferences; providing stipends for teachers to present their maritime and navigation lessons at conferences; and developing a Great Lakes Maritime Transportation education website that can showcase all of the education/outreach activities and is linked to the GLMRI website. Partners have included: Minnesota Sea Grant, Duluth Seaway Port Authority, Great Lakes Shipwreck Historical Society, Lake Carriers' Association and University of Wisconsin Madison's Center for Freight & Infrastructure Research & Education Program.
wupcenter.mtu.edu/education/great_lakes_maritime/index.htm

University of Toledo
2801 West Bancroft Street, Toledo, OH 43606
Richard Martinko, Director
Intermodal Transportation Institute & University Transportation Center

The Intermodal Transportation Institute at The University of Toledo was organized by public and private stakeholders to encourage the development of technology-enabled intermodal transportation systems and supply chains that promote economic development and quality of life. The Goals and Objectives of the UT-ITI are to create an internationally recognized center of excellence; advance technology and expertise in the many disciplines comprising transportation; educate a multi-disciplinary workforce; attract students, faculty and staff in undergraduate, graduate and professional programs; and to enhance diversity in the various fields related to transportation. The UT University Transportation Center is housed within the ITI. The UT ITI/UTC has been named a Center of Excellence in Logistics and Transportation by the Ohio Board of Regents.

John Carroll University
20700 North Park Boulevard, University Heights, OH 44188
Dr. Bradley Hull, Associate Professor and Ried Chair
Department of Management, Marketing and Logistics

John Carroll University has offered a logistics major since 1950. Established shortly after WWII by the U.S. Army Transportation Corps, the program is now domiciled in the Department of Management, Marketing, and Logistics.

The Department is dedicated to educating and serving its

students, the University and the community through quality teaching, significant research and appropriate community involvement with shippers and carriers.

The primary goals of the logistics faculty are to achieve national recognition and to provide students, the University and the business community with comprehensive, up-to-date information about business logistics theory and practice. Methods of achieving these goals include, excellent teaching, quality research (both academic and practitioner), student internships and faculty/student involvement in logistics-related organizations.

The University of Findlay
1000 North Main Street, Findlay, OH 45840
Jeff McGuire, Director of Operations, All Hazards Training Center

The All Hazards Training Center (AHTC) was established as a department within The University of Findlay in 1986 with the initiation of the Bachelor of Science in Hazardous Materials Management Degree program. A practice-based and regulatory compliance/competency-based training center was added in 1989. Today AHTC's educational and training programs include: environmental, safety and occupational health (ES&H); emergency response; emergency management; OSHA safety; public health; homeland security; maritime security; school safety and security; and many other customized programs. AHTC's Maritime Security program includes three courses approved by the U.S. Maritime Administration: Facility Security Officers (UNFIND-560); Maritime Security Awareness (UNFIND-561); and Maritime Security for Facility Personnel with Specific Security Duties (UNFIND-565). Additionally, AHTC has a course developed for and approved by U.S. Department of Homeland Security (DHS) titled Port and Vessel Security for Public Safety Officials and is developing a second Maritime Security course for DHS titled Small Vessel Security, scheduled for release in mid-2012. To date, AHTC has awarded Bachelor and Master degrees to more than 1,250 people through the Academic Degree Programs and through the practice-based training center, more than 150,000 people have been trained.

Purdue University North Central
1401 South U.S. Hwy 421, Westville, IN 46391
Dr. Thomas F. Brady, Department Chair
Engineering and Engineering Technology

The Purdue University North Central College of Engineering and Technology provides degree programs in technical disciplines and engagement assistance in economic development for citizens in north central Indiana. The college has conducted research in the areas of coal transportation infrastructure, electricity distribution and control, and simulation of large scale systems.

Rochester Institute of Technology
Dr. James Winebrake, Co-Director
Laboratory for Environmental Computing and Decision Making
92 Lomb Memorial Drive, Rochester, NY 14623

Our Great Lakes Research Program is housed in the RIT Laboratory for Environmental Computing and Decision Making (LECDM). The LECDM has as a central focus the study of freight movement, transportation logistics, environment and cyberinfrastructure. Our goal is to improve freight-related transportation decision-making by advancing and integrating environmental cyberinfrastructure tools and modeling techniques into supply chain logistics analyses. Our Great Lakes Research Program is aimed at understanding and improving the efficiency and environmental footprint of intermodal cargo flows in and around the Great Lakes.

University of Wisconsin-Green Bay
2420 Nicolet Drive, WH303, Green Bay, WI 54311-7001
Dr. Sue J Mattison, Dean
College of Professional Studies

The University of Wisconsin-Green Bay (UW-Green Bay) is unique among other state universities in its emphasis on an interdisciplinary, problem-focused educational experience that prepares students to think critically and address complex issues in a multicultural and evolving world. The university enriches the quality of life for students and the community by embracing the educational value of diversity, promoting environmental sustainability, encouraging engaged citizenship and by serving as an intellectual, cultural and economic resource. UW-Green Bay's Urban and Regional Studies Program, Center for Biodiversity, and Institute for Environmental Management and Business are just a few examples of how the university facilitates research on social and economic development and community development in the greater Green Bay region and beyond.

University of Wisconsin-Madison
1415 Engineering Drive, Room 2205, Madison, WI 53706
Dr. Teresa Adams, Director
National Center for Freight and Infrastructure Research and Education

The University of Wisconsin-Madison is home to the National Center for Freight and Infrastructure Research and Education (CFIRE). CFIRE is a U.S. Department of Transportation National University Transportation Center with a multimodal research, training, education and outreach focus on Sustainable Freight Transportation Infrastructure and Systems. CFIRE has an annual budget of approximately $7 million. It facilitates the Mississippi Valley Freight Coalition, a 10-state regional organization to cooperate in the planning, operation, preservation and improvement of multimodal freight transportation infrastructure systems, operations and networks.

2011 Special Projects and Outreach

TOP: Annual Advisory Board Meeting at the Radisson Hotel in Duluth, Minnesota, September, 2011. BOTTOM left: Carol Wolosz and Dr. Mike Parsons at the Great Lakes Waterways Conference, February 2011. BOTTOM right: Tom Brady, Brad & Sheila Hull at the GLMRI Annual Dinner.

Simo Mäkiharju & Terry Guggenbuehl at the Affiliates meeting.

Annual Program Meeting

The Great Lakes Maritime Research Institute (GLMRI) held its annual advisory board meeting and affiliate research meeting at the Radisson Hotel in Duluth, Minnesota Thursday and Friday, September 22 and 23. The meeting was hosted by Dr. Richard Stewart, GLMRI Co-Director and Carol Wolosz, Executive Director. Representatives from the following agencies participated in the discussions: the U.S. Maritime Administration (DOT), the Saint Lawrence Seaway Development Corporation (DOT), the U.S. Army Corps of Engineers (DOD), the U.S. Coast Guard (DHS), the Lake Carriers' Association, the American Great Lakes Ports Association, the Great Lakes Commission and the Society of Naval Architecture and Marine Engineering.

The agenda for the GLMRI affiliates meeting included presentations of the on-going projects. Highlights from three new projects included a new ship design concept to minimize drag (Simo Mäkiharju from the University of Michigan), a look at combining dredged materials with the bio-solids that remain from the wastewater treatment plant to expand the utility of the two bi-products (Dr. Nathan Johnson from the University of Minnesota Duluth) and an economic feasibility study for a cross-lake truck ferry between Milwaukee, Wisconsin and Muskegon, Michigan across Lake Michigan (Dr. Thomas Brady from Purdue University, North Central). Researchers provided updates on several of the continuing projects, such as the Great Lakes Maritime Data Clearinghouse (Sarah Schafer with Dr. Peter Lindquist from University of Toledo) and the University of Minnesota Duluth's biology studies with harbor infrastructure corrosion (Ryan Oster with Dr. Randall Hicks) and the joint project with University of Wisconsin-Superior's Lake Superior Research Institute looking at the reproduction and life cycle of plankton related to ballast water (Matthew TenEyck with Dr. Donn Branstrator).

The Michigan Technological University's education program coordinator (Joan Chadde) provided a photo summary of the two co-sponsored maritime teachers' workshops held over the summer. The University of Wisconsin-Madison's Center for Freight and Infrastructure Research and Education (Dr. Teresa Adams) partnered with GLMRI and MTU to support the workshops.

As an added presentation, Libby Ogard, President of Prime Focus LLC, provided a preliminary review of the findings for the National Cooperative Freight Research Program's funded study on Great Lakes-Saint Lawrence basin's current multi-modal freight transportation, including the economic impact of the freight transportation system on regional, U.S. and Canadian economies.

GLMRI Receives New Cooperative Agreement with MARAD

In August 2011, GLMRI received a five year cooperative agreement with the U.S. Department of Transportation's Maritime Administration (MARAD) to address environmental issues facing shipping and marine transportation. Studies funded by MARAD will address maritime commerce on the Great Lakes. The results of the studies should benefit maritime commerce in the Great Lakes region, as well as other transportation modes, ports and vessels operating on the inland rivers and coastal waters.

GLMRI's research team will work with their affiliate universities, industry and government agencies as the cooperative agreement progresses during the coming years as the projects are defined. MARAD, in partnership with industry, has directed that during the first year, GLMRI will research the feasibility of converting the existing steam-propelled vessels to using natural gas, either compressed (CNG) or liquefied (LNG), as their primary fuel source.

The first study will analyze the engineering, financial, environmental and energy issues associated with steamship conversion. In August, the GLMRI research team hosted a meeting with MARAD representatives and members of the Great Lakes shipping industry. As a demonstration project, GLMRI will work with the Lake Michigan Carferry Service and marine engineering experts in exploring the feasibility of converting the *S.S. Badger* to run its engines on natural gas. Over the coming year, the team will be modeling the vessel's fuel consumption, routes, shore-fueling station(s) and engineering to look at the viability of using natural gas. The demonstration project will also consider training needs and shipyard implications of the power conversions.

The *S.S. Badger* is the only coal-fired steamship in operation in the United States. The 410-foot ferry entered service in 1953, designed to handle the rough conditions that it would likely encounter during year-round sailing on Lake Michigan. Today, the *S.S. Badger* sails daily between Manitowoc, Wisconsin and Ludington, Michigan from mid-May through mid-October. Converting the vessel to natural gas as a primary fuel could have the potential to make the *S.S. Badger* one of the greenest vessels operating on the Great Lakes.

GLMRI Part of MARAD Great Lakes Study Team with ABS Consulting

In November 2010, the U.S. Maritime Administration announced the contract award to the American Bureau of Shipping Consulting of Houston, Texas, with GLMRI and other team members, to conduct a year-long study reviewing investment options for the revitalization of the U.S.-flagged Great Lakes fleet and related regional maritime infrastructure. MARAD's study, when published, is expected to include an overview of existing market conditions, an inventory of the U.S.-flagged Great Lakes vessels and regional port infrastructure, an examination of private/public sector financing options and a benefit-cost analysis for each of the investment options.

As part of the study, MARAD hosted three stakeholder meetings in the Great Lakes region. Carol Wolosz assisted with the meetings in Cleveland, Ohio (Feb 15), Duluth, Minnesota (Feb 23) and Chicago, Illinois (Feb 25). Dr. Teresa Adams from the GLMRI affiliate University of Wisconsin-Madison attended the Cleveland and Chicago meetings. Dr. Stewart served as an expert advisor on regional shipping and transportation.

Dr. Adams assisted the team on the topic of TIGER Grant processes. Dr. Peter Lindquist from the University of Toledo provided data support for the port studies. For more information, go to GreatLakesStudy@dot.gov.

Educational Partnerships with K-12 Schools

GLMRI is working with The Maritime Academy of Toledo (TMAT) to support its programs and initiatives. Dr. Stewart met with the Superintendent Renee Marazon in June and received a tour of the school. Also, Carol Wolosz works closely with Renee on the SOCP educational sub-committee and Captain Rick Brown, Maritime Instructor, has provided the "maritime" lessons at the GLMRI K-12 Teacher workshops. In the summer of 2010, TMAT hosted the GLMRI K-12 Teachers Workshop at its school and facility.

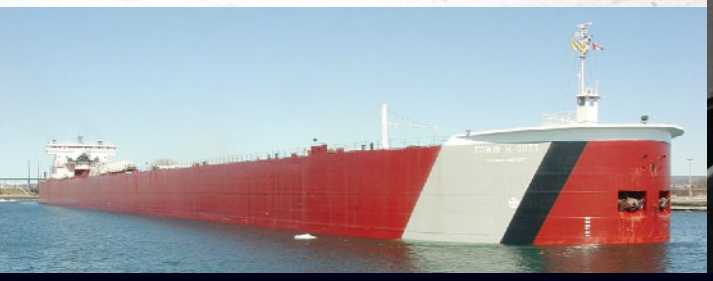
Educational and Outreach Presentations

In February 2011, Dr. Richard Stewart presented on Great Lakes Shipping at University of Wisconsin-Manitowoc as part of the university's spring lecture series.

In April, Carol Wolosz and Dr. Stewart tag-teamed on classroom presentations to the graduate students in University of Wisconsin's Colloquium for Transportation Management and Policy at the UW-Madison campus. Carol presented an overview of GLMRI research projects and maritime focus areas and discussed current issues impacting Great Lakes shipping. The next week, Dr. Stewart provided a lesson in intermodal transportation, shipping and maritime commerce. Advisory Board member Craig Middlebrook from the Saint Lawrence Seaway Development Corporation participated in the colloquium as a guest speaker, providing an overview of the Seaway and the current policy issues impacting trade.

In June, Dr. Stewart provided a presentation to the Minnesota National Guard on the various ports and harbor agencies involved in the governance of port operations.

In September, Dr. Stewart provided a presentation on transportation issues for proposed iron ore mining in northern Wisconsin at a seminar of Wisconsin state cabinet members. The meeting was sponsored by the Iron Range Resources and Rehabilitation Board (IRRRB) in Eveleth, Minnesota.



TOP: Enterprise engines that were removed and scrapped from the M/V Gott under the EPA Clean Diesel Grant. Dr. Richard Stewart, Mr. Fransisco Aceveto and Mr. Anthony Maietta. BOTTOM: M/V Edwin Gott.

Alan Moore, USCG & Carol Wolosz at the GLMRI Annual Dinner.

***M/V Gott* Repowering Project**

On February 24, 2011 Dr. Richard Stewart and a U.S. Environmental Protection Agency (EPA) team of Steve Marquardt, Anthony Maietta and Francisco Acevedo visited the *M/V Edwin Gott* in the shipyard in Sturgeon Bay, Wisconsin. Special Projects Engineer Rick Harkins from Keystone Shipping led a tour of the vessel. The main propulsion engines were in the process of being replaced and a portion of the cost is being paid for by a $750,000 EPA Clean Diesel grant the GLMRI was awarded in partnership with Key Lakes 1 Inc.

The two former 16-cylinder enterprise engines were replaced with eight cylinder engines that conform to EPA Category 3 Tier 2 engine emission requirements. The original engines were installed in 1979 and were still running but could not be retrofitted to meet the new EPA air emission standards.

The process of repowering a vessel's engines requires that the gears, clutch, shafts and propeller work together for maximum efficiency. This means new electronic systems, adaptors, fuel filtration packages and quill shafts have to be installed, as well as the engines. A new engine bed of approximately 3 feet by 20 feet by 3 inches thick steel had to be fabricated and installed so the engine could be secured to resilient mounts to reduce vibration.

Each of the two new MAK/Caterpillar 8M43C engines will produce about 7200 Kilowatts (9650 horsepower) each while powering the *M/V Edwin Gott* as it carries cargo on the Great Lakes. The *Gott* is now the most powerful vessel on the Great Lakes. Prior to being shipped to the U.S. from Germany, the engines were operated in a test facility at maximum rated power. After the several-hour test run, all components were examined to see that they functioned without problems under maximum load. These engines are expected to operate in the vessel for decades.

The old enterprise diesel engines were removed by cutting a large hole in the deck then another one through the ballast tank to enter into the engine room. Cutting the openings and preparing the rigging to take out the old engines took almost two weeks. Once preparations were completed, the old engines that weighed 102 tons each were removed by the crane operator and line handlers in a few days. Just like truck engines that are removed when supported by an EPA clean diesel grant, these engines will be rendered unusable.

Preparing the space for the new engines took another couple weeks. On the coldest day in December, the new engines, which weigh 117 tons each, were set onto the beds in about four hours. When the crane operator brought the engines close to the mounting bolts, the alignment was only a few millimeters off and the rigging crew could ease the massive machines into place.

If someone wants to see quality work, they should spend time with these shipwrights. Trucks, rails, vessels and planes all required dedicated, creative, intelligent people to design, manufacture, operate and maintain their systems.

In addition to the main engine repowering, the company has taken proactive steps to reduce the sediment that comes in the vessel when ballasting. Moving beyond compliance with existing environmental laws additional ballast water intakes were installed, at considerable expense, higher up on the side of the vessel. American Steamship Company as well as Key Lakes 1, Inc. are taking these steps to reduce the environmental footprint of their vessels on our Great Lakes.

On March 25, the *M/V Edwin Gott* underwent sea trials to test her new engines and systems in a variety of evaluations required by the U.S. Coast Guard and the American Bureau of Shipping. On March 26, she began her maiden voyage with new engines.

American Great Lakes Ports Association Meetings in Toronto

Dr. Richard Stewart participated in the American Great Lakes Ports Association meeting in January 2011 and presented an update on GLMRI and the MARAD Great Lakes Study. He also met with Marine Delivers, as a member of their Oversight Committee. These meetings were held in conjunction with the annual Marine Club meetings in Toronto, Canada.

Ship Operations Cooperative Program

Carol Wolosz participated in the Ship Operations Cooperative Program (SOCP) meeting in December 2010 in Linthicum, Maryland. Congressman Elijah Cummings (Maryland) provided an update on the activities of the Coast Guard Sub-Committee to the House Transportation and Infrastructure Committee. She provided an overview of GLMRI and an update on the educational programs at the meetings. Also, Ms. Wolosz was elected to the Operations Board of SOCP for 2011.

Captain Art Sulzer, Chairman of the Maritime Primary and Secondary Education Coalition, set up a tour of the Philadelphia Maritime Charter School for the afternoon preceding the SOCP meeting. The school is located in northeast Philadelphia in the former U.S. Army facility. The program has taken root in the community and focuses youth toward careers in the maritime industry.

The spring meeting was held in Dania Beach, Florida in April. As the Co-Chair of the Maritime Primary and Secondary Education Coalition, Ms. Wolosz led the panel of education speakers at the meeting and provided the information to the membership for the upcoming GLMRI summer education workshops.

Great Lakes Waterways Conference Venue

In February 2011, GLMRI was included on the agenda at the Great Lakes Waterways Conference (formerly known as Marine Community Day) in Cleveland, Ohio. Carol Wolosz provided an update on the recent research and education projects and Dr. Michael Parsons provided an overview of the GLMRI design and engineering projects underway at the University of Michigan.

The GLMRI 2010 Annual Report made its debut at the conference.

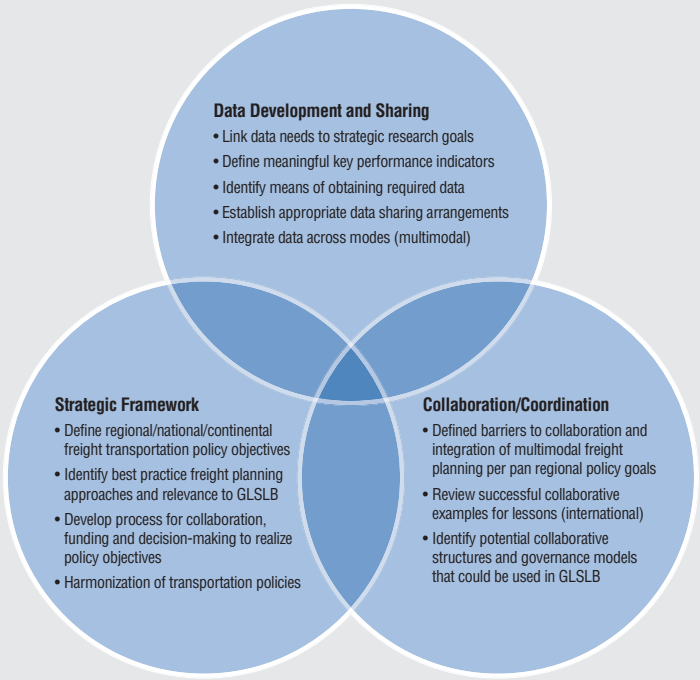
Special Presentation on TRB Study at the GLMRI Annual Meetings (NCFRP-35)

Libby Ogard, President of Prime Focus LLC, provided an update on the National Cooperative Freight Research Program Study, titled Multimodal Freight Transportation within the Great Lakes-Saint Lawrence Basin (NCFRP-35), at the GLMRI Fall meetings.

This study was sponsored by the Transportation Research Board and funded by the National Academy of Science and awarded to a research team lead by CPCS Transcom Limited in association with: GLMRI affiliate University of Toledo, Economic Development Research Group, Prime Focus LLC, Sustainable Ports and Dr. Richard Stewart of the GLMRI.

The study covered the Great Lakes St. Lawrence Basin (GLSLB), a bi-national region (United States and Canada) comprising eight states (Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio, Pennsylvania and New York), two provinces (Ontario and Quebec) and hundreds of municipalities, large (e.g. Chicago, Toronto) and small. The GLSLB region generates 30 percent of U.S and Canadian gross domestic product (GDP), is home to 31 percent of the two countries' population and represents the fifth largest global economy in the world. It spans numerous modes, geographies and jurisdictions, serving a wide variety of commodity and supply chains.

Much of the infrastructure in the GLSLB region was developed more than 100 years ago and is in need of modernization. In such a complex system, making informed, fact-based policy decisions can be particularly challenging. In this report, a process framework for strategic freight planning is included that's based on the lessons from this study and several key supply chain performance reviews. The research is ambitious and in many respects represents a departure from the status quo approach to freight transportation planning in the GLSLB. It nevertheless may be a useful framework for addressing a number of the issues, barriers and constraints noted by stakeholders consulted vis-à-vis freight transportation planning in the GLSLB. A link to the study and the data can be found at www.glmri.org.



Framework for the NCFRP-35 Study.

M/V Hon. James L. Oberstar dedication ceremony.

IAGLR's Annual Freshwater Conference

GLMRI provided sponsorship support to the 54th Annual Conference for the International Association of Great Lakes Researchers (IAGLR). This year's conference was held in Duluth, Minnesota from May 30-June 3. This is the first time that the conference has been held on Lake Superior. Several presentations throughout the agenda highlighted GLMRI research projects.

Dr. Randall Hicks' GLMRI research findings on the accelerated corrosive loss on port transportation infrastructure were presented by graduate students Jon Bostrom and Ryan Oster. Dr. Hicks chaired the panel on Microbial Issues.

Matthew TenyEck, PhD candidate working with Dr. Donn Branstrator, presented the findings on their project, Testing Relationships Between Propagule Pressure and Establishment Success of a Non-Native Species, *Daphnia magna*.

Congratulations to Congressman James L. Oberstar

On May 24, 2011, Interlake Steamship Company (ISC) honored Congressman James L. Oberstar in a ceremony christening an ore boat to commemorate his extensive service to the Great Lakes. The ceremony was held in Duluth, Minnesota. Mark Barker, President of ISC, presided over the ceremony. GLMRI staff members were honored to be invited to the distinguished event.

Society of Naval Architects and Marine Engineers

Friday, February 18, 2011, the Society of Naval Architects and Marine Engineers (SNAME) held its Great Lakes and Ohio River Section meeting in Cleveland, Ohio. Dr. Michael Parsons presented an in-depth report of the work on the Integrated Electric Plants in Future Great Lakes Self-Unloaders authored by Dr. Parsons, Dr. David Singer and Samuel Denomy.

Advisory Board Member, Jim Sharrow, and Carol Wolosz attended the meeting held in Chicago, Illinois September 28-29. Planning is underway to host speakers on LNG/fuel alternatives at the Great Lakes Waterways Conference and the SNAME meetings scheduled for February 2012.

Great Lakes Maritime Academy Board of Visitors

Dr. Richard Stewart attended the Great Lakes Maritime Academy's Board of Visitors meeting in Traverse City, Michigan, in October 2010. Carol Wolosz attended the The Great Lakes Maritime Academy's Training Vessel the *State of Michigan* reception for their Board of Visitors at their Duluth port call in June on the cadet training voyage.

Carol Wolosz & Teresa Adams at Affiliates meeting.

Todd Ripley, Simo Makiharju, Ken Gerasimos, Becky Depta, and Floyd Miras GLMRI Annual Dinner

GLMRI Projects Reach National Publications

The FY2010 project Refinement of the Ballast-Free Ship Concept (PI: Professor Emeritus Michael G. Parsons, University of Michigan) was further reported by the publication of the paper Parsons, Michael G. and Kotinis, M., "Trim and Draft Control Capability of the Variable Buoyancy Ship," *Journal of Ship Production and Design*, Vol. 27, No. 3, August 2011, pp. 118-126 published by the Society of Naval Architects and Marine Engineers (SNAME).

The FY2010 project Evaluation for Integrated Electric Plants in Future Great Lakes Self-Unloaders (PI: Assistant Professor David J. Singer, University of Michigan) was further reported by the publication of the paper Parsons, Michael G., Singer, David J. and Denomy, Samuel J., "Integrated Electric Plants in Future Great Lakes Self-Unloaders," *Journal of Ship Production and Design*, Vol. 27, No. 4, November 2011, pp. 169-185. This was an extended version of the preliminary paper of the same title presented before the meeting of the Great Lakes and Great Rivers Section of SNAME in Cleveland, OH, on February 18, 2011.

Dr. Richard Stewart's paper on "The Energy Inefficiency of Marine Transportation: A Case Study of Flawed Data and Analysis" was published in the peer reviewed Transportation Research Record, Journal of the Transportation Research Board May 2011.

Also, Dr. Stewart's material was included in the following textbooks: "Navigation, Dredging and Protection: The Checkered History Of Channel Maintenance, Chapter 10," Fruin, Jerry and Stewart, Richard, Water Policy in Minnesota: Issues, Incentives and Actions, Edited by Ester, K. William and Perry, Jim, The RFF Press Water Policy Series, 2011; and International Logistics, 3rd Edition, Pierre David and Richard Stewart, Cengage, January 2011.

2011 Transportation Research Board Participation

In January 2011, the GLMRI staff and researchers were active throughout the week's schedule for the Annual Transportation Research Board meetings. On Sunday evening, GLMRI co-sponsored the Wisconsin reception hosted by the University of Wisconsin's Center for Freight and Infrastructure Research and Education. Dr. Teresa Adams, Jason Bittner and Bob Gollnik from C-FIRE and Dr. Lindquist, Sarah Schafer and Samir Dhar from the University of Toledo Maritime Data Clearinghouse team were in attendance. Dr. Richard Stewart brought several students to the conference from the University of Wisconsin-Superior's Transportation and Logistics program.

Dr. Stewart gave a presentation on the issues with the

Dr. Stewart at MARAD Firefighting School, Toledo, Ohio, June 2011.

lack of accurate and consistent maritime data for policymakers. He also had a poster on the lack of maritime research funding in the U.S.

Dr. Stewart is a member of the Marine Environmental Committee of TRB.

Duluth/Superior Harbor Technical Advisory Committee (HTAC)

Dr. Richard Stewart and Carol Wolosz regularly participate in the Duluth/Superior Harbor Technical Advisory Committee (HTAC) meetings. The HTAC is an advisory committee to the Metropolitan Interstate Council, meeting quarterly and bringing together a large group of stakeholders to discuss and formulate recommendations addressing issues relevant to the Duluth-Superior harbor. Current topics include dredged material management, environmental restoration and enhancement activities, and land use development activities in the St. Louis River bay and estuary. Updates on GLMRI research projects and events are regularly part of the agenda.

Dr. Stewart – Ready and Able

Dr. Richard Stewart was busy over the summer updating his credentials for his license. In addition to teaching classes in Marine Transportation and Port and Terminal operations in June, he completed The MARAD Firefighting School in Toledo, Ohio. Dr. Stewart was able to log some observer time on the *M/V Roger Blough* in August on a round-trip voyage between Duluth, Minnesota and Conneaut, Ohio. He has served as an observer on other vessels during the past five years. He also performs surveys for the National Cargo Bureau. In October, he passed his open book Nautical Rules of the Road exam and in October his Master of Steam or Motor Vessels of any Gross Tons upon Oceans Unlimited license was renewed by the U.S. Coast Guard for another five years.

Great Lakes Maritime Data Workshop Held in Ohio

The University of Toledo hosted a workshop on the Great Lakes Maritime Information Delivery System for members of Highway H_2O on September 19, 2011. Participants were provided with a hands-on introduction to data resources and query applications in the newly-developed prototype version of Midwest FreightView and provided valuable feedback to the project team. The bi-national workshop was sponsored by the St. Lawrence Seaway Management Corporation with participants from regional port authority offices, universities and industry.

Ryan Oster, Teresa Adams, Joan Chadde, Randall Hicks, & Nathan Johnson GLMRI Annual Dinner

Intermodal Association of North America

Dr. Richard Stewart is an active member of the Intermodal Association of North America. He participated in its annual meeting and exposition held in November of 2010 at Ft. Lauderdale, Florida.

Green Bay Port Symposium

In April 2011, Drs. Ray Hutchison and John Stoll, GLMRI researchers from the University of Wisconsin-Green Bay, presented an update on their GLMRI project titled "The Great Lakes Marine Container Feasibility Study" at the 2011 Port of Green Bay Symposium. The symposium was well attended and received regional media coverage.

Carol Wolosz attended the symposium and met with Port Director Dean Haen. In addition to the project at UW-Green Bay, GLMRI worked closely with the Port on the GLMRI economic analysis project. Also, in the summer of 2011, the Port of Green Bay provided a tour and other regional shipping information to the group of K-12 teachers and educators participating in the GLMRI summer teachers' workshop.

Federal/Industry Logistics Standardization Meeting

Samir Dhar from the University of Toledo's Geographic Information Science and Applied Geographics Center participated in the Federal/Industry Logistics Standardization meeting held in Tampa, Florida in May 2011. Dhar, as the primary programmer and the database specialist for the Great Lakes Maritime Data Clearinghouse, served as an advisor to the federal agencies to help in coming up with new ideas or methodology from the university's work with the U.S. Coast Guard and the U.S. Army Corps of Engineers maritime data.

Seafarer's Center in Duluth

Carol Wolosz, in her free time, is working with the Seafarer's Center in Duluth, Minnesota serving on its Board of Directors. The mission of the Center is to offer hospitality and support to the crews of ocean-going and freshwater ships who work and visit the Twin Ports of Duluth, Minnesota and Superior, Wisconsin.

2011 Project Reports

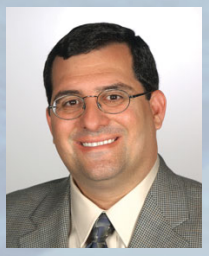
Beluga Elegance loading beet pellets at the General Mills elevator in Duluth.

Summary Reports

This report provides summary reports and progress updates on the research efforts selected in 2010. With a reduced amount of funding provided in the FY10 Federal Appropriation, GLMRI released a limited request for proposals in April 2010. Eleven proposals were received within the submission period. External reviewers were selected based on the content/topic of the proposal. Each proposal was reviewed by multiple reviewers from academia, the maritime industry and governmental agencies. In order to maximize the funding allocation, reduced offers were made on many of the proposals. Seven projects were awarded in September 2010 for research through 2011. In addition, two continuation reports are also included from the previous year's projects.

- **Air Lubrication Drag Reduction on Great Lakes Ships**
  University of Michigan, Dr. Steven Ceccio
- **Phase II-Developing a Risk Assessment Tool to Predict the Accelerated Corrosive Loss of Port Transportation Infrastructure: *Model Validation and Regional Application***
  University of Minnesota Duluth, Dr. Randall Hicks
- **Year 4, Building Sustainable Solutions to the Issue of Ballast Water Treatment: *Testing Relationships Between Propagule Pressure and Colonization Success of Invasive Species***
  University of Minnesota Duluth and the University of Wisconsin-Superior Lake Superior Research Institute, Dr. Donn Branstrator
- **Expanding Regional Freight Information Resources for the Upper Midwest Phase VI: *The Great Lakes Maritime Information Delivery System: A Resource for the Regional Analysis of Intermodal Freight Flows in the Great Lakes Region***
  University of Toledo, Dr. Peter Lindquist
- **WebGIFT-GL: Expanding Access to the Great Lakes Geospatial Intermodal Freight Transportation (GL-GIFT) Model**
  Rochester Institute of Technology, Dr. J. Scott Hawker
- **The Economics of a Bi-State Truck Ferry**
  Purdue North Central University, Dr. Thomas Brady
- **Economic Impact of the Great Lakes and St. Lawrence Seaway System (GLSLS), Oct 2010-Oct 2011**
  University of Minnesota Duluth, Dr. David Doorn
- **Combining Fine Dredged Materials and Biosolids for Sustainable, Beneficial Reuse**
  University of Minnesota Duluth, Dr. Nathan Johnson
- **Great Lakes Maritime Education Program for K-12 Teachers, Students and Communities**
  Michigan Technological University, Ms. Joan Chadde

Air Lubrication Drag Reduction on Great Lakes Ships



CO- PRINCIPAL INVESTIGATOR
Dr. Steven L. Ceccio

PRINCIPAL INVESTIGATOR
M.Sc. Simo Mäkiharju

Dr. Steven L. Ceccio is Chair and Professor of Naval Architecture and Marine Engineering and Professor of Mechanical Engineering and Applied Mechanics at the University of Michigan. He received his B.S. degree in mechanical engineering from the University of Michigan in 1985, his M.S. degree in 1986 and his Ph.D. in 1990 both in mechanical engineering from the California Institute of Technology. He was appointed as an Assistant Professor at the University of Michigan in 1990. He was promoted to Associate Professor with tenure in 1996 and Professor in 2003. He served as an Associate Vice President for Research at the University of Michigan from 2004 to 2009. He is currently the Director of the Naval Engineering Education Center. Prof. Ceccio is a fellow of the American Society of Mechanical Engineers and of the American Physical Society.

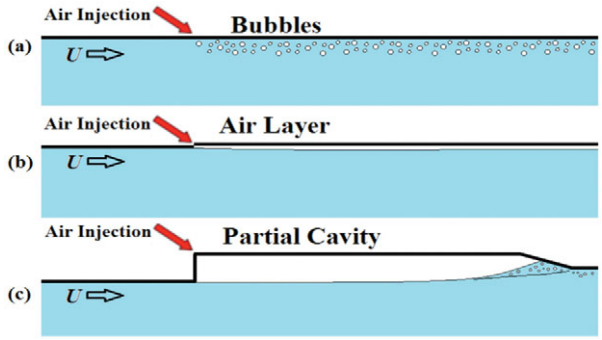


Figure 1: *(a) In DBR discrete air bubbles are introduced into the boundary layer on the hull and they are thought to reduce the frictional drag by reduction of bulk density and by modifying momentum transport. However, downstream from the injection site the bubbles can migrate away from the surface and their effect is reduced. (b) In ALDR a continuous film of gas separates the liquid and hull, thus reducing friction. This film has been found to persist far downstream of the gas injection site. (c) In PCDR a thick recess filled with gas separates the liquid and hull, thus reducing friction of the area of the recess. The closure of the cavity is designed to minimize loss of air.*

DUE TO ENVIRONMENTAL CONCERNS and rising fuel cost, it would be advantageous for the future of the Great Lakes shipping industry to reduce fuel consumption. One potential way to achieve this is by reducing ship resistance. Without major hull form changes or decrease in operational speed, the form and wave resistance of a ship are mostly fixed and only frictional drag could be reduced. As interest in drag reduction has increased over the last two decades, several research projects in the USA, Europe and Asia have investigated the possibility of reducing frictional drag by using air lubrication. Air lubrication is achieved by pumping air beneath the hull and thus reducing the area of hull in direct contact with the liquid flow, or in the case of discrete bubbles by modification of momentum transport and average density in the boundary layer. If properly implemented, it is estimated that air lubrication could lead to net fuel savings of between 5 and 20 percent, with the corresponding reduction in NO_x, SO_x, particulate and CO_2 emissions.

Air lubrication techniques can be divided into three major categories; Bubble Drag Reduction (BDR), Air Layer Drag Reduction (ALDR) and Partial Cavity Drag Reduction (PCDR). Proposed ships utilizing PCDR are often called Air Cavity Ships (ACS) in the literature. Figure 1 illustrates the conceptual difference between these three techniques.

For any air lubrication technique to be considered for implementation, the potential net energy savings must be sufficient to justify the added complexity of the air supply system and the capital, operational and maintenance costs. We performed an energy cost-benefit analysis for ALDR and PCDR and discussed the results and some of the limitations of their validity. A more simplified cost-benefit analysis for ALDR has been previously provided by Ceccio *et al.* (2010). The current study focuses on the two air lubrication techniques that seem most viable based on current data: ALDR and PCDR.

The air layer or partial cavity will reduce the frictional drag on the area covered. It is assumed that the ship's form drag is not appreciably changed by the air injector, strakes or other appendages attached to the hull to achieve air lubrication. Assuming further that practically all of the ship's energy consumption is used for propulsion, the possible percentage net energy savings can be estimated by considering the ratio of net energy savings to total energy consumption. To estimate the energy required by the air supply system, we must first estimate gas fluxes required to achieve ALDR and PCDR.

To show the results of the energy cost-benefit analysis, we considered a specific ship type. The American Steamship Company's *M/V American Spirit*, shown in figure 2, was chosen for these calculations, albeit not all the technical detail on the ship was available to us and hence some additional assumptions were required.

Assumptions:

- The ship has a very large block coefficient. While the exact hull shape is not available to us, we assume that

Figure 2: *The M/V American Spirit is a cargo ship operating on the Great Lakes. L = 306 m, w = 32m and midsummer draft 8.8 m (picture from American Steamship Company's web page).*

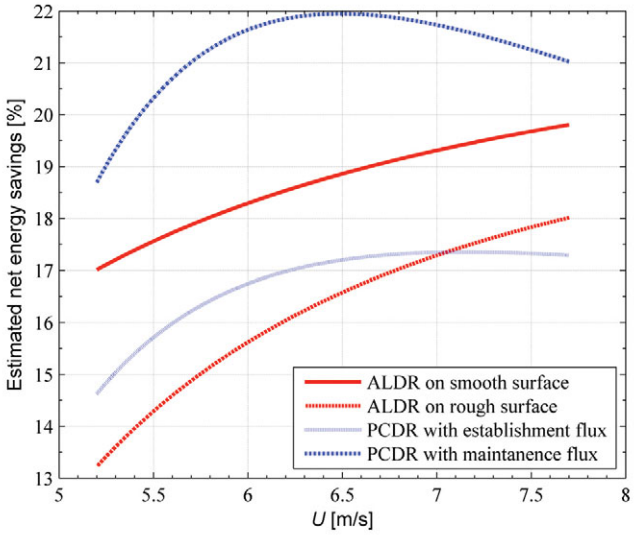


Figure 3: *Estimates of the potential net energy savings for a ship similar to the M/V American Spirit, where the required air fluxes were estimated based on curve fits shown in figure 2.*

7 percent of the beam has curvature and 15 percent of the length is bow and stern, so that approximately 50 percent of the wetted hull is flat and horizontal making it ideally suited for air lubrication.

- The top speed for this ship is approximately 7.5 m/s, leading to a maximum Froude number of 0.14, hence we assume that the frictional drag accounts for 60 percent of the ships total resistance.
- For both air layers and partial cavities we assume that the friction on the area covered is reduced by 80 percent, which is the lower bound of the frictional drag reduction observed in experiments.
- Propulsor efficiency is assumed to be high (75 percent), as the higher this value is, the lower the net energy savings available will be.
- Efficiency of the generator providing electricity for the compressor is assumed to be 90 percent.
- The air compressor efficiency was assumed to be 60 percent.
- Pressure drop due to piping losses was assumed to be 15 psi.
- For ALDR, the air layer is assumed to persist indefinitely once formed.
- For PCDR, a single multi-wave partial cavity is assumed to span the length of the recess.

With these assumptions the net energy saving as function of speed can be estimated. The results are presented in figure 3.

There have been two sea trials where the flow was likely in the BDR-transitional-ALDR region (based on flow regions as defined in Elbing *et al.* 2008). One such sea trial on the *Pacific Seagull* yielded 5 to 10 percent net energy savings according to Hoang *et al.* (2009) while a second sea trial by Mitsubishi Heavy Industries achieved 8 to 12 percent net energy savings (Mizokami *et al.* 2010). The potential net energy savings predicted for ALRD in figure 3 are higher than observed in these sea trials. This is likely explained by either or both of the following: the sea trials may not have had sufficient air flux supplied to achieve a true air layer (as could be assumed from the local frictional drag measurements presented by Hoang *et al.* 2009), or the area fraction of the wetted hull covered for these ships was less than what was assumed possible for ships with large block coefficients, such as those operating on the Great Lakes (or the new triple-E class cargo ships). For PCDR, a scale test by MARIN recently showed 15 percent net energy savings (Foeth, 2011) and a 1:12th scale test by STENA achieved resistance reduction of 20 to 25 percent (*Surveyor*, 2011).

In the analysis, the percentage of frictional drag reduction for the surfaces covered by air was assumed to be a conservative 80 percent, given that other components of drag may in fact increase. It is important to note that any effects of possibly increased form drag and all other details, such as the effect of air entrainment into the propulsor, were omitted. It is not the intent to make a strong quantitative argument, but rather to show qualitatively the trends of the energy economics of air lubrication and thereby to determine whether the energy savings break-even point could be surpassed. The energy savings break-even point depends on three principal parameters: ship's draft, length and operating speed. The net energy savings achieved will likely deviate from those estimated here as they depend on all the assumptions made in the analysis and on how the experimental results would scale to conditions not tested in the experiments. There are certainly boundaries for these techniques that have not been encountered within the limited parameter ranges of the experiments on which estimates of required air flux were based. The economic cost-benefit is highly ship specific, but would easily provide a net benefit if the estimated 10 to 20 percent net energy savings are realized. ■

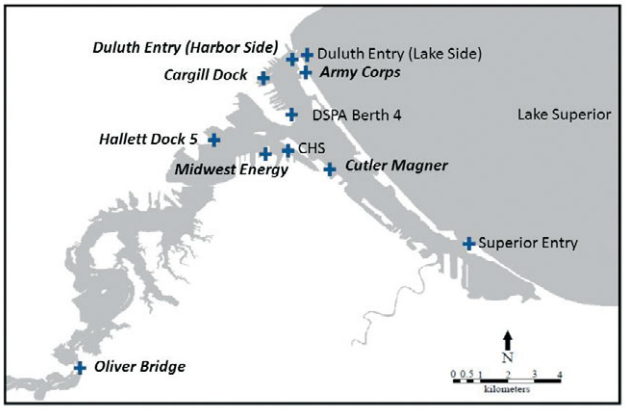
Developing a Risk Assessment Tool to Predict the Risk of Accelerated Corrosion to Port Infrastructure

PRINCIPAL INVESTIGATOR
Randall E. Hicks
University of Minnesota Duluth

CO-INVESTIGATOR
Ryan J. Oster
University of Minnesota Duluth

Dr. Randall E. Hicks is Director of the Center for Freshwater Research and Policy and a Professor in the Department of Biology and at the University of Minnesota Duluth. He completed a Ph.D. in Ecology at the University of Georgia and did postdoctoral work at Woods Hole Oceanographic Institution before joining the faculty at the University of Minnesota Duluth. Dr. Hicks is an environmental microbiologist who studies the diversity and productivity of aquatic microbial communities, their role in the degradation and transformation of organic compounds, and the survival and virulence of pathogenic microbes in these communities. Current research efforts in his lab focus on great lakes of the world and watersheds in northern Minnesota.

Corrosion pitting and tubercle formation at Hallett Dock 5.



ABOVE: Map of locations that were sampled in the Duluth-Superior Harbor during August 2010 and July 2011.

RIGHT: Locations at harbors sampled along the north shore of Lake Superior in July 2011. Map courtesy of Discovery Communications, 2011.

CORROSION OF STEEL INFRASTRUCTURE in the Duluth-Superior Harbor (DSH) and other ports in the Laurentian Great Lakes is a major economic concern. It is estimated that corrosion in the United States costs $275.5 billion per year or 3.14 percent of our GDP, and in the DSH alone $200-250 million may be needed to replace 20 km of steel structures already impacted by corrosion.

The ultimate goal of this study was to develop a risk assessment tool that can be used by businesses and governments to predict whether other ports may experience corrosion similar to that seen in the DSH. Ten sites in the Duluth-Superior Harbor and Lake Superior (Duluth, MN and Superior, WI) ranging from low to severely corroded were selected for this study in 2010 and 2011. A new area of the Duluth Entry on the harbor side of the entry, which is moderately corroded, was also sampled in 2011 to compare with samples taken from the Lake Superior side of this entry in 2010. Additional sites in four harbors along the north shore of Lake Superior were also sampled in 2011 to gain a better understanding of the geographic extent of the corrosion of steel infrastructure in the lake. Multiple water chemistry parameters were analyzed and used to calculate the Larson-Skold Index of water corrosivity, and their relationship to long-term corrosion rates was evaluated. The lowest long-term corrosion rates of steel structures were observed at the head and mouth of the DSH, while higher corrosion rates were observed in the outer and inner harbor areas. Long-term estimates of steel corrosion were inversely related to dissolved oxygen concentration, positively related

AMI consulting engineers Chad Scott and hard hat diving team at Midwest Energy Resources.

Undergraduate Jack Bergman assisting with sample collection at Midwest Energy Resources dock.

Ryan Oster sampling at Midwest Energy Resources dock.

to water chloride, alkalinity and conductivity, but not the sulfate concentration or the Larson-Skold Index. The Larson-Skold Index decreased at two of three sites in the DSH from 1972 to 1997 and this index predicted a low risk of corrosion for ten sites visited during 2010 and 2011, indicating that water quality alone may not explain the severe corrosion seen in this harbor.

The abundances of iron-oxidizing bacteria (*Gallionella* spp.) and sulfate-reducing bacteria (SRB) on steel surfaces were estimated at ten sites in the DSH and three other harbors in the western arm of Lake Superior by quantitatively amplifying the 16S rRNA and dsrA genes, respectively. Corrosion tubercles in the DSH were enriched with *Gallionella* ssp. compared to biofilm on adjacent steel surfaces and the surrounding water. The abundance of *Gallionella* ssp. on corroded steel surfaces ranged from 10^8 to 10^{10} 16S rDNA gene copies/dry gram of corrosion tubercle. SRB were at least 2 orders of magnitude less abundant within corrosion tubercles than *Gallionella* spp. with abundances ranging from 10^5 to 10^8 dsrA gene copies/dry gram of tubercle. In 2010, *Gallionella* spp. abundance was positively related to long-term corrosion rates but not in 2011. SRB abundance was not related to corrosion rates.

In summary, the analysis of water quality from the early 1970's to the late 1990's in the DSH indicated dissolved oxygen increased during this period at two sites, but there were few major changes in water quality parameters associated with corrosion. In fact, the corrosivity of the water, as indicated by the Larson-Skold Index, remained unchanged at two sites and appeared to decrease from the 1970's to the 1990's at the upper most part of the DSH. We interpret this to mean that changes in water quality alone may not be responsible for the appearance of severe, and possibly accelerated corrosion of steel structures that was recently discovered in this harbor. Bostrom (2010) reached a similar conclusion but suggested that water chemistry may influence the composition of bacterial communities found on these structures.

While a logistic regression model was not useful for predicting corrosion risk, a multiple linear regression model did predict long-term corrosion rates from alkalinity and SRB abundance. When this model was used to predict corrosion rates at two harbors on the north shore of Lake Superior, it slightly underestimated the measured long-term corrosion rate. Overall, it appears that water chemistry alone is not likely the cause of accelerated corrosion in the DSH, but rather a combination of microbiological and chemical factors appear to influence the corrosion rate of sheet steel structures in this harbor and possibly other areas in the western arm of Lake Superior. ■

Year 4: Building Sustainable Solutions to the Issue of Ballast Water Treatment Testing Relationships Between Propagule Pressure and Colonization Success of Invasive Species

PRINCIPAL INVESTIGATOR
Dr. Donn K. Branstrator
University of Minnesota Duluth

CO-PRINCIPAL INVESTIGATOR
Matthew C. TenEyck
University of Wisconsin-Superior
Lake Superior Research Institute

Dr. Donn Branstrator received the B.A. in Biology from Lawrence University, Wisconsin, and the Ph.D. in Biology from the University of Michigan. He teaches courses in general ecology, lake ecology, and plankton biology, and leads a team of undergraduate and graduate students that study the ecology of freshwater zooplankton at the University of Minnesota Duluth.

Image of Daphnia magna (ref: Wikipedia). This female (2-3 mm length) carries a clutch of 15-20 eggs in the dorsal brood pouch. The eggs were produced clonally and can reach maturity within days at typical summer temperatures.

FRESHWATER ECOSYSTEMS ARE HIGHLY vulnerable to invasions by non-native species because of their close association with human activity, including uses for municipal and industrial water supplies, natural resource development and commercial navigation and recreation. Ballast water ferried by ships and used to correct imbalance in cargo is believed to be an agent of coastal non-native aquatic biota in North America. In an effort to prevent additional species introductions via this vector, the U.S. Congress passed and reauthorized legislation in the 1990s that requires vessels to manage their ballast water through Ballast Water Exchange or to perform Ballast Water Treatment (BWT) by proactive decontamination. Because it is widely recognized that no BWT technology will perform with 100 percent effectiveness, standards will allow a certain level of biological pollution (viable non-native organisms) to escape in post-treated water. As one standard, the International Maritime Organization (IMO) recognizes that no more than 10 viable organisms per m^3, each greater than 50 µm length in minimum dimension, may be discharged.

This multi-year project uses an experimental, does-gradient approach to test the efficacy of the IMO discharge standard for preventing the establishment of biological pollution in post-treated ballast water. In years one and two of this project we used a comprehensive field survey to characterize the natural density and diversity of crustacean zooplankton in the Duluth-Superior Harbor and St. Louis River Estuary. This enabled us to identify threshold densities that the surrogate invader in our experiments would be expected to achieve in order to be considered established.

The common crustacean zooplankton, *Daphnia magna*, served as the surrogate invader in our experiments. *D. magna* is found throughout the Northern Hemisphere in freshwater lakes and ponds but is not native to northern Wisconsin, Minnesota and Lake Superior and is not currently found there. *D. magna* serves as a "worst-case" scenario surrogate invader because this organism is capable of rapid population growth by asexual reproduction following the introduction of a few individuals.

Experiments were conducted in 230-L square polyethylene mesocosm tanks (61 cm L x 46 cm W x 91 cm H) equipped with air stones to promote gentle mixing and gas exchange with the atmosphere. Tanks were housed in a climate controlled laboratory and administered a 16:8 hour light:dark cycle.

On the day before each experiment began, tanks were filled with water, and its ambient concentrations of biota, drawn directly from the Duluth-Superior Harbor by submersible pumps. Triplicate tanks were randomly assigned to a stocking density. Tanks were stocked with *D. magna* on the first day of the experiment. Each experiment ran for 8 weeks during which densities of *D. magna* and other zooplankton in the mesocosms were monitored weekly. We also monitored the physiochemical conditions of the tanks on a weekly basis including temperature, dissolved oxygen, pH, specific conductivity, Chl-*a* fluorescence and turbidity. On the final day of each experiment, all contents were passed through a 20-µm

Cenex Harvest States (CHS) grain terminal, Superior, Wisconsin.

Water sampling in the Duluth-Superior harbor.

mesh net and preserved.

We have conducted seven experiments including one in 2009, three in 2010 and three in 2011. The results indicate that initial stocking density of *D. magna* and time of year both influence the establishment success of *D. magna* in Duluth-Superior Harbor water. In the spring and fall experiments, *D. magna* populations in many of the trials demonstrated clear episodes of establishment success during the eight-week period. These included trials where the starting densities of *D. magna* were either at the IMO threshold (10 individuals per m^3) or below this recognized IMO threshold. By contrast, in the summer experiments the population densities of *D. magna* rarely achieved levels that were high enough to be considered established by our criteria. Only when the background assemblage of zooplankton was first removed (filtered) from the tanks in the summer was *D. magna* able to achieve densities above threshold standards.

These results suggest that the IMO standards, as currently defined, may be sufficiently restrictive under some, but not all natural circumstances to prevent colonization of non-native zooplankton such as *D. magna* in the Duluth-Superior Harbor. Preliminary analyses of our results suggest that the risk of establishment of *D. magna* in the Duluth-Superior Harbor is higher in spring (May-June) and fall (October-November) than it is during summer (July-August) months as a consequence of lower densities and fewer zooplankton competitors in the spring and fall periods.

Further analysis and refinement of the risk-release relationship for non-native species in ballast water discharge is critical. Standards that are too lenient may pose serious, long-term threats to the environment and economy. Standards that are too strict may require unnecessary investments in time, labor and materials necessary to meet the standards. Empirical justification of accepted standards should strengthen support among stakeholders and encourage timely and sustained compliance. ■

Image of a 230-L mesocosm tank partially filled with harbor water and a scientist holding a sampling tube used to retrieve zooplankton during routine, weekly monitoring of the tank.

Expanding Regional Freight Information Resources for Upper Midwest: Phase VI - The Great Lakes Maritime Information Delivery System: A Resource for the Regional Analysis of Intermodal Freight Flows in the Great Lakes Region

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THIS IS THE SIXTH PHASE of a long-term effort to develop and manage the Great Lakes Maritime Information Delivery System (GLMIDS). This web-based data repository, information clearinghouse and online geographic information system (GIS) is designed to serve as a comprehensive data resource linking maritime freight transportation in the Great Lakes to the wider regional economy (see http://www.maritime.utoledo.edu). Users can take advantage of the GIS location-based query and selection capabilities, as well as mapping functions to report data concerning transportation networks, ports, economic activities and commodity flows in the region. This project collectively contains the following functions and data sets in its current state:

- An information clearinghouse and centralized data facility furnishing links to other sites, private vendors furnishing commercial products and government agencies, etc.
- A data delivery system that includes detailed regional economic data, weather and climatic data, dock and terminal facilities, commodity movements, intermodal connectivity, lock data and navigation facilities, movements and intermodal transportation networks (including rail, highway and air).
- Preferred access to AIS data for tracking vessel movements in the Great Lakes.
- An interconnected intermodal network (water, rail and highway) that will enable analysts to incorporate transshipment costs and characteristics at terminals.
- An online *Atlas of Great Lakes Maritime Commerce* that includes maps for download in pdf format.
- A data delivery function in the form of a secured FTP site at the project web page for approved users.
- A customized GIS data viewer in the form of Midwest FreightView.

This phase of the project has been devoted, in large part, to continued efforts in data collection and management, with an emphasis toward automated data collection and in the collection of newly-discovered sources of data. In addition, the project team collaborated with researchers in GLMRI partner institutions through data sharing and providing access to the online GIS. This phase of the project concentrated on phasing out the current version of Midwest FreightView in favor of a newer, more user-friendly online GIS data viewer that will include the same data viewing features of the old system, but with improved data download capabilities and a new set of analytical tools (see Figure 1). The project team has programmed modules for seamless incorporation into the new MWFV for the routing of cargoes, definition of market and port catchment areas and intermodal connectivity on the data delivery site. In a number of parallel projects, the project team has also devoted attention to technology transfer activities, including workshops, online documentation and publications.

Cooperative work and data sharing. If the data products and online data delivery tools are to be useful to the maritime community, it is essential that members of the project team find ways to put them to work in the hands of analysts with the skills to optimize their use. The project team has continued involvement in disseminating and sharing data with our GLMRI partners and a wider community of partners. Selected cooperative ventures are summarized as follows:

- Workshop: Freight Data Resources for the Great Lakes Region, Highway H_2O, Toledo, Ohio, September 19, 2011
- A GIS Connection between Brownfield Sites, Transportation and Economic Development (Joint project between the University of Toledo GISAG Center and the University of Toledo University Transportation Center)
- Multimodal Freight Transportation within the Great Lakes-Saint Lawrence Basin TRB National Cooperative Freight Research Program-35 (Joint project between CPCS Transcom Limited, GLMRI, University of Toledo GISAG Center, Economic Development Research Group, Prime Focus LLC and Sustainable Ports)
- Data Acquisition, Management and Delivery Functions in Support of U.S. Flag - Great Lakes Shipping Revitalization Study (Joint project between the University of Toledo GISAG Center and GLMRI)

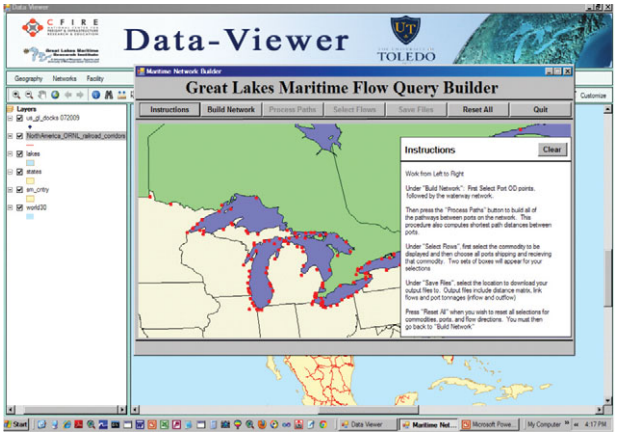

Figure 1. *New Data Viewer to Replace Midwest FreightView*

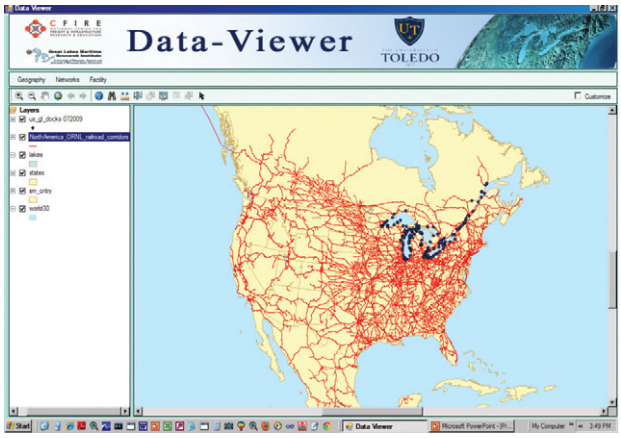

Figure 2. *Tools Built into New Data Viewer – GL Maritime Query Builder*

- FINDE: Federal Integrated Navigation Data Enhancement (Joint automated data acquisition project between University of Toledo GISAG Center, USACE, IRS, U.S. Customs and U.S. Coast Guard)

In addition to these projects, the project team is also involved with a number of other joint projects with researchers at UW-Madison, UW-Milwaukee and The University of Illinois-Chicago. The project team will continue to solicit opportunities for joint work with our affiliate universities and outside contractors.

Ongoing data collection. Data collection also continued in this phase through the acquisition of information relating to the regional economy, transportation networks, port and terminal facilities, and cargo movements. The project team will continue to maintain and improve the web site and our online GIS MWFV platform for data delivery purposes through parallel projects. In terms of continued data acquisition, preprocessing, and incorporation into MWFV, the following tasks (as outlined in the project proposal) are completed:

- ORNL CTA North American Rail Interlining Network.
- Integrated Network—Great Lakes Waterway, Highway, Rail linked to Commercial Docks, Locks (U.S. Army Corps of Engineers).
- Updated U.S. Highway Network Speed/Estimated Travel Times with ATRI Travel Time Data (by time of day, day of week).
- Add ESRI Traffic Counts to integrated highway network.
- Link BEA Regions/BEA GDP Data to Public Rail Waybill Data.
- Encode enhanced EPA eGRID Power Plant Database into MWFV and link to Rail and Waterway Networks.
- Link USACE Foreign Traffic Vessel Entrances and Clearances to Ports.
- Add legends, labels and text to “Last Mile” Connections on Satellite Imagery.
- Input County-to-County Mileage and Impedance Tables into MWFV for analytical procedures (Useful for Analytical Tools—Accessibility, Location Analysis, etc.). The primary modes for these tables include: highway, rail and water.

The vision for the Great Lakes Maritime Information Delivery System has evolved over the course of the project to produce a multidimensional system that can support a wide array of functions that include data storage, delivery of prepared documents, GIS functionality and a clearinghouse of information for maritime commerce. The main objective originally envisioned for the project remains the same: to maintain a long-term database and data distribution system that is available for port authorities, state transportation agencies, regional planning agencies and economic development organizations, as well as other interested decision makers and stakeholders within the region.

During phase six, the project team has continued its efforts in data collection, cooperative work and data sharing with GLMRI partner institutions and other partners. As the current phase of the project progresses, emphasis will shift to the implementation and application of a new MWFV data viewer, as shown in Figure 1. In addition, a new set of analytical tools will be implemented within the new viewer (see Figure 2). The new MWFV, as previously discussed, will be more dynamic and user-friendly than the current viewer. This new improved data display and delivery system will better serve the Great Lakes Maritime Community by providing easily downloadable data sets in the form of graphics, tables and maps from a more accessible platform serving a wider range of users. ■

WebGIFT-GL: Expanding Access to the Great Lakes Geospatial Intermodal Freight Transportation (GL-GIFT) Model

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IN PRIOR RESEARCH PROJECTS sponsored by the Great Lakes Maritime Research Institute (GLMRI), the Rochester Institute of Technology and the University of Delaware demonstrated the value of a geospatial model of intermodal freight transportation in the Great Lakes-St. Lawrence Seaway region. That model, called GL-GIFT (Great Lakes Geospatial Intermodal Freight Transportation) is unique in that it integrates energy consumption and pollutant emissions along with the usual time, distance and cost attributes associated with moving freight between analyst-designated locations. GL-GIFT also allows the analyst to vary the energy and emissions rates, modeling the varying operation conditions of different vehicles (marine vessels, trains and trucks) and different fuels. This allows policy analysts to perform trade-off case studies to compare, for example, the cost/benefit of alternate fuels, the time and emissions trade-offs of using different modes (vessels compared to trucks, for example, including intermodal transfer delays and emissions at ports, rail yards, etc.), the cost/benefit trade-offs of transportation network and intermodal transfer facility infrastructure development or removal) and other policy case studies.

Our earlier research demonstrated the use of GL-GIFT in case studies for the Great Lakes region. Our learning enabled us to apply similar methodologies to study the carbon impact of port-generated traffic in California and the delays and additional emissions caused by port and rail congestion in major transportation bottlenecks. Example results of these studies include the potential for significant reduction in CO_2 emissions and operational costs by using maritime routes for significant distances (such as the Great Lakes or coastal short-sea routes) and that the wide variation in vessel performance has significant impact on the size of these reductions and may, in fact, cause an increase, especially compared to rail transport.

Based on the value we have gained from using GL-GIFT for policy case studies, we desired to make the model more widely available to policy analysts, state, regional and federal departments of transportation, metropolitan planning organizations, freight shippers and carriers, and others. However, our experience performing case studies in previous research exposed a number of limitations to making the current model more widely available.

The first limitation is cost, as the current GL-GIFT would require the analyst to have and maintain an installation and license of ESRI's ArcGIS Desktop, the underlying commercial geospatial engine that supports GL-GIFT, as well as the multimodal network geodatabase we have developed and continue to update. Second is complexity, as Desktop GL-GIFT is not intuitive to use and there are many features available which are not necessary and can confuse the non-expert user. Third is the need for skilled policy analysts to appropriately set-up and interpret results of case studies in this complicated Desktop GL-GIFT environment.

So the goal of the current GL-GIFT effort is to make the basic functionality of GL-GIFT available to analysts via the Web (accessible through a Web browser), along with an intuitive user interface and user guidance to set up and understand case studies. This new system is called WebGIFT-GL.

Looking at WebGIFT-GL. WebGIFT-GL builds on ESRI's ArcGIS Server, which allows multiple users to access GIFT functionality through a Web browser. The geodatabase and route solver functionality reside on servers

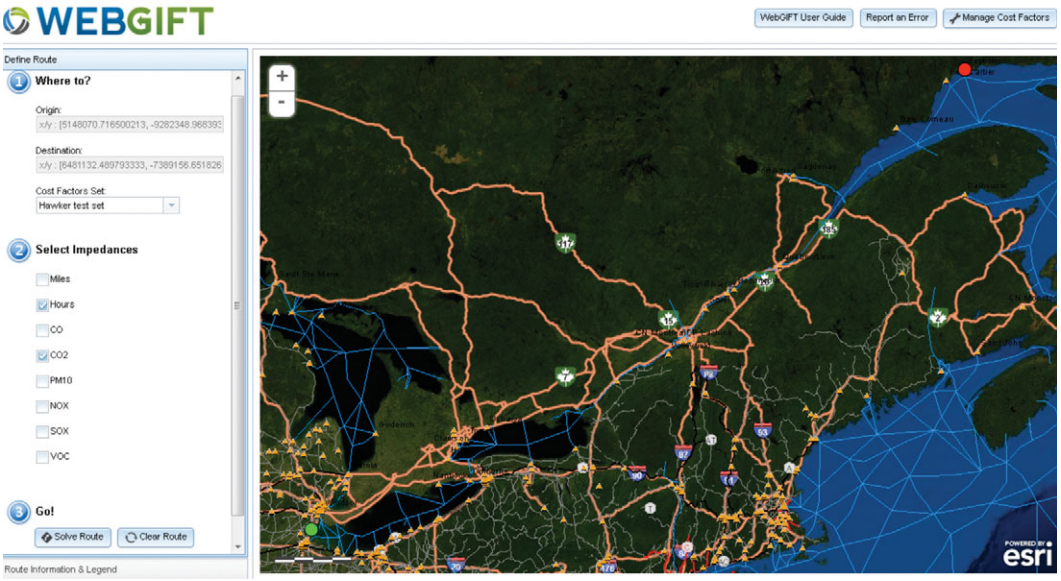

Figure 1. *The green dot is the origination of the route and the red dot is the destination to show the steps in specifying a route to analyze.*

hosted by the Rochester Institute of Technology and mirrored at the University of Delaware. We have developed a user-friendly interface by integrating JavaScript, JQuery, Dojo and ASP.NET (common Web technologies supported by virtually all relatively modern browsers). The user interface interacts with the server through Web services.

As Figure 1 shows, the user first defines a route origin and destination by pointing and clicking on the map. The map can be panned and zoomed to find desired locations. In Figure 1, the origin is near Toledo, Ohio and the destination is in the St. Lawrence Gulf. In this first step, the user also selects the cost factor set to use, which defines the emissions rates for marine vessels, trains and trucks. The user then selects which variables to find optimal routes for (one route for each selected variable and that route minimizes that variable compared to all alternative routes) and then the user launches the route solver.

After a few minutes, depending on the number of routes/variables and the ArcGIS server load, the resultant routes are displayed with associated route attributes, as Figure 2 shows. The attributes are color-coded with the route display. Figure 2 shows the minimal CO_2 route (in pink) with the total accumulated emissions along the route and a breakdown of how much of the route was covered by each of the three modes. Notice that this route used all three modes, but was predominately marine vessel (ship). The minimum time route (in blue, but the attributes are not shown in Figure 2) was predominately truck, but did use rail for part of the route. The minimum time route took about one-quarter of the time as the minimum CO_2 route, but emitted almost four times the CO_2.

A key feature of Desktop GL-GIFT is the ability for the user to adjust emissions cost factors to reflect the specific vessels, trains and trucks for their scenario. We have brought that functionality over to WebGIFT-GL, as Figure 3 shows. The user can create new cost factor sets by copying and editing an existing set or edit the values in existing cost factor sets and then select the cost factor set they wish when setting up and solving their routes.

Progress and next steps. WebGIFT-GL is now available for beta-level testing at http://WebGIFT.rit.edu/. It is still a bit rough in places, but we have accomplished our goal of providing basic GL-GIFT functionality on the Web with a much friendlier user interface than Desktop GL-GIFT. Advanced analysts will still want the power and features of Desktop GL-GIFT, but WebGIFT-GL provides a quick start for policy feasibility and trade-off studies. For more elaborate studies, they can work with the GIFT team at RIT and University of Delaware for support.

We are integrating WebGIFT-GL with our Multi-Modal Energy and Emissions Calculator (http://EmissionsCalc.rit.edu), which is a tool that computes consumed energy and produced emissions for trucks, trains and marine vessels used in freight transportation. It uses fundamental concepts about fuel (energy density, carbon content, sulfur content, etc.), engine efficiency, engine load (cargo capacity, etc.) and emissions control technologies to compute the emissions expected from operating that vehicle for freight transportation. From this, instead of the analyst needing to know emissions cost factors, they can select from a library of pre-defined vehicles to obtain cost factors, or they can define a new vehicle and compute the emissions cost factors.

Because some of the cost factor data may be proprietary to the using analyst and to support documenting and saving

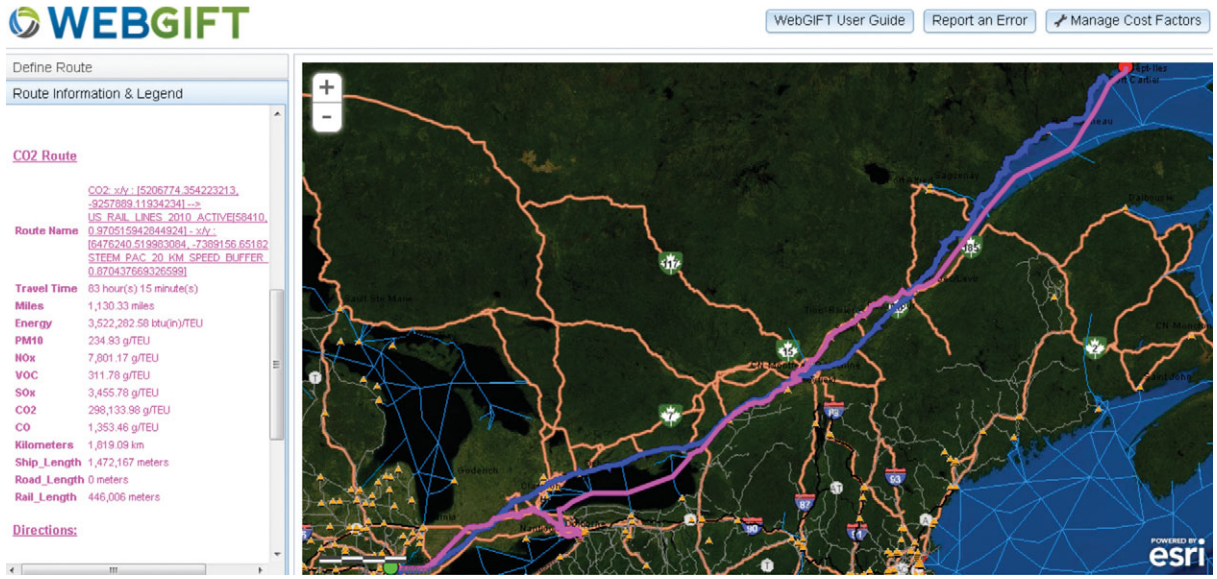

Figure 2. *Results of route analysis defined in Figure 1. The pink route and associated attribute information is the least CO_2 route and the blue route (the attributes are not shown in this screen snapshot) is the least time route. Note that the least CO_2 uses all three modes (with intermodal transfers), but is predominately marine transportation.*

Vehicle	Cost Factor	Value	Units
Truck	CO2	1111.79	gm/TEU-mile
Truck	CO	1.637	gm/TEU-mile
Truck	NOx	6.863	gm/TEU-mile
Truck	PM10	0.1185	gm/TEU-mile
Truck	SOx	0.22169	gm/TEU-mile
Truck	VOC	0.339	gm/TEU-mile
Rail	CO2	143.602	gm/TEU-mile
Rail	CO	0.3947	gm/TEU-mile
Rail	NOx	2.8067	gm/TEU-mile
Rail	PM10	0.0665	gm/TEU-mile
Rail	SOx	0.0319	gm/TEU-mile
Rail	VOC	0.1368	gm/TEU-mile
Ship	CO2	292	gm/TEU-mile
Ship	CO	1.3982	gm/TEU-mile
Ship	NOx	8.0128	gm/TEU-mile
Ship	PM10	0.2458	gm/TEU-mile
Ship	SOx	3.9564	gm/TEU-mile
Ship	VOC	0.3112	gm/TEU-mile

Figure 3. *A view of the tool to modify emissions cost factor rates. The values are for a specific truck, train and ship.*

the results of analysis sessions, we are implementing a user login and public/shared/private repositories of cost factors and analysis results. This will be integrated with parallel capabilities in the Multi-Modal Energy and Emissions Calculator.

In our GLMRI proposal, we had planned for a user testing period, but the period of performance of our grant is now complete. Even so, we will continue to support the use and enhancement of WebGIFT-GL with other funding. We expect WebGIFT-GL to be a useful tool for a broad number and range of freight transportation policy analysts, and we are eager to roll it out for operational use.

Expected outreach. Once we shake the bugs out of the beta release of WebGIFT-GL, we will provide a training video or webcast to train key users on the operation of the system and to solicit feedback on desired changes and improvements. We will also continue to mention Web-GIFT in professional meetings and conferences around the world. In addition, we met with Administrator David Matsuda and members of his staff at the U.S. Department of Transportation Maritime Administration (MARAD) to demonstrate WebGIFT-GL, and he encouraged us to accelerate our schedule to get the functionality out as quickly as possible, in a beta-testable form. We believe we have accomplished this task, and we will work with GLMRI and MARAD to help publicize and disseminate WebGIFT-GL. ■

The Economics of a Bi-State Ferry

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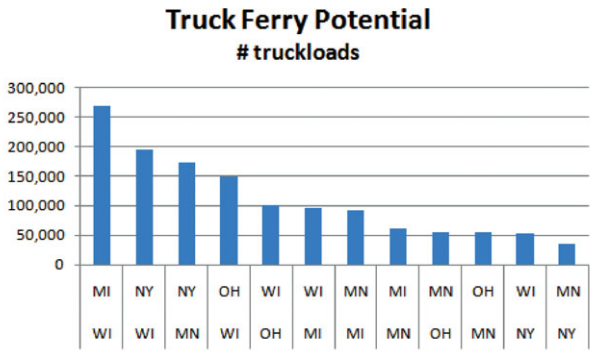


INFRASTRUCTURE IS THE BASIC building block of economic activity, development and growth. An enabling infrastructure is a key to creative, sustained economic growth. In this research project, a natural infrastructure, the Great Lakes, is investigated as a supplement to a congested artificial infrastructure, the Interstate Highway System through the use of a short-sea shipping concept.

The supply chain of the American economy consists of the movement of raw materials, components and finished products across a vast infrastructure that includes ports, railroads and interstate highways. Growth of the global economy over the last few decades resulted in increased intermodal traffic, using trucks and trains to move standardized containers of goods that were offloaded from large ocean vessels. This has led to an increase in the number of trucks on the highways. Trucks, while a necessary and critical component of the economy, create congestion and impose large social and environmental costs to society.

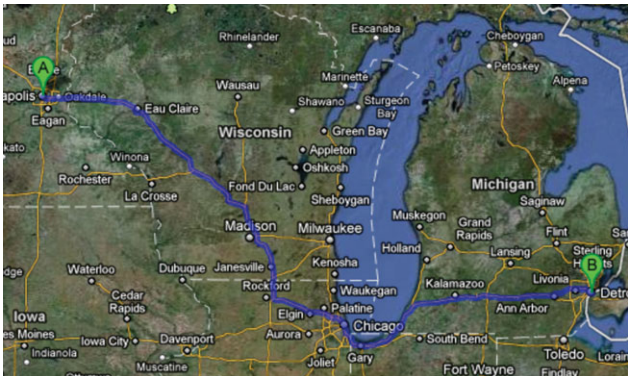
The objective of this project is to investigate the impact a roll-on, roll-off truck ferry across Lake Michigan would have on routes that necessitate travel through the I-90/I-94 Chicago corridor. The ferry operation would be a classic case of short-sea shipping, which is popular in the European Union. Chicago, while being known as the crossroads of America, is suffering from severe traffic congestion. This congestion is causing increased wear and tear on the highways, increased costs to truckers in terms of time and fuel, increased time to commuters and an increase in CO_2 into the atmosphere. A large portion of the truck traffic in the Chicago vicinity is simply passing through, as evidenced in the associated graph. Thus, any bypass method would alleviate congestion and be a potential candidate to use a ferry operation. Throughout the duration of the project, anecdotal evidence from a number of stakeholders continually reinforced the feasibility and need for a ferry operation. This project analyzes the operation of a ferry that goes from Milwaukee, Wisconsin to Muskegon, Michigan in terms of the impact of avoiding the Chicago corridor.

Traffic flow carried out over any mode is subject to a large amount of variability. This variability is compounded by the interdependencies of the infrastructure, weather and other traffic. Thus, any predictive model of traffic flow must be able to accurately depict variability effects and factor them into the type of analysis being carried out. For this project, a computer simulation model of the ferry operation was developed. Computer simulation is the ideal tool for the analysis of dynamic systems. It can provide accurate, long-term estimates of performance metrics of interest. The model is used to generate performance characteristics of time, reliability, cost and fuel usage of transit between select origin/destination points for truck and combined truck/ferry modes.

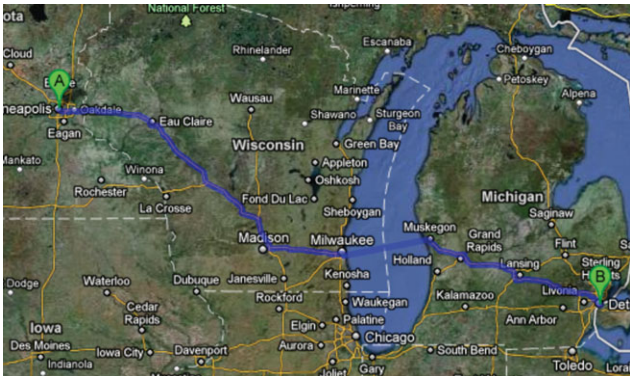
The scope of the project was limited to an area in which a semi truck could potentially traverse within a 12-hour period and required passage through the Chicago corridor. The cities of Minneapolis, Minnesota, Madison, Wisconsin, Milwaukee, Wisconsin, Lansing, Michigan, Toledo, Ohio and Detroit, Michigan were chosen for the study and an analysis of the movement between the combinations of the west and east cities using the ferry operation was performed. The following maps illustrate the routes between Minneapolis and Detroit using the conventional route and the proposed ferry operation.

The process of the ferry operation is a classic roll-on roll-off operation in which an eastbound semi delivers a trailer to the port where it awaits the ferry. The driver and the tractor is not a part of the ferry operation and, in a steady state operation, would pick up a westbound trailer delivered by the ferry. Once the ferry arrives, the trailers would be loaded onto the vessel by a stevedoring or port crew. This process would then be repeated on the other side of the lake.

Map depicting truck route about the Chicago corridor.



Map depicting the bi-state ferry route across Lake Michigan.



The ferry vessel chosen for the analysis of this project is a tug and barge. While this type of vessel is significantly slower and smaller than a dedicated ship, it is significantly cheaper from a capital investment perspective. For the analysis, the number of barges ranged from one to four.

The simulation model was used as the basis to capture and fully represent the operation of trailer movement between the origin and destination cities by traditional truck transport and the combined truck/ferry method. By its nature, simulation modeling technology can capture minute details of any process operation. To accurately compare the performance characteristics of the two systems in terms of cost, reliability, time and fuel usage, a number of cost items for the transport modes were considered and built into the model. These elements are described in the following table:

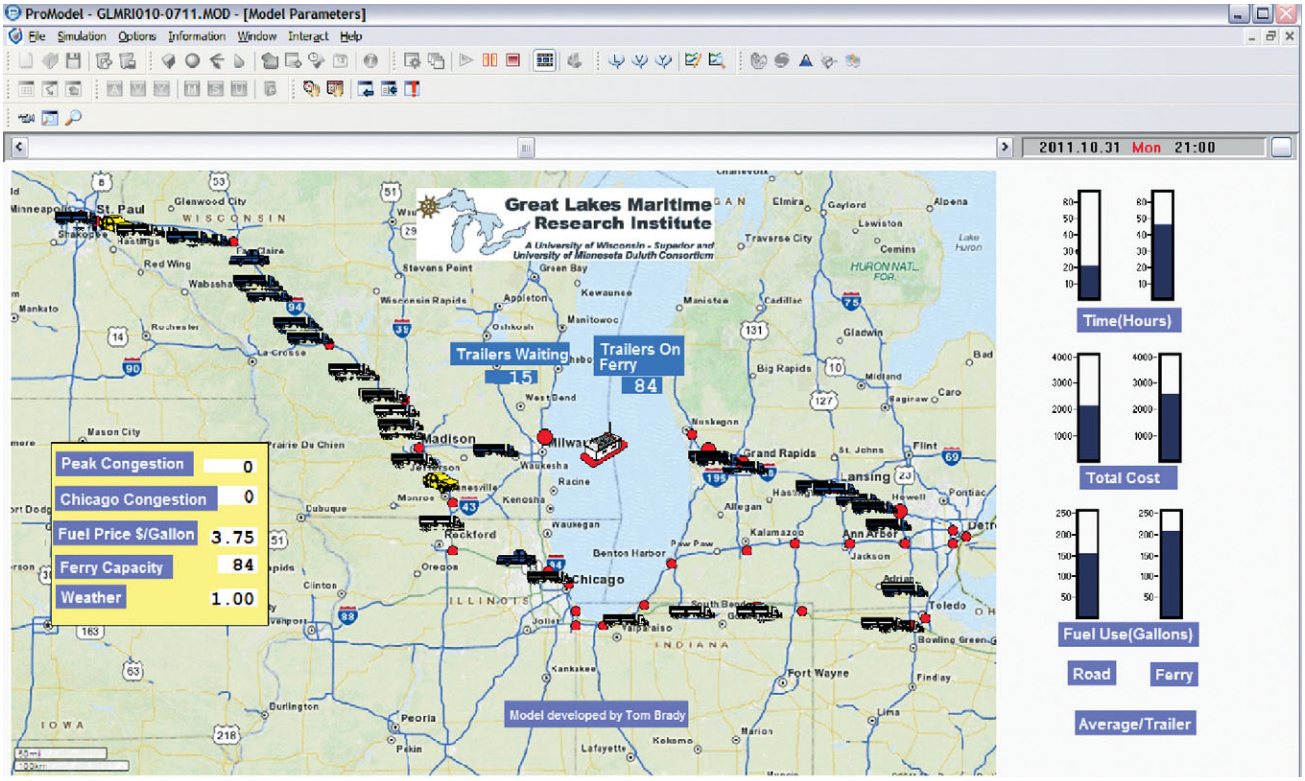
PROCESS STEP	COST ELEMENTS
Truck Travel to/from Origin to Port	MPG
Truck Travel	Driver Style
	Cost of Fuel
	Driver Cost
	Truck Operating/ Maintenance Cost
	Tolls
	DOT regulations
Trailer Moved to Port Storage	Stevedoring Rates
Trailer Waits at Port	Storage
	Insurance
Trailer Loaded/Unloaded on Ferry	Stevedoring Rates
Ferry Movement	Ferry Crew
	Ferry Costs
	Fuel
	Harbor Maintenance Tax

During the conceptualization and development of the model, several issues arose concerning the collection and application of critical cost and operational aspects of the project. These issues included the Harbor Maintenance Tax and the Chicago corridor speeds. The resolution of how to include these elements into the analysis reinforced the methodology and validity of this study and the results obtained. In any system where variability and volume exist, the calculation of long-term performance estimates are dependent on the fidelity of the input data.

The Harbor Maintenance Tax has been a controversial issue since it was enacted. Opponents contend that it will render waterway movements economically unviable while proponents contend that it will fund necessary upkeep and improvements. The tax is set at .125 percent of the value of the cargo. To appropriately include this on a trailer by trailer basis, the model required that each trailer be assigned a cargo value. Using data from the American Trucking Association, it was estimated that the average value of the cargo in a trailer in 2010 was $550,000. Applying the HMT based on these figures would incur a cost of approximately $700 per trailer, putting the ferry cost at a significant disadvantage. However, data from the U.S Army Corps of Engineers estimated that an average HMT of $137 per trailer was realized in 2010. The model used Corps of Engineers figure.

The Chicago corridor portion of route consists of approximately 85 miles. To approximate normal and congested conditions, the INRIX Travel Tax time method was built into the model using figures from the 2010 INRIX report. Subsequent meetings with personnel from the Chicago Metropolitan Agency for Planning (CMAP) revealed that the INRIX figures were significantly underestimating the congestion effects. CMAP provided the study with a very detailed set of hourly speed figures at each milepost of the Chicago corridor highway system. These values were

The simulation model developed as the basis of this project is shown below.

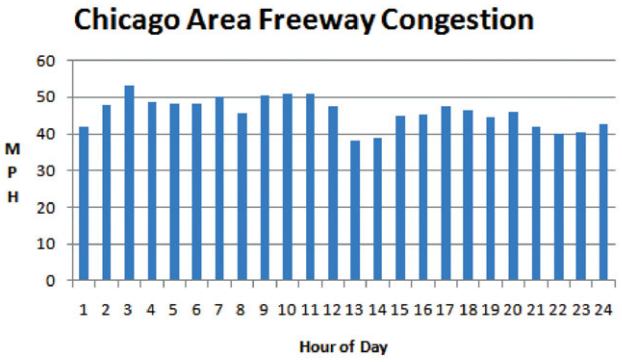


summarized and included into the model. The following graph shows the average speed by hour of the day along the Chicago corridor.

The comparison of the truck versus truck/ferry operation is based upon four performance metrics: transit time, cost, fuel usage and reliability. Each metric is expressed in terms of a single trailer unit. The transit time is the total elapsed time to move a trailer from origin to destination. The cost is the sum of all costs to move a trailer from origin to destination. The fuel usage is the sum of all fuel used to move a trailer from origin to destination. The reliability measure is the standard deviation of the transit time to move a trailer from origin to destination.

For the ferry portion of the route, the total cost of the ferry trip is allocated on an equal basis to the number of trailers that are on board for the particular trip. The model input assumes that the ferry will attain a capacity utilization rate of approximately ninety percent.

The distance across Lake Michigan from the respective ports is approximately 80 miles. For the set of origin and destination cities, the ferry distance represents between 12 and 23 percent of the entire trip. Thus, whichever mode is used, a significant portion of the trip will be made by truck movement. Thus, the project will essentially determine the



breakeven point between the cost of a ferry operation and the cost of travelling through the congested Chicago corridor. Preliminary analysis has shown that the proposed truck ferry using a tug/barge configuration can be cost competitive with conventional trucking over shorter distance routes. Preliminary analysis has also shown that the ferry operation can be a more reliable operation.

The full report is expected to be released by March 2012 and will be posted to the GLMRI web page. ■

Economic Impact of the Great Lakes and St. Lawrence Seaway System (GLSLS): Phase II (continued)

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David Doorn is an Associate Professor of Economics at the University of Minnesota Duluth. He joined UMD after working for two years at the Bureau of Labor Statistics in Kansas City. David received his Ph.D. from North Carolina State University in 2003 with a specialization in econometrics. His teaching interests are in the areas of macroeconomics and econometrics. Dr. Doorn's research activities focus on macroeconomics, applied time series econometrics and economic impact analysis.

THE GOALS OF THIS PROJECT WERE to make use of economic impact analysis to estimate the economic value of the Great Lakes and St. Lawrence Seaway (GLSLS) system for different regions of interest. The study areas were to include individual port communities, the eight states bordering the Great Lakes, the Great Lakes and St. Lawrence Seaway System (GLSLS) region and the nation. The intention was to report impact results in terms useful to a range of stakeholders, including port authorities, government agencies, policymakers and the general public, industry contributions to employment, incomes, value added (contribution to GDP or GSP) and tax revenues. The economic variables of interest in such an analysis include measures of employment, industrial output, incomes, value added (contribution to GDP or GSP) and tax revenues.

Input-output (IO) modeling depends on inter-sectoral linkages across a region's economy. Adding together the direct, indirect and induced effects of an activity provides a measure of the total impact it has on a region's economy. Typical IO models use links between hundreds of industrial sectors. However, for accuracy IO models require underlying data to be representative of the region of analysis. These models also require direct effects as inputs to the model to determine total economic impact.

Due to potential modeling costs and uncertainty as to the efficacy of alternative modeling procedures, it was determined that a pilot attempt of the project, specific to a smaller area, was desirable before purchase of a more complete model for the whole Great Lake's region. As reported previously, the project team had initially chosen the MARAD Port Kit model over the IMPLAN model for this pilot study, but after problems became apparent, it was decided to also attempt the use of IMPLAN. The MARAD Port Kit seemed the best option because it provides a port-specific interface that generates direct effects from data on shipments and inland movements. It also has minimal survey requirements. Despite an ostensibly updated version recently becoming available, the MARAD-funded model was only available on a national basis, making it inappropriate for use in analysis of the GLSLS. To pursue the Great Lakes impact it would be necessary to order a regionally-customized version from the Rutgers University source, which would be quite expensive and potentially beyond the funding scope of this project, leading to the decision to do a pilot study to test the model first.

The selected initial pilot study region was the Twin Ports of Duluth/Superior, to which Green Bay was later added. The version of the MARAD Port Kit purchased for the pilot study contains significant updates from previous releases of the kit that were used for past economic impact analyses. In particular, all underlying regional data was updated to the latest available in the spring of 2010, when the model was obtained.

The MARAD Port Kit requires minimal input data to drive the direct effects. This includes types and amounts of cargo shipments through the ports being assessed, along with information on inland transportation mode. The model also depends on expenditure patterns associated with the maritime industry's handling of the various types of maritime cargo. Ideally these can be updated through surveys of firms in the local port industry in order to make the model more representative of local conditions, otherwise the model defaults to national averages for these expenditures. Unfortunately, these default values were not updated in the current version of the model and represent the national average expenditures associated with port activity in 2000. Significant changes may have occurred in the expenditure patterns of the industry over the ensuing period and this should be kept in mind when considering impact results derived from the model when updated data is not available.

As previously reported, test runs of the Twin Ports version of the model revealed another problem with the MARAD

Table 1: LIMITED SAMPLE IMPLAN RESULTS — Twin Ports 2009 Shipping Season

Impact Type	Output	Employment	Labor Income	Total Value Added
Direct Effect	139,323,904.00	449.8	32,096,960.00	46,717,568.00
Indirect Effect	20,500,352.00	117.3	5,699,376.00	9,230,240.00
Induced Effect	21,758,144.00	203.1	6,873,552.00	12,560,864.00
Total Effect	**$181,582,848.00**	**770.2**	**$44,669,824.00**	**$68,508,672.00**
Multiplier	**1.3**	**1.71**	**1.39**	**1.47**

Port Kit. The impact report based on actual shipments through the Twin Ports gave a large negative value for wages and incomes in the region. This is clearly not correct and indicates a flaw in the model that leads other reported results to be suspect, as well. The developers at Rutgers University were contacted and promised to provide a solution. New model components were eventually received, but once the model was reconfigured with the new components the problem with negative wages had not been fixed, leading to the decision to also make use of the IMPLAN model for the pilot study. (The Green Bay version of the Port Kit did not suffer from the same negative wage and income impacts.)

Surveys were designed and sent out to collect the minimal data required for the MARAD Port Kit, as well as to get data to update and localize the underlying cost components of the model. In addition, the surveys included a request for employment data for potential input as direct effects into IMPLAN. For the Twin Ports the initial survey, including a cover letter from the Port Authority, went out to 24 dock/terminal operators and shipping agents in August 2010. Unfortunately, we received only seven responses and even those had little information included to aid in adjusting the national average cost data. Surveys also went out to 14 Green Bay terminals, from which only five responses came back. With such minimal survey response, even after several rounds of follow-up calls, there was insufficient information to adequately adjust the outdated national cost data.

Even if data collection in this first round been adequate to update the cost data in the Port Kit, the Twin Ports model could not have been used, as the negative wage and income problem had not been overcome. As a result, another survey was developed for additional firms and other port-related organizations to collect employment data for input into the IMPLAN model. With the selection primarily compiled from a list obtained from the Duluth Seaway Port Authority, the survey was sent to 80 firms and other establishments in September 2010. This second survey list also included the 17 non-respondents to the initial survey. With the MARAD Port Kit, the model could have been run with data on shipments gathered from the Port Authority. But, the use of IMPLAN would require a response rate close to 100 percent to generate a valid impact analysis. Unfortunately this did not happen, as only 16 additional responses were received. Follow-up calls were conducted in October and again in February to try to collect 2010 shipping season data, to no avail.

Despite the poor survey response, a trial run of the IMPLAN model was done. The results are given in Table 1. Although the actual impacts from this run are certainly not sufficient in magnitude, as only limited input data from 23 of the 80 establishments surveyed was available, the multipliers from the trial run are in line with what would be expected from such an analysis. This indicates that if sufficient resources were available to successfully complete a survey of all of the firms involved, adequate results are certainly obtainable through use of the IMPLAN model.

As mentioned, minimal requirements for use of the MARAD Port Kit are the data of actual shipments through a particular port. This information can typically be gathered from the Port Authority. This was done for both the Twin Ports and Green Bay. Although the MARAD Port Kit model for the Twin Ports produced problematic results that was not the case for Green Bay. Despite lack of survey results to update the cost basis underlying the model, it could still be run using the outdated national average cost data, as long as that is taken into consideration when reviewing the model outcomes. The Port Kit was run using shipments from the 2010 shipping season and a report was provided to the Port of Green Bay Port Authority laying out the economic impact of that port for 2010. Some highlights from the report follow:

University of Minnesota Duluth Large Lakes Observatory Research Vessel Blue Heron.

Shipments:

- During the 2010 shipping season, the Port of Green Bay handled a total of 1,730,153 metric tons of cargo in all commodity categories compared to 1,810,311 metric tons of cargo in 2009, a decrease of approximately 4.4 percent. This included:
  - 1,674,639 metric tons of dry bulk commodities, including 251,314 metric tons of cement, 587,222 metric tons of coal, 8,856 metric tons of gypsum, 587,222 metric tons of limestone, 50,457 metric tons of petroleum coke, and 189,327 metric tons of salt.
  - 31,453 metric tons of break bulk commodities, including 25,467 metric tons of pig iron, and 5,986 metric tons of stone.
  - 24,061 metric tons of liquid asphalt.

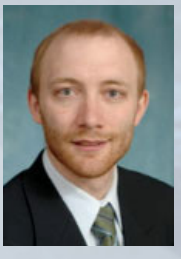
The Port of Green Bay's 2010 Economic Impacts:

- Distribution of Effects
  - The direct effects of the Port's activities accounted for an estimated $58,472,500 in Output; 506 jobs; $18,627,500 in income; and $27,259,600 in Gross State Product.
  - The indirect and induced effects of the Port's activities accounted for an estimated $24,957,800 in output; 317 jobs; $8,033,200 in income; and $13,237,800 in Gross State Product.
- Total Impact
  - In 2010, port activity produced an estimated $83,430,300 in economic output.
  - The MARAD Port Kit estimated that there were 823 jobs directly and indirectly associated with port activities in 2010.
  - Port activities produced an estimated $26,660,700 in income.
  - The Port of Green Bay produced an estimated $40,497,400 in "gross state product," comprised of:
    - An estimated $23.732 million in wages, net of taxes.
    - An estimated total of $5,786,800 in taxes, including $890,600 in local taxes, $802,000 in state taxes, and $4,094,200 in federal taxes.
    - An estimated $10,978,200 in profits, dividends, rents and other.

Conclusions. Despite reasonable results from the Port of Green Bay impact analysis (keeping in mind that they are based on outdated cost data), it is felt that the MARAD model would not be useful to expand to analysis of additional ports. Beyond the prohibitive expense, additional reasons for this include: the cost data is too outdated, contact with MARAD indicates they also have had difficulties with the vendor in obtaining a satisfactory model, future updates of underlying data components are not worthwhile pursuing without adequate funding.

Unfortunately continuation with the use of IMPLAN does not seem feasible without significant increase in funding. Reasons for this include: the survey process was even more intensive than expected for IMPLAN; severe lack of survey response, even with Port Authority involvement; and implementing sufficient survey procedures would be overly expensive. ■

Investigating the Use of Fine Dredged Material in Combination with Biosolids to Reclaim Abandoned Mine Lands



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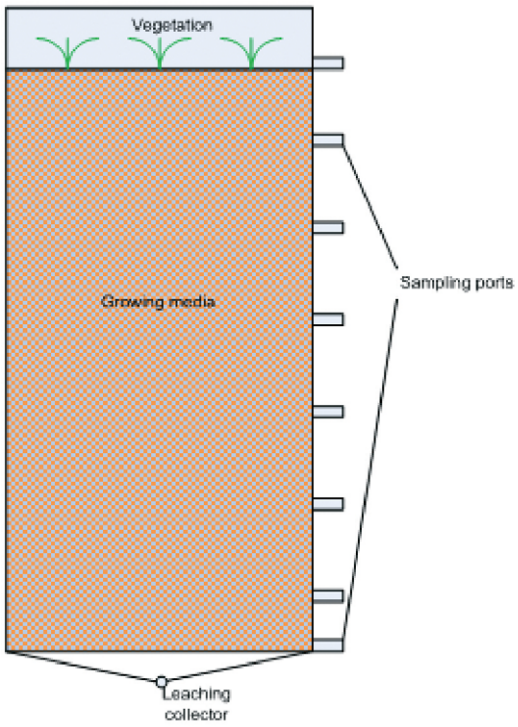
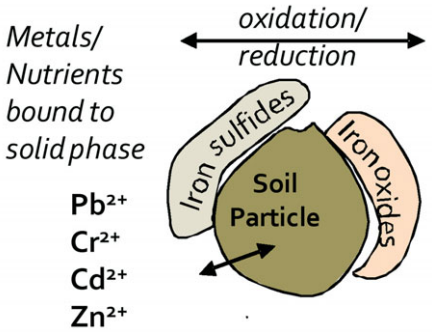
Dr. Nathan Johnson is Assistant Professor in the University of Minnesota Duluth's Department of Civil Engineering. He received his Ph.D. from the University of Texas in 2009 and has been teaching classes and performing research related to engineered solutions to water quality problems since arriving at UMD. He is currently involved in projects related to the environmental impacts of mining and the remediation of contaminated sediments.

ERIE PIER IS THE CONFINED DISPOSAL facility that stores dredged material removed to sustain shipping operations in the Duluth-Superior Harbor in Duluth, Minnesota. Coarse material from Erie Pier is currently being reused; however, the facility is nearing its capacity and the U.S. Army Corps of Engineers (USACE) is investigating several alternative, environmentally-sound beneficial uses for fine-grained material. Biosolids from the Western Lake Superior Sanitary District (WLSSD) are used widely for agricultural applications, but application rates are limited due to concerns about the leaching of nutrients.

The present study seeks to understand the water quality implications of utilizing a mixture of these two materials in mineland reclamation applications. With GLMRI funding, Dr. Johnson is partnering with researchers from the USACE Engineering Research Development Center (ERDC) to measure the release of nutrients and metals from a mixture of fine dredged material and biosolids under conditions likely to be encountered during reuse applications.

During the summer and fall of 2011, material from both facilities was obtained and mixed at ratios ranging between 10 and 50 percent biosolids. In experiments initiated during the fall of 2011 at UMD, Dr. Johnson is investigating the mechanisms of nutrient and metal release under both anaerobic and aerobic conditions using various dredged:biosolids mixture ratios. These well-mixed bench-scale experiments are quantifying metals and nutrients released from the mixtures during a transition from the oxidized conditions prevalent in Erie Pier to reduced conditions likely to be found in some reuse applications. The work will also quantify the changes to predominant binding sites on the soil particles.





At ERDC, the same mix ratios of fine dredged material and biosolids are being used in vegetation experiments to examine the leaching of metals and nutrients under periodic wetting and drying cycles. Samples are being collected periodically and will be analyzed for a suite of metals commonly present in dredged material and for nutrients known to be released from biosolids. Costs and labor for chemical measurements are being split between the two partnering institutions. These separate, but related studies will continue through the winter of 2011-2012 and provide the basis for an application on a field mineland reclamation site in the summer of 2012. ■

Great Lakes Maritime Education for K-12 Teachers & Community

PRINCIPAL INVESTIGATOR
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Joan Chadde is the education program coordinator for the Center for Science and Environmental Outreach at Michigan Technological University in Houghton, Michigan since 1995. Ms. Chadde has more than 25 years of experience in science/natural resources education, water resource management, and program development. She has designed and implemented numerous K-12 science programs and over sixty teacher professional development workshops and summer teacher institutes. She earned an M.S. in Water Resources from the University of Wyoming, BS in Natural Resources from the University of Michigan, and secondary science teaching certification from Michigan Technological University.

Charting Exercise at K-12 Workshop with Capt Rick Brown.

Charting Exercise at K-12 Workshop.

Teachers working with Great Lakes floor map to demonstrate possible classroom shipping lessons.

THE CENTER FOR SCIENCE & Environmental Outreach at Michigan Technological University partnered with GLMRI and the National Center for Freight & Infrastructure Research and Education (CFIRE) at the University of Wisconsin-Madison to conduct two summer teacher institutes: Great Lakes Maritime Transportation in Door County, Wisconsin, June 20-24, 2011 and Teaching Mathematics through Navigation held at Michigan Technological University June 27-July 1, 2011.

Great Lakes Maritime Transportation Workshop

Twenty teachers from Michigan, Wisconsin, Virginia and Ohio explored the historical, economical and environmental aspects of Great Lakes shipping in beautiful Door County, Wisconsin from June 20-24 at the Great Lakes Maritime Transportation Workshop. Participants learned about the challenges of managing the Port of Green Bay from Director Chuck Larscheid, visited the Green Bay NOAA weather station to learn about marine weather forecasting and toured the Sturgeon Bay shipyard. Visits to lighthouses, the Wisconsin and Door County Maritime Museums, a variety of speakers and hands-on maritime activities rounded out the week's schedule.

Captain Rick Brown, an instructor at The Maritime Academy of Toledo, described the diverse job opportunities available in the maritime field. The teachers enjoyed meeting the "coasties" at the U.S. Coast Guard Station in Sturgeon Bay as they shared their passion for ensuring human safety and environmental protection on the Great Lakes. The variety of presenters, from naval architects and

2011 Summer Maritime Education Workshop attendees at the Sturgeon Bay, Wisconsin U.S. Coast Guard Station.

marine engineers to maritime historians and educators, provided a broad view of the many related career opportunities.

This was the sixth Great Lakes Maritime Teachers' Summer Institute held, with past institutes in Duluth, Michigan's Upper Peninsula and Toledo, Ohio. This summer's teacher institutes were funded jointly with grants from the Great Lakes Maritime Research Institute and from the Center for Freight and Infrastructure Research and Education at the University of Wisconsin-Madison.

Teaching Math Through Navigation Teacher Institute

Eleven teachers from Michigan, Maryland and Illinois spent a week at Michigan Technological University (MTU) from June 27-July 1 developing their navigational skills so they could take it back to their students. Now in its second year, the Teaching Math Through Navigation Teacher Institute was taught by mariner and MTU math professor emeritus, Stephen Roblee. Teachers spend the morning in the classroom learning nearshore marine navigation, including finding position, DED reckoning, chart-reading, using a compass and making speed, time and distance calculations. Afternoons were spent aboard the *R/V Agassiz* on the Keweenaw Waterway where classroom learning is put into practice. Students even tried their hand at nighttime navigation.

Teachers earned two graduate credits for completing the coursework for each of the institutes and developing two lessons each. Teachers earned one credit for completing the course requirements of the workshop and developing one lesson. A total of 48 new lessons have been created and are posted online. Teachers attending the two summer institutes estimate that they will teach 1,875 students about navigation and Great Lakes maritime transportation this school year.

In addition to the two week-long institutes, the Center conducted two weekend workshops. Chadde conducted a workshop at the Great Lakes Maritime Historical Shipwreck Museum on November 5-6, 2010 with nine educators participating from Wisconsin and Michigan. Carolyn Rock, a participant of the 2009 Great Lakes Maritime Summer Workshop, led a weekend program at Whitefish Dunes State Park in Door County, Wisconsin.

In addition to the workshops, four of the Maritime Education Chests were distributed for Great Lakes educational programs: Oshkosh, Wisconsin; Wild Rose Fish Hatchery (WI DNR) in Wisconsin; Racine Elementary School, Wisconsin; and Belle Isle Nature Zoo in Detroit, Michigan.

The teacher participants of past institutes continue extending the maritime education. Jay Sinclair, a teacher participant from the 2010 summer institute (Toledo), presented a maritime update at the Michigan Science Teachers Association.

Planning is underway to continue the summer institutes for 2012. Location and dates will be posted. http://wupcenter.mtu.edu/education/great_lakes_maritime/index.htm is regularly updated with lessons and new workshop offerings. This link is available on the GLMRI web page: www.glmri.org. ■

Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

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This study was supported by the U.S. Department of Transportation
Office of the Secretary and the Maritime Administration

Grant Number DTMA1G10001