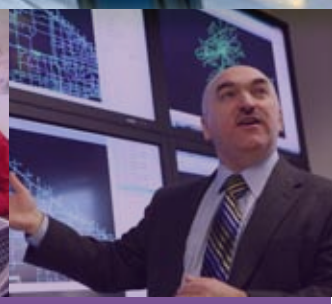
McCormick

Northwestern Engineering



Annual Report 2009

Center for the Commercialization of Innovative Transportation Technologies

CCITT

The Transportation Center at Northwestern University

Welcome

Welcome to the Center for the Commercialization of Innovative Transportation Technology (CCITT) 2009 Annual Report.

The **theme of the Center** is to foster the commercialization or implementation of innovative technologies for multiple modes of surface transportation including, but not limited to, railways, mass transit, highways, and waterways.

To achieve this vision, CCITT awards funding to Northwestern faculty to conduct later-stage "innovation gap" research projects that reduce technical risk barriers that stand in the way of technology adoption. CCITT seeks proposals that clearly identify the problem or pain in the transportation sector, the users of the potential solution, and the path to get the solution into their hands.

In 2009, the Center funded four new projects from a diverse set of academic departments, which impact several modes of transportation. Inside this annual report, you will learn more about these projects and others recently completed. You will meet the wide array of faculty and students involved in research, education, and technology transfer.

I invite you to learn more about CCITT, operated by the Transportation Center within the McCormick School of Engineering and Applied Science at Northwestern University.

Yours truly,

Bret Johnson
Director

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Management Structure

In 2009, CCITT's organizational home moved from Northwestern University's Office for Research to the McCormick School of Engineering and Applied Science (MEAS). As shown on the organization chart on the following page, CCITT now operates within MEAS as a component of the Transportation Center (TC) at Northwestern University. As part of this move, CCITT Center Director Breton "Bret" Johnson also assumed the role of Associate Director of the TC and reports to the TC's Director, Dr. Hani Mahmassani. Director Johnson joined the University in 2000 as a member of a technology commercialization program that provided consulting services to Northwestern faculty and local technology businesses.

Director Johnson is responsible for the day-to-day operations of CCITT including:

- Oversight of the research selection process consistent with the Center's strategic plan;
- Developing and managing the Center's annual budget;
- Consulting with the principal investigators on technology transfer (commercialization) strategy;
- Leading an educational internship program; and
- Collaborating with university departments, research centers and institutes, transportation agencies, and industry partners.

From January through August 2008, Bronwen Murray served as a temporary Project Coordinator managing all aspects of marketing and communications for the Center. Murray is a graduate of the Integrated Marketing Communication Program at the Medill School of Journalism at Northwestern.

CCITT obtained research administration and operations support from several sources on campus before, during, and after the transition. At the Office of Research, CCITT received assistance from Mary Tobin, Director of Administration and Resource Planning; Damien Trimuel, Business Coordinator; and Aaron Rosen, Business Coordinator. In its new home in the TC, CCITT received significant support from Diana Marek, Assistant Director; Rebecca Weaver-Gill, Research Coordinator; and Jennifer Crosby, Financial Analyst.

Advisors

David Boyce
Professor
Civil Engineering
Northwestern University

Jeff Coney
Director
Economic Development
Northwestern University

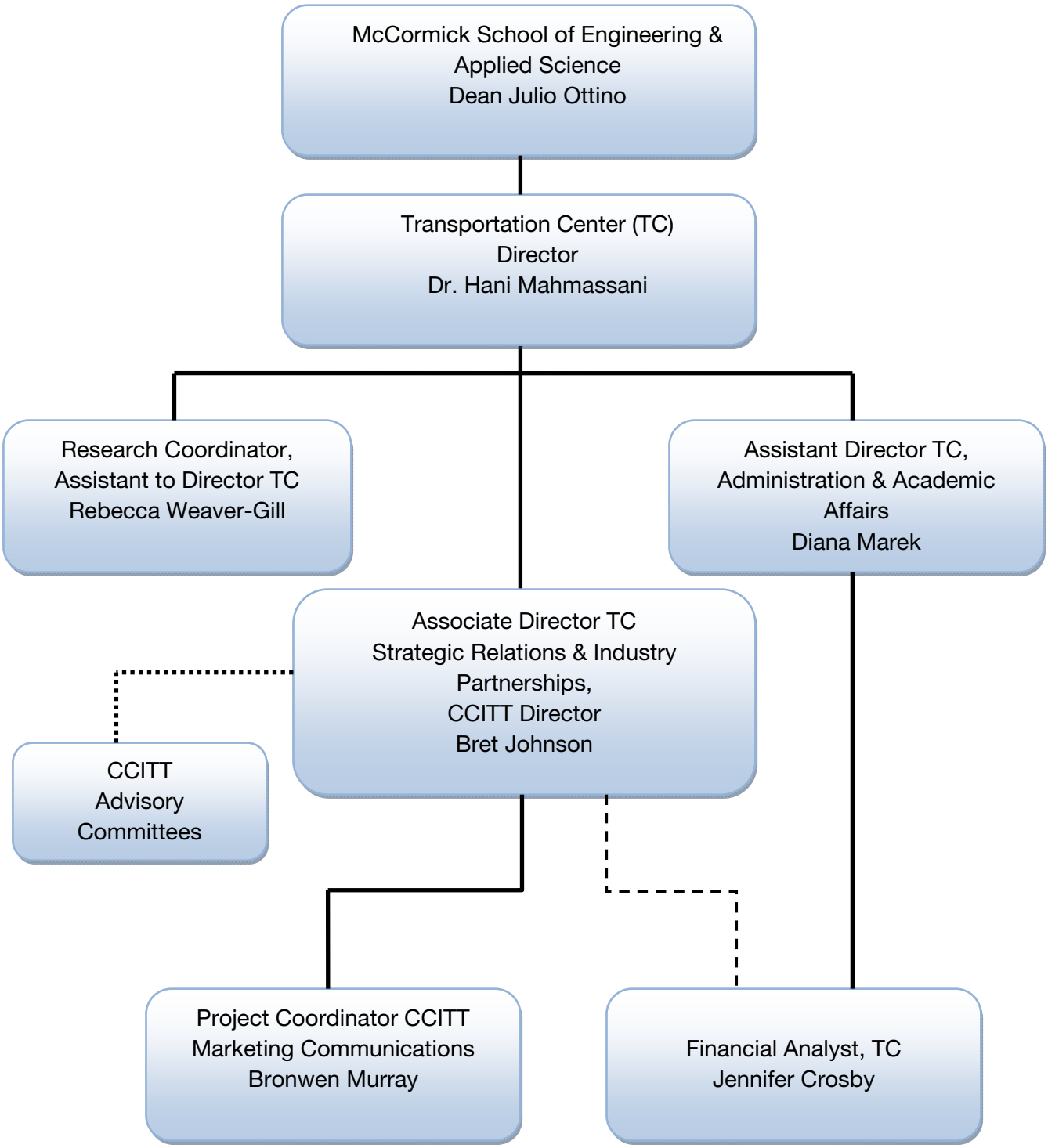
Thomas Ewing
Senior Scientist
Associate Division Director
Nuclear Engineering
Argonne National Laboratory

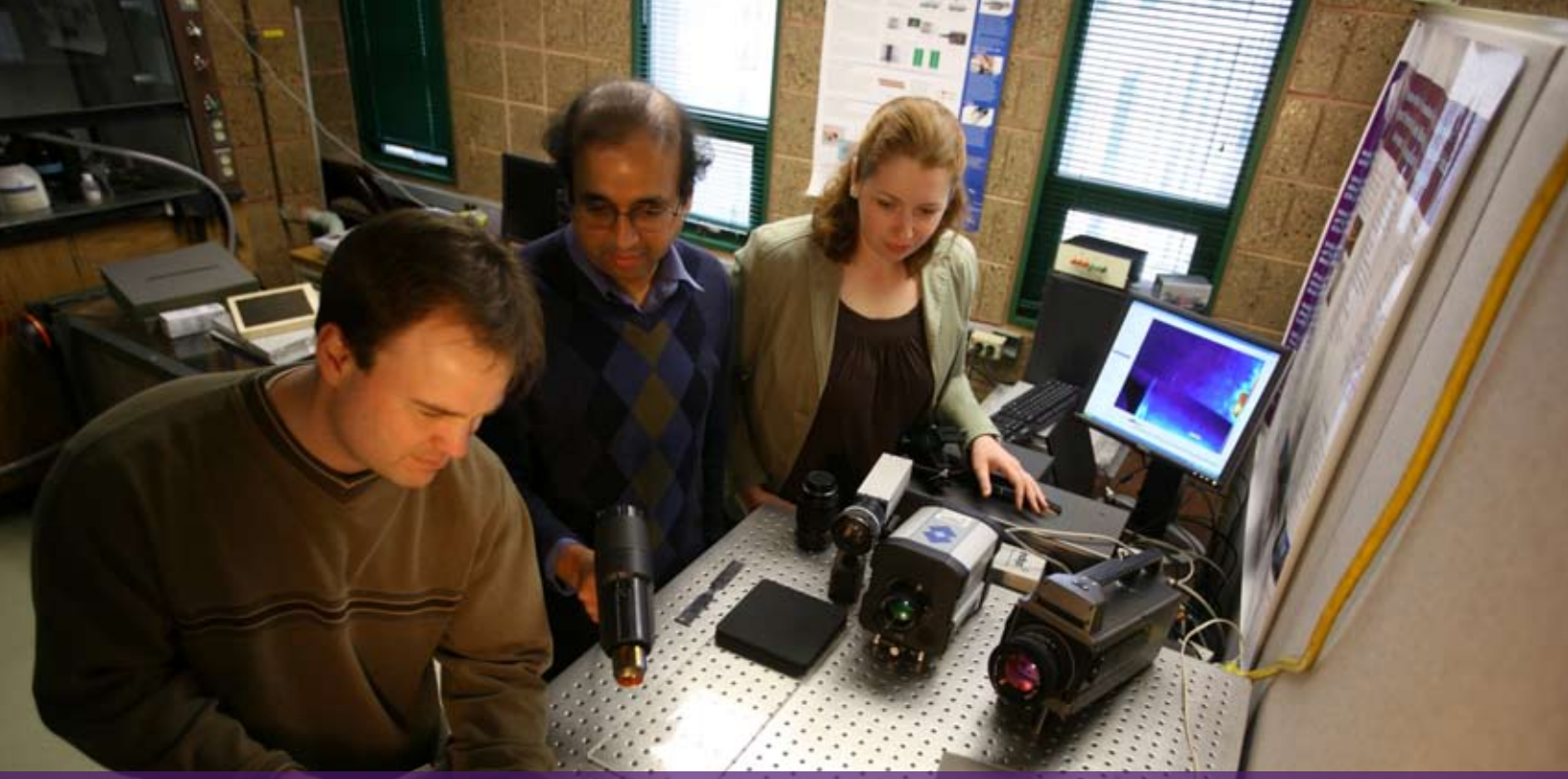
Aaron Gellman
Professor
Transportation Center
Northwestern University

Michael A. Marasco
Director
Clinical Associate Professor
Center for Entrepreneurship and Innovation
Northwestern University

Michael J. Shiffer
Vice President for Planning
Translink - South Coast British Columbia
Transportation Authority

CCITT Organization Chart





Faculty

Oluwaseyi Balogun
Assistant Professor
Mechanical Engineering &
Civil Engineering

Yip-Wah Chung
Professor
Materials Science and
Engineering

Morris Fine
Professor Emeritus in
Service
Materials Science and
Engineering

Aggelos Katsaggelos
Professor
Electrical and Computer
Engineering

Sridhar Krishnaswamy
Professor
Mechanical Engineering

Yu Nie
Assistant Professor
Civil Engineering

Sotirios Tsaftaris
Research Professor
Electrical and
Computer Engineering

Semyon Vaynman
Research Professor
Materials Science
and Engineering

Diego Klabjan
Associate Professor
Industrial Engineering &
Management Science

Ying Wu
Associate Professor
Electrical Engineering
and Computer Science

Post-Doctoral Research Fellows

Seokcheol Chang
McCormick School of Engineering & Applied Science
Industrial Engineering and Management Science

Brad Regez
McCormick School of Engineering & Applied Science
Center for Quality Engineering & Failure Prevention

Dengfeng Yang
McCormick School of Engineering & Applied Science
Industrial Engineering and Management Science

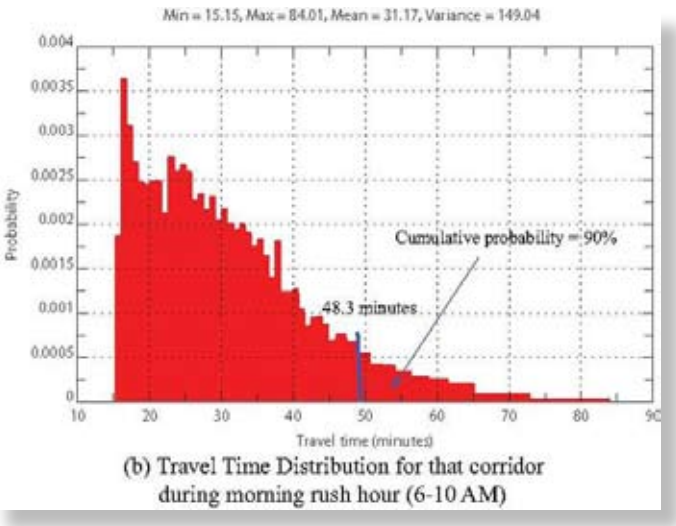
Education

In 2009, CCITT hosted three undergraduate students as part of its marketing research internship program. The program has two primary goals:

- Expose a diverse base of students to the field of transportation research, operations, and business
- Produce market and industry research, product development plans, and commercialization strategies for the benefit of faculty and the potential adopters of CCITT research outcomes

Route Guidance Project – Part 2

In Summer 2009, CCITT Market Research Intern Caitlyn Carpenter further developed industry analysis research completed by fellow intern Kelila Venson in Fall 2008 and Winter 2009. Carpenter conducted market research interviews with nine shippers, carriers, and logistics firms, all of which are members of the Northwestern Transportation Center Business Advisory Committee. In her research, she gained insight from the firms about the perceived value of predictive travel time information for scheduling and delivery optimization. Several companies expressed interest and asked to learn more, including requesting access to a demonstration of a prototype travel time prediction software tool. Carpenter summarized her interviews and key findings for Professor Yu Nie in a final report delivered to CCITT. Her report prioritized companies for follow-up discussions and recommended additional companies, particularly last mile haulers, for further primary research. In completing her project, Carpenter verified the interest in predictive travel time estimation for a variety of applications.



(b) Travel Time Distribution for that corridor during morning rush hour (6-10 AM)

Illustration of travel time variance from Nie's "Chicago Testbed for Reliable Routing" software application

Gang Scheduling

CCITT Market Research Intern Carlos Calegari developed a product development plan for Professor Diego Klabjan's Gang Scheduling project during Summer and Fall 2009. Calegari's plan included market research, market size estimates, customer targets, industry and competitor analysis, product feature analysis, and product marketing suggestions. Calegari also provided go-to-market recommendations and strategies for product adoption. He also spent substantial time learning about the extensive railroad network in the United States, including the Class 1, 2, and 3 railroad operators. Calegari conducted both primary research phone interviews and secondary research using Northwestern's extensive library and other online trade publications. Beyond this, he reached out to a local software entrepreneur and, through the process of several conversations, learned sophisticated real-world tactics for launching new software products into the marketplace. At the culmination of his internship and in addition to his final report, Calegari gave a presentation and answered questions about his findings.

Carlos Calegari
Senior, Industrial Engineering and Management Science

Educational Events and Outreach

CCITT provides opportunities for students and faculty to learn about technology commercialization and industry trends and problems. In 2009, CCITT launched the "Transportation Technology Commercialization Speaker Series" and helped develop programming for "The Greening of Transportation," an educational workshop for Transportation Center Business Advisory Committee members and a diverse group of students interested in sustainable transportation issues. Both events are described in further detail below.

Technology Commercialization Speaker Series

The Transportation Technology Commercialization Speaker Series" inaugural speaker was Mil Ovan, Co-Founder and Senior Vice President of Firefly Energy Inc., a battery technology spin-out company of Caterpillar.

The intent of the speaker series is to host a wide variety of business leaders, entrepreneurs, and technology transfer managers, among others. Topics include insights into licensing a technology, starting a business, financing product and company creation, creating value through consulting engagements, and integrating a new product or technology from the perspective of a public or private sector user.

As stated by Mr. Ovan, "technology commercialization is not a straight path." Based on this understanding, CCITT created the speaker series to educate faculty, students, and industry adopters about the challenges, pitfalls, and roadblocks of technology transfer and commercialization.

Greening of Transportation Workshop

In addition to his role as CCITT Director, Johnson serves a second role as Associate Director of the Transportation Center (TC) at Northwestern University. Johnson collaborated with Industrial Engineering and Management Science Professor Diego Klabjan to organize an informational workshop of speakers called "The Greening of Transportation." The workshop was held at the TC's Fall 2009 Business Advisory Committee meeting.

Leaders from CSX Corporation, Philips Corporation, Schneider National, and UOP discussed challenges and opportunities related to the reduction of carbon footprints in operations and supply chains. The leaders also presented information on the uses and sources of alternative energy and fuels. The half-day event, co-sponsored by the Initiative for Sustainability at Northwestern (ISEN), attracted over 50 business leaders and students and generated several ideas for further research.

Student of the Year

CCITT selected Joseph Zissman as its 2009 Student of the Year. Zissman, born and raised in Newton, Massachusetts, is a member of the Class of 2011 at Northwestern University majoring in Civil Engineering, to which he hopes to add a minor in Political Science.

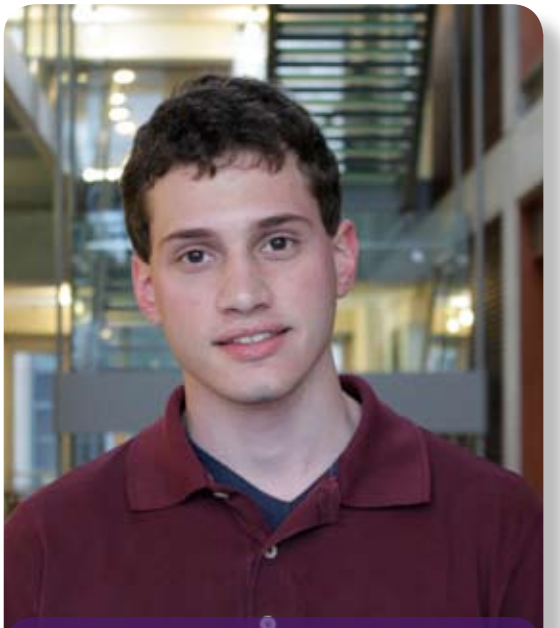
First Place:	**Runner up:**
Joseph Zissman	Matthew Christner
Civil Engineering	Mechanical Engineering

In Summer 2009, Zissman worked at the Chicago Transit Authority (CTA) headquarters for eleven weeks on a research project under the direction of Professor Yu Nie in the Department of Civil and Environmental Engineering. During his time at the CTA headquarters, Zissman worked as a research liaison between the CTA Technology Department and Professor Nie's lab. He helped Professor Nie, his graduate student researchers, and a CTA project manager in an effort to extract time and location information from a database of bus automatic vehicle locator (AVL) sensor readings.

Zissman's specific role at CTA was to work with CTA technical staff to optimize the software used to convert raw bus time and location reports to speeds on known street segments. Professor Nie's lab continues to use

this information to develop travel congestion forecasts for Chicago arterial streets. Zissman made noteworthy contributions to the project by learning Oracle database management software, writing software code in Oracle API, and dealing with the complex interface between Oracle SPATIAL datasets and ESRI's Arc GIS software package. At the end of the project, his CTA mentor was so impressed with Zissman's work that he commented to Professor Nie that Joe "did not know how good he is."

The Student of the Year is selected based on the technical merits of his or her research, academic performance, professionalism, and leadership. Eligible candidates must be nominated by Northwestern faculty members and participate in and receive financial support from a CCITT-funded research project for at least one quarter prior to receiving the award. Eligible candidates must also have grades of B or better in at least 12 hours of course work and a minimum 3.25 cumulative grade point average.



Joseph Zissman
Junior, Civil Engineering

Student Contributions

Undergraduate Research Students

Matthew Christner
McCormick School of Engineering & Applied Science
Mechanical Engineering

Joseph Zissman
McCormick School of Engineering & Applied Science
Civil Engineering

Undergraduate Marketing Interns

Carlos Calegari
McCormick School of Engineering & Applied Science
Industrial Engineering & Management Science

Caitlyn Carpenter
Weinberg School of Arts & Sciences
Political Science

Kelila Venson
Weinberg School of Arts & Sciences
Spanish

Graduate Research Assistants

S. Derin Babacan
McCormick School of Engineering & Applied Science
Electrical and Computer Engineering

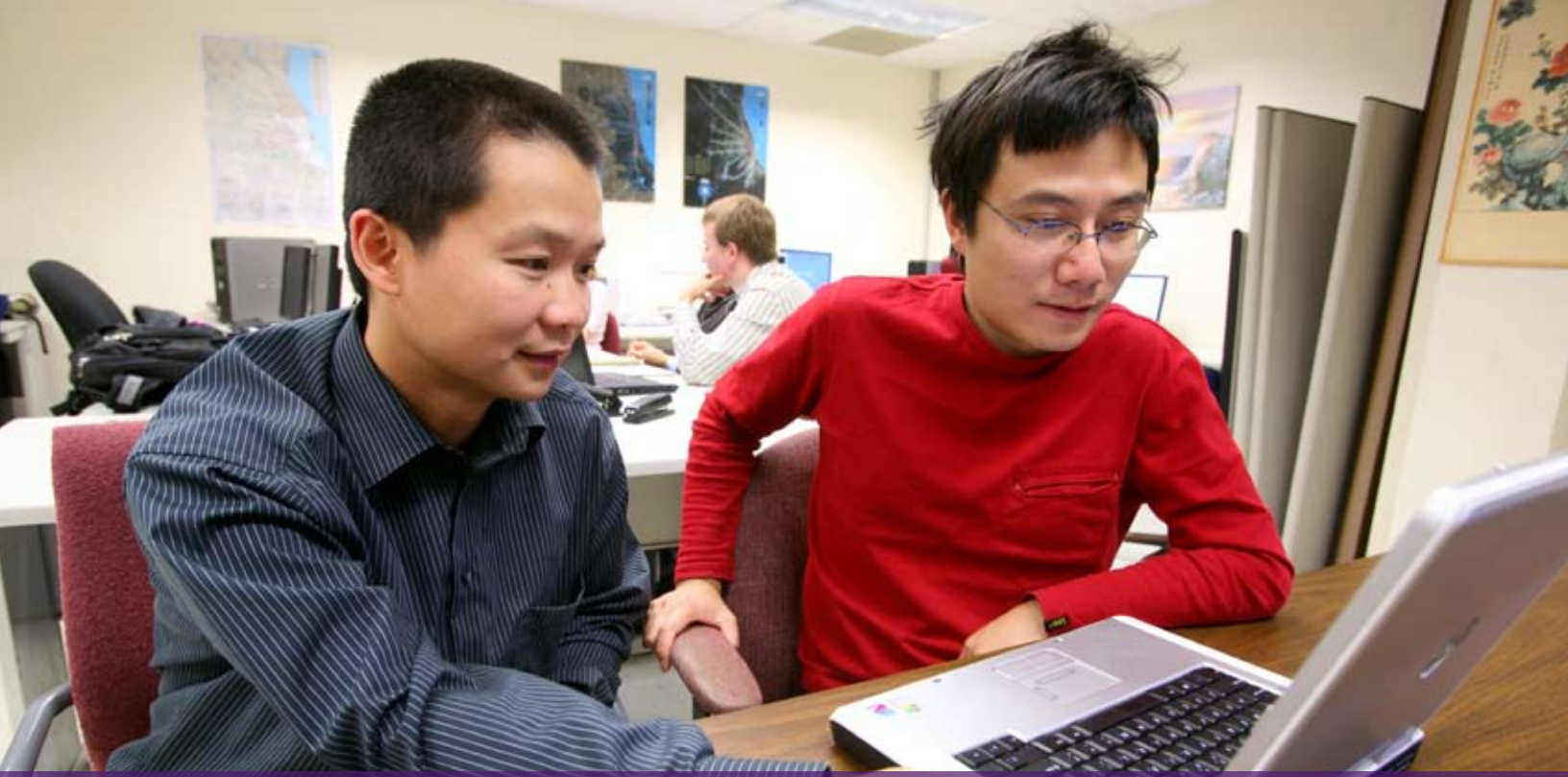
Fan Jiang
McCormick School of Engineering & Applied Science
Electrical and Computer Engineering

Eren Soyak
McCormick School of Engineering & Applied Science
Electrical and Computer Engineering

Xing Wu
McCormick School of Engineering & Applied Science
Civil Engineering

Mujing Ye
McCormick School of Engineering & Applied Science
Industrial Engineering and Management Science

Yan-Jin Zhu
McCormick School of Engineering & Applied Science
Mechanical Engineering



Research

In 2009, CCITT funded four new "innovation gap" research projects. In the interdisciplinary nature of CCITT's program, the transportation research projects originated from four different departments in the McCormick School of Engineering and Applied Science: Civil Engineering, Electrical and Computer Engineering, Industrial Engineering and Management Science, and Mechanical Engineering. The total amount of research support, including cost match, is projected to exceed $550,000. CCITT expects these projects to result in measurable technology transfer, knowledge transfer, or product implementation outcomes within 36 months of the kick-off dates.

Providing Reliable Route Guidance - Part 2

Principal Investigator
Yu Nie
Assistant Professor
Civil Engineering

Problem
Travel time estimation tools for personal travelers, shippers, and others provide average times without consideration of variability or reliability

Intended Impact
Provide the ability to predict reliable future and real-time travel times in an urban area

Proposed Solution
As a demonstration project, use newly developed routing algorithms and archived traffic data to create a travel reliability inventory of Northeastern Illinois and develop a web-based prototype

In the past decade, a proliferation of traffic and travel time information has been made available to highway users, including personal travelers, shippers, carriers, and public safety organizations. Information is available from TV and radio broadcasts, Internet mapping applications, car navigation systems, and handheld navigation devices.

The overall goal of this project is to enhance travel reliability of highway users by providing them with reliable route guidance produced from newly developed routing algorithms which are validated and implemented with real traffic data. Industry players in the traffic information market include NavTeq, Google, INRIX, and Westwood One. The next iteration of travel time information will provide enhanced predictive capabilities, including the consideration of travel time variance, and reliability.

During Part I of the project (also funded by CCITT in 2008), Nie focused on demonstrating the value of reliable route guidance through the development of a Windows-based software prototype, the Chicago Testbed for Reliable Routing (CTR). In Part II, Nie is enhancing the travel network model by including data for arterial streets and implementing more efficient reliable-routing algorithms. During 2009, Nie collaborated with the Chicago Transit Authority to generate travel time information for arterial streets from bus automatic vehicle locator (AVL) data. A primary objective of Part II is to create a travel reliability inventory (TRI) of Northeastern Illinois.

Nie's TRI will archive travel reliability indices (e.g., 95 percentile route travel times) between noteworthy origin and destination pairs in the region of interest to personal travelers, regional transportation planners, and traffic management operations. Also, an Internet version of CTR will be developed and made available for evaluation by individuals, agencies, and private companies. CTR will be hosted at Nie's NU-TREND (Transportation - Reliability - Equilibrium - Network – Dynamics) Web site, hosted by the Northwestern University Civil Engineering Department. The Windows-based software from Part I is currently available for download on the NU-TREND Web site, http://translab.civil.northwestern.edu/Nutrend/homepage.aspx.

Business Intelligence for Gang Scheduling

Principal Investigator
Diego Klabjan
Associate Professor
Industrial Engineering and Management Science

Problem
Inefficient scheduling of rail maintenance workers creates unnecessary expenses

Intended Impact
Increase the labor efficiency and reduce costs of rail companies

Proposed Solution
Develop a software system based on business intelligence and state-of-the-art analytics to streamline maintenance scheduling

Railway tracks wear down and need to be constantly maintained. Groups of maintenance workers, called gangs, are responsible for such maintenance tasks. Throughout a year, gang works for a few days on a particular track section and then relocates to another section.

Railways incur significant expenses related to gangs. They range from the direct costs such as salary and travel allowance to indirect costs consisting primarily of the impact to operational disruptions. It is thus of vital importance to railways to schedule the gangs as efficiently as possible.

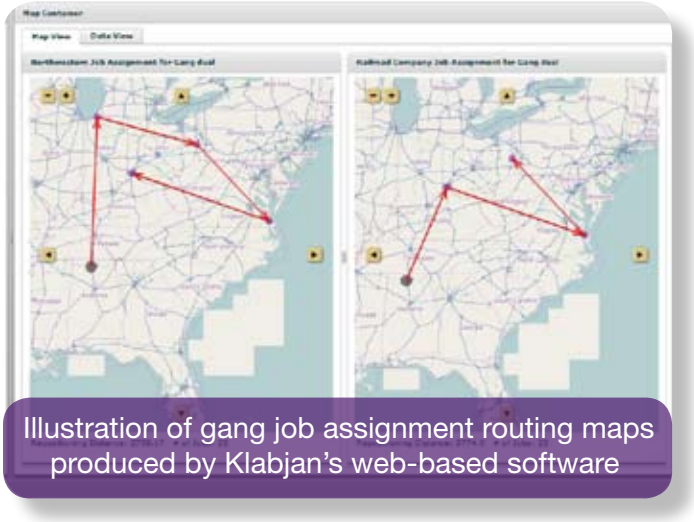


Illustration of gang job assignment routing maps produced by Klabjan's web-based software

To help solve this problem, Professor Klabjan is developing a gang scheduling information system based on business intelligence and state-of-the-art analytics. The core of the system is a sophisticated optimization algorithm. The algorithm initially constructs a schedule and then iteratively refines the schedule based on innovative mathematical programming techniques combined with large neighborhood local search strategies. The optimization module is connected with a database on the back-end. The front-end is a web-based interface allowing the user to visually compare various solutions by displaying on a geographical map all maintenance jobs together with the flow of gangs.

For the majority of railroads, the development of a gang schedule is a tedious and labor intensive process. An information system will substantially reduce scheduling time, including back-and-forth manual attempts to match budgets with gang schedules. Klabjan's algorithms produce superior solutions in terms of the overall cost, train schedule interferences, and business requirements. The resulting labor efficiencies and cost reductions will also minimize the possibility of cancelled projects due to lack of funds. Safety will also be enhanced because more projects will be completed each year. After rolling out the system to Klabjan's development collaborator, the delivery of the software to other railways will be evaluated.

Intelligent Structural Health Monitoring of Vehicular Bridges

Principal Investigator
Sridhar Krishnaswamy
Professor
Mechanical Engineering

Co-Principal Investigator
Oluwaseyi Balogun
Assistant Professor
Mechanical Engineering, Civil and Environmental Engineering

Problem
Piezoelectric sensors used for structural health monitoring of bridges and other infrastructure have inherent performance and cost limitations

Intended Impact
Improve the integrity of structural health monitoring by implementing more accurate, more reliable, and more cost-effective sensor technologies, thus enhancing safety

Proposed Solution
Develop, deploy, and test optical Fiber Bragg Grating (FBG) sensors for structural health monitoring of infrastructure

After the catastrophic I-35W bridge collapse in 2007, engineers have been pursuing alternative inspection techniques to better monitor civil infrastructure for structural health. One current technique involves using piezoelectric (PZT) sensors to "listen" to the acoustic emissions (AE) of a structure. This technique helps monitor problems like crack propagations or structural fatigue. However, PZT sensors are susceptible to electromagnetic interference, have limited operating frequencies, are vulnerable to signal loss over long cable runs, and lose measurement sensitivity over time requiring frequent calibration (and therefore additional labor and costs). Also, the deployment of each PZT sensor requires a preamplifier which further drives up costs.

As an alternative to PZT sensors, Krishnaswamy and Balogun are developing a rugged spectral demodulation system for optical readout of distributed FBG sensor arrays that can be used as a tool for AE monitoring of large infrastructure. FBG sensors are inexpensive, readily available, light-weight, immune to electromagnetic noise sources, and do not require pre-amplification. Using the spectral demodulation with FBG sensors, it is possible to replace the bulky PZT sensors and cables with fiber optics that take up less space and are less susceptible to signal degradation. Moreover, the fiber optics can be permanently mounted to civil infrastructure.

In 2009, the research team developed a laboratory breadboard prototype of the FBG monitoring system. During 2010, the team will work with the Infrastructure Technology Institute at Northwestern to install the system on a bridge structure in the Chicago area and compare its performance in parallel with a PZT installation. Several optic sensor manufacturers and system integrators have already expressed interest in the FBG system and could be natural partners for commercialization.

iTRAC: Intelligent Compression of Traffic Video

Principal Investigator
Sotirios Tsaftaris
Research Professor
Electrical and Computer Engineering

Co- Principal Investigator
Aggelos Katsaggelos
Professor
Electrical and Computer Engineering

Problem
Widespread adoption of video surveillance for intelligent traffic monitoring and object tracking is limited by installation (labor) and infrastructure (high bandwidth, power) costs

Intended Impact
Enable the wide-scale deployment of video-based traffic monitoring applications for traffic management and public safety

Proposed Solution
Apply a combination of existing and newly developed software-tracking algorithms to compressed video data (H.264) to achieve more accurate tracking results using up to 50% less video transmission bandwidth

Professors Tsaftaris, frequent collaborator Ying Wu, and Katsaggelos (left-right)

Non-intrusive video imaging sensors are commonly used for traffic surveillance. Traffic analysis applications require high-quality video information that is generally achieved with wired (e.g., fiber optic cable) networks. However, the widespread deployment of wired networks for intelligent traffic monitoring and analysis is constrained by the vast cost of installation and infrastructure requirements.

A solution to this roadblock is the use of wireless communication networks, but these generally provide lower video bandwidth, and thus lower video quality. With wireless communications, video compression techniques, such as the newly proposed H.264 standard, are required to pump the video at high enough frame rates (bit rates) for useful application. In turn, video compression can severely compromise the ability to perform traffic monitoring and tracking tasks.

Because of this, Tsaftaris and Katsaggelos are developing iTRAC, an intelligent algorithmic software module to be used in conjunction with the H.264 video compression encoding standard. In general, software tracking algorithms use video histograms to compare one video frame to the next. However, compression techniques can severely distort the histograms, and therefore the ability to track objects. Unlike existing applications, the research team will employ kurtotic video segmentation techniques on the compressed video information to distinguish moving objects (e.g., cars) from stationary objects (e.g., trees). In partnership with Ingenient Technologies, a provider of embedded multimedia software solutions, iTRAC will then be integrated into the logic of hardware video compression encoders for commercial applications, including traffic monitoring.

Technology Transfer

CCITT's goal is to move research to realization for all modes of surface transportation. Thus, CCITT's overarching focus is technology transfer and technology commercialization.

During 2009, three research projects were completed. The outcomes are highlighted below. Full reports are available on the CCITT Web site, http://www.ccitt.northwestern.edu.

Cryogenic Super-Tough Steel for Bridges and other Applications

Principal Investigator
Semyon Vaynman
Research Professor
Materials Science and Engineering

The aim of this project was to develop steel with higher fracture toughness (less brittle) at lower temperatures than existing steels by introducing titanium. ASTM A710 Grade B, a steel previously developed at Northwestern University for bridge and other infrastructure applications, was successfully used in the construction of a bridge in Lake Villa, Illinois. This A710 Grade B steel is produced by hot-rolling and air-cooling (i.e., without costly quench and temper or thermo-mechanically-controlled processing), can be easily welded without pre-heating or post-heating, is very corrosion-resistant, and possesses very good fracture toughness at low temperatures (approximately 100 ft-lbs at -40°F; the A709 Bridge Steel Standard requires 30 ft-lbs at -30°F).

Experiments by Dr. Vaynman in the 1990s involving 710 steel showed that adding 0.1% titanium not only improved the steel's welding properties, but also provided exceptional fracture toughness. After evaluating A710 Grade B steel samples with 0.03%, 0.07%, and 0.1% titanium in the current project, the research team partnered with Union Tank Car Company and Sophisticated Alloys, Inc. to produce and test 300 pounds of steel with 0.11% titanium. The fracture toughness of the new steel exceeded the limits of the testing equipment, 700 ft-lbs at all temperatures down to -60°F.

Based on these results, the research team envisions uses for infrastructure applications like bridges and tank cars that transport cryogenic liquids such as liquid chlorine or compressed natural gas. Finally, assuming the steel outperforms other steels in further tests, Union Tank Car Company has expressed an interest in using the A710 Grade B steel with 0.1% to 0.11% titanium to build experimental tank cars for field testing.

Providing Reliable Route Guidance Using Chicago Data

Principal Investigator
Yu Nie
Professor
Civil Engineering

This project culminated in the creation of an innovative software tool, Chicago Travel Reliability (CTR). CTR provides an integrated environment to visualize and analyze traffic data, construct and display travel reliability measures for the Chicago highway network, and recommend reliable routes for travelers. At the core of CTR is a reliable shortest path (RASP) routing algorithm that has been tested using archived Chicago area traffic data. Reliable routing, as defined by this project, is measured by the probability of arriving at a destination on time or earlier (e.g., 95% probability). For motorists who travel during rush hours and seek high reliability, results show that reliable route guidance could reduce travel time by 10%-30% compared to conventional routing solutions. The study also verified the capability of existing algorithms to solve large-scale reliable routing problems within a practical amount of time. CTR can be reviewed and downloaded from Professor Nie's lab Web site, NU-TREND, which can be found at http://translab.civil.northwestern.edu/Nutrend/homepage.aspx.

Video Traffic Analysis for Abnormal Event Detection

Principal Investigator
Aggelos Katsaggelos
Professor
Electrical and Computer Engineering

As a result of CCITT funding, the research team developed a dynamic hierarchical clustering (DHC) method for the detection and classification of abnormal events from surveillance video. The DHC method's primary use will be to mitigate traffic congestion. The team also investigated anomalous motion in the context of multiple moving objects and neighborhood motion. Preliminary results demonstrate the ability of the new data-mining tracking techniques to detect point, sequential, and co-occurrence anomalies in traffic video.

The primary advantage of this approach is that it does not require prior knowledge about the nature of normal or unusual events. The benefit of anomalous trajectory detection is its application to the detection of traffic rule violations, accidents, and other direct causes of traffic disruption (e.g., traffic slowing, traffic congestion).

Publications

Wu, X.; Y. Nie (2009) Implementation Issues in Approximate Algorithms for Reliable A Priori Shortest Path Problem. Journal of the Transportation Research Board, 2091, pp. 51-60.

Nie, Y.; Wu, X. (2009) Reliable A Priori Shortest Path Problem with Limited Spatial and Temporal Dependencies In Proceedings of the 18th International Symposium on Transportation and Traffic Theory, Chapter 9, pp. 169-196.

Presentations

Fine, M.; S. Vaynman; D. Isheim; Y. W. Chung (2009) A Paradigm for Designing Strong Ductile Alloys with High Peierls Stress: Low Carbon BCC Steels. Presented at David Seidman Symposium, TMS San Francisco.

Nie, Y.; X. Wu; P. Nelson (2009) Implementation Issues in Approximate Algorithms for Reliable A Priori Shortest Path Problem. Presented at the 88th Annual Meeting of the Transportation Research Board.

Nie, Y.; X. Wu; P. Nelson; J. Dillenburg (2009) Reliable Route Guidance: A Case Study from Chicago.

Nie, Y.; X. Wu; T. Homem-de-Mello (2009) A Diversity Maximization Algorithm for Optimal Path Problems with Stochastic Dominance Constraints. Presented at INFORMS Annual Meeting 2009.

Vaynman, S.; Y-W. Chung; M. Fine; R. Asfahani (2009) Effect of Ti on Charpy Fracture Energy and Other Mechanical Properties of ASTM A 710 Grade B Cu-Precipitation-Strengthened Steel. Presented at the Materials Science & Technology 2009 Conference (MS&T'09), Pittsburgh, PA.

Reports

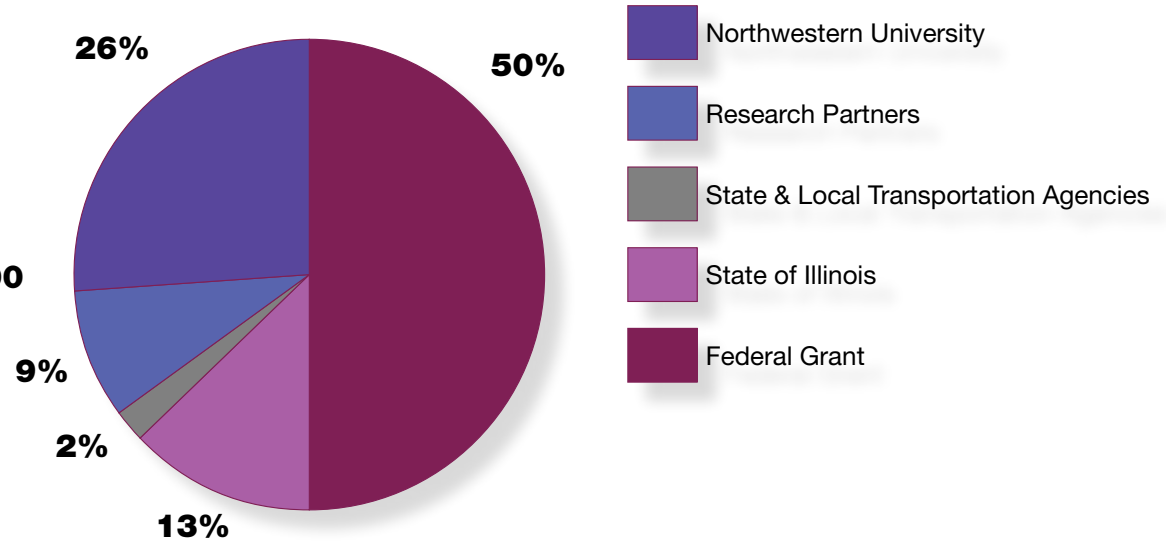
Nie, Y.; X. Wu; P. Nelson; J. Dillenburg (2009) Providing Reliable Route Guidance Using Chicago Data. Technical Report 2009-001. Center for the Commercialization of Innovative Transportation Technology.

Vaynman, S.; M. Fine; Y-W. Chung (2009) Super-Tough Steel for Bridges and Other Applications. Final Technical Report Y1-02. Center for the Commercialization of Innovative Transportation Technology.

Funding

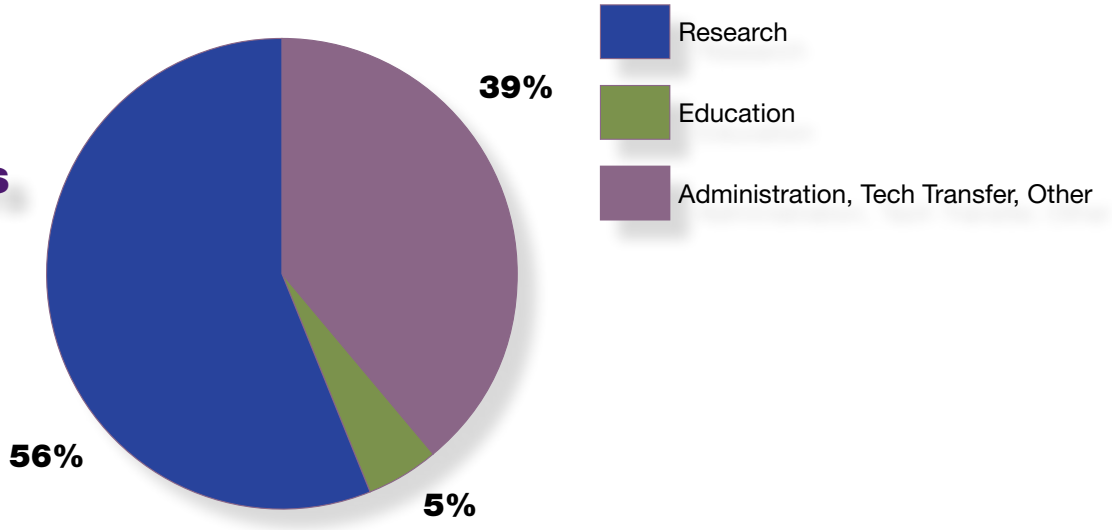
Funding Sources

Total: $2,590,600



Expenditures

Total: $1,168,000



Note - The totals presented are cumulative totals from Years 1, 2, and 3.

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Center for the Commercialization of Innovative Transportation Technologies

CCITT is a USDOT-funded university transportation center operated within the Transportation Center in the Robert R. McCormick School of Engineering and Applied Science at Northwestern University.

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UNIVERSITY