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(Cover Photo: Wikimedia Commons: https://commons.wikimedia.org/wiki/File:Amboy_bnsf_grade_crossing.jpg)

BOOK REVIEW

A Message from the JTRF Co-General Editors

The Summer 2015 issue contains the usual wide variety of contemporary transportation topics that is the distinguishing characteristic of *JTRF*. Topics in this issue include the following:

- Sustainability in marine terminals
- Highway interchange lighting prioritization
- Severity of vehicle crashes at highway-rail grade crossings
- Effect of compressed work week on transportation network performance
- Traffic demand models for mid-size networks
- Severity of pedestrian crashes at highway-rail grade crossings
- Effects of increased shuttle train movements on rail pricing in the Northern Plains

In “Sustaining Sustainability in Marine Terminals: A Strategic Framework,” Neha Mittal and co-authors examine “green” initiatives of top-five global marine terminal operators using a core competency framework. The authors classify the initiatives as technology centric, process centric, and relationship centric and develop strategies to implement the initiatives. They found that technological initiatives are easy to adopt and yield quicker impacts in reducing emissions. On the other hand, process centric and relationship centric initiatives are more difficult to deploy and take longer to yield benefits, but are difficult for competitors to imitate.

Srinivas Pulugurtha and Ravishankar Narayanan compare their interchange lighting prioritization called the “Total Design Process” to traditional methods in “Weights from a Safety Perspective for Interchange Lighting Prioritization.” The authors gathered data from 80 interchanges along nine road segments in North Carolina in both rural and urban areas to identify new factors, and to compare results obtained from current and updated lighting priority index tools. The authors found that considering the number of nighttime crashes by severity, instead of night-to-day crash ratios, for prioritization of lighting system installation or maintenance, would reduce the bias toward interchanges with fewer crashes.

In “Analyzing Severity of Vehicle Crashes at Highway-Rail Grade Crossings: Multinomial Logit Modeling,” Wei Fan and co-authors use a nominal response multinomial logit model to identify important factors in injury severity differences of vehicle crashes. They also explore the impact of these factors on three severity levels of vehicle-related crashes at highway-rail grade crossings (HRGCs). The authors found that when rail equipment with high speed strikes a vehicle, the chance of a fatality increased. They also found that pickup trucks and concrete and rubber surfaces were more likely to be involved in more severe crashes. However, truck-trailer vehicles, snow and foggy weather, development area types (i.e., residential, commercial) and higher traffic volumes were more likely to be involved in less severe crashes.

Venkata Duddu and Srinivas Pulugurtha evaluate and assess the effect of a compressed work week strategy on transportation network performance in “Assessing the Effect of Compressed Work Week Strategy on Transportation Network Performance Measures.” The network performance measures include link-level traffic speed, travel time, and volume to capacity ratio using data from Charlotte, North Carolina. They found that reducing 15% to 20% of the traffic during the morning peak hours using a compressed work week would increase travel speeds by up to 5 mph on at least 64% of center-lane miles. They also found that a compressed work week would decrease the travel time by up to two minutes on at least 61% of center lane miles.

In “What Matters Most in Transportation Demand Model Specifications: A Comparison of Outputs in a Mid-size Network,” Donna Chen, Kara Kockelman, and Yong Zhao examine the impact of travel demand modeling (TDM) disaggregation techniques for mid-size communities. Specific TDM improvement strategies are evaluated for predictive power and flexibility with case studies based on the Tyler, Texas, network. The authors found that adding time of day disaggregation, particularly in conjunction with multiclass assignment to a basic TDM framework, has the most significant impacts on outputs. Other strategies that had an impact on outputs include adding a logit mode choice model and incorporating a congestion feedback loop.

Aemal Khattak and Li-Wei Tung quantify the impacts of various factors on three different severity levels of pedestrian injuries in crashes at highway-rail grade crossings in “Severity of Pedestrian Crashes at Highway-Rail Grade Crossings.” The authors employed an ordered probit model estimated with maximum likelihood with crash seventy as the dependent variable. The severity levels of pedestrian injuries were classified as no injury, injury, and fatality. The explanatory variables were grouped in five categories, including pedestrian characteristics, crash characteristics, crossing characteristics, train characteristics, and environment. The authors found that pedestrian fatalities were associated with higher train speeds and with female pedestrians. Crossings with more highway lanes and those with standard flashing light signals were associated with lower likelihood of pedestrian fatalities.

In “Hard Red Spring Wheat Marketing: Effects of Increased Shuttle Train Movements on Railroad Pricing in the Northern Great Plains,” Elvis Ndembe examines the impact of shuttle trains on hard red spring wheat transport from North Dakota. The author specified a model of railroad pricing estimated with OLS. The explanatory variables include the following:

- Length of haul
- Distance to a barge loading location
- Number of railcars in the shipment
- Weight per railcar
- Time trend
- Seasonal dummy variables
- Shuttle train shipment dummy variable
- Origin region dummy variables

With one exception, all the explanatory variables have the theoretically expected sign and are statistically significant. The author found that intermodal competition and shuttle trains played a significant role in rail rate reduction in North Dakota during the 1999-2012 period.

Michael W. Babcock
Co-General Editor, JTRF

James Nolan
Co-General Editor, JTRF

Sustaining Sustainability in Marine Terminals: A Strategic Framework

by Neha Mittal, Alok Baveja, and Ramji Krishnan

Sustainability initiatives in maritime industry, despite their global need and relevance, are often riddled with strategic and implementation issues. Here we examine "green" initiatives of top-five global marine terminal operators. We classify their initiatives as technology-centric, process-centric and relationship-centric, *and develop a core-competency-driven framework for these initiatives. Our findings indicate that technological initiatives are easy to adopt and yield quicker impact in reducing emissions and increasing ROI. On the other hand, process-centric and relationship-centric initiatives are more difficult to deploy, take longer to yield benefits, but are difficult to imitate. We argue that terminal operators should recognize the value of long-term initiatives that are difficult to replicate, to build competency.*

INTRODUCTION

Over the last 20 years, maritime transportation and port terminals have seen a significant increase in container volumes. Despite recent economic uncertainties and trade fluctuations, world container traffic has more than tripled in volume between 1995 and 2009 (Bureau of Transportation Statistics 2011). This massive and continuous growth in global trade has increased environmental concerns of transportation. Since almost all movement of goods requires burning of high-carbon-fossil fuels, it results in an increased concentration of gases like carbon-dioxide, methane, nitrous oxide, and hydrofluorocarbons. These atmospheric-polluting gases prevent heat from escaping, somewhat like the glass panels of a greenhouse, and result in significant climatic changes/ abnormality (Environmental Education Outreach Program 2007).

According to the International Transport Forum (2010), the transport-sector alone accounts for nearly one-quarter (24%) of all greenhouse gas (GHG) emissions in the world. International standards (European Commission 2014) mandate emissions to be cut by at least half of the 1990 levels by 2050. In 1990, maritime transportation accounted for 7% of the world's transport-related CO_2 emissions; in 2000, the industry was responsible for nearly one billion tons of emissions each year, translating to 15% of the overall transport emissions (Michaelowa and Krause 2000). Contrary to the target, numbers are likely to more than double by 2050, if no immediate and sustained action is taken (Michaelowa and Krause 2000). Indeed, this is the primary motivating factor for this paper and we focus singularly on providing rigorous strategies for long-term sustenance of sustainability in the maritime industry.

SUSTAINING SUSTAINABILITY STRATEGICALLY

Sustaining sustainability or long-term survival of a sustainability system, by definition, requires a strategic viewpoint and analysis. Areas where quantitative data are readily available and analytical models have been *proven* to yield results in strategic decision-making, quantitative methodology may yield the best solution. However, situations where (largely) non-numerical, context-driven data, called qualitative data, are available and the situation is complex/multi-layered, are better suited for deploying qualitative tools. A qualitative strategic framework can often adeptly handle complex issues and help decipher patterns, resulting in insights that can be easily understood and used by decision makers.

In our past work (Boile et al. 2008), we proposed a strategic system of Inland-Depots-for-Empty-Containers (IDEC) to support sustainable regional repositioning of empty containers. This work utilized mathematical models for a holistic framework that incorporated environmental, economic, and societal objectives yielding sustainable solutions. The idea was to utilize restored/cleaned land originally contaminated due to industrial use, called Brownfield sites, for proposed inland depots that are closer to customer clusters in the region. Deterministic (Boile et al. 2008), stochastic (Mittal et al. 2012), and multi-criteria decision models (Mittal et al. 2013) were developed and tested with case-study data from the New York/New Jersey port region.

In this paper, for the context of *green initiatives* where qualitative data are more readily available, we consider the traditional, qualitative strategic management concept of core competency. The focus is on sustainability practices undertaken by terminal operators, inside their facilities. Instead of considering regional initiatives, attention is provided to individual "green" initiatives adopted by terminal operators. A framework to develop competitive advantage, through the proper adoption of sustainability initiatives, is provided. Keeping in mind the triple bottom line approach (profit, people, and planet) (Slaper and Hall 2011), energy and emission reduction practices are analyzed and then structured into a broader strategic framework. We expect practicing managers at marine terminals, maritime stakeholders, and companies involved in strategizing sustainability initiatives to gain insights from this qualitative framework. Before we delve into the framework, we discuss some of the past relevant work.

LITERATURE REVIEW

According to Climate KIC (Climate KIC 2014), most of the emissions in ports are generated at container terminals. Due to the cranes' fluctuating demand and supply for energy, abnormalities or faults (i.e., temporary or momentary abnormalities or faults that quickly disappear when power is disconnected and restored in a short duration of time) are common, which makes its power management difficult and complex. Due to smog produced from crane operation, diesel exhaust emissions from ships, railroads, trucks, and other cargo handling equipment at the terminal, an increased level of air pollutants are found in and around the ports.

In the last decade, considerable attention has been given to the issue of climate change and global warming. There is an increasing pressure in the transportation industry to devise and implement environment-friendly strategies for global freight movement. A myriad of approaches have been developed through research-driven studies, technological advances, and innovative activities to limit energy consumption and carbon emission in maritime transportation.

Environmental impact of freight shipping on our lives as well as our planet is studied by Bailey and Solomon (2004). Their study on mitigation strategies suggested a range from low cost methods (such as, restriction on truck idling) to systems requiring more significant investments (such as, cold ironing and alternative fuels). Cold ironing is another name for providing shore-side electrical power to ships. This requires installation of an expensive electrical grid/sub-station at the terminal and cable-laying. The advantage of cold ironing is that it reduces the consumption of fuel for vessels while in port, and eliminates the associated air and noise pollution. In a similar effort, Eyring (2010) assessed the contribution of gaseous and particulate emissions from oceangoing ships to anthropogenic emissions (i.e., emissions resulting from human activities, which includes burning of fossil fuels for energy, deforestation, and land-use changes that result in net increase in emissions) and air quality.

Michaelowa and Krause (2000) studied trends in international maritime transport and provided policies/measures to reduce emissions in a cost-efficient way. Psaraftis and Kontovas (2010) illustrated three ways to reduce maritime greenhouse-gas (GHG) emissions: (a) technical methods such as adoption of efficient ship hulls, energy-saving engines, more efficient propulsion, alternative fuels, cold ironing in ports, and sails to reduce power requirements; (b) market-based instruments such as emissions trading and carbon levy schemes; and (c) operational strategies like speed optimization, optimized routing, improved fleet planning, and other logistics-based measures. Morais and Lord (2006), in their review of programs and strategies at North American ports, found that automation technologies, extended gate hours, and reservation appointment systems can be effective in reducing the overall truck idling time at terminals and limiting GHG emissions associated with terminal drayage activities. However, contrary to this study, another study (Giuliano and O'Brien 2007) that evaluated the outcomes of the legislation permitting terminals to adopt either gate appointments or off-peak operating hours as a means of reducing truck queues at gates, found no evidence of reduced queuing or transaction times.

A Canadian study emphasized implementing Internet-based cargo information systems (advanced freight scheduling appointment and container tracking) to improve terminal productivity and reduce congestion/pollution inside the terminals (Transport Canada 2006). A study by Lun (2011) found that container terminal operators can improve their throughput and profitability and have an efficient and cost-effective operation if they adopt green management practices (GMP). It suggested that GMP consists of: (1) cooperation with supply chain partners, (2) environmentally friendly operations, and (3) internal management support. Sisson (2012) described the concept of "zero emission" terminals and gave three basic rules for reducing gas emissions: 1) do everything possible with electric power, 2) generate as much renewable power on site as possible, and 3) make the terminal as efficient as possible.

The study by Rijsenbrij and Wieschemann (2011) emphasized the fact that the future will bring increasing demand for sustainable designs in port handling facilities. Terminal operators looking for cost reductions may look into the design of terminal (stack) handling systems. It presented a design approach and directives for stacking systems and connected transportation systems in container terminals. Leonardi and Browne (2010) calculated the carbon footprint of more than 25 international maritime supply chains and identified main shipping characteristics. They found that by changing vessel type and its routing, a 20% reduction in energy use can be achieved. Network analysis models to explore tradeoffs among alternative route selection across different modal combinations and to identify optimal routes for minimizing carbon emissions are presented (Winebrake et al. 2008). In an interesting study, the high service speed of ships was found as a significant reason behind increased air pollution (Kontovas and Psaraftis 2011). To further reduce energy use and maritime emissions, a study recommended constructing compact terminals to transfer stacks directly at the quayside and replacing diesel-powered terminal equipment by a hybrid or all-electric energy source (Geerlings and Duin 2011).

In summary, various studies have examined the impact of maritime shipping on society and the environment and have proposed different ways for mitigating its negative environmental effects - whether it is by ship re-routing or redesigning, modification of terminal layouts, improvement in vessels' operational characteristics, or assessment of terminal-equipment's emission reduction strategies.

At the local/government level, zoning is one of the widely used methods to control the physical development of land. Countries such as the United States and Canada have requested the International Maritime Organization (IMO) to designate their coastal regions as areas where oceangoing ships would face strict controls on emissions of sulfur, particulate matter like soot, and other pollutants that endanger human health. According to the new rules in California, roughly 2,000 oceangoing vessels that enter California ports each year must switch to fuel with lower sulfur content before coming within 24 nautical miles of the state's coast (Los Angeles Times 2009). Similarly, European Union legislation established a set of rules that target reducing sulphur oxide emissions from maritime transport (Miola et al. 2011).

On the private initiatives and innovations stance for greener maritime transportation, there has been tremendous growth. Companies around the world are developing new ways to lower fuel consumption and air pollution. In one example, SkySails, a German company, has put large towing kites on oceangoing vessels to take advantage of ocean winds thereby reducing the fuel requirement and its associated pollution. Experiments show that towing kites can help reduce emissions by up to 35% annually (Environmental Leader 2010). Figure 1(A) shows the system components of SkySails, which primarily consists of a large Flexifoil kite, an electronic control system, and an automatic system for the kite's retraction.

From wind to harnessing solar power, a Japan-based company, Eco Marine Power, is developing a way to use both solar and wind energy for powering tankers, cargo ships, and other seafaring vessels (Eco Marine Power 2014). It uses solar panels as rigid sails [shown in Figure 1(B)] that harness the energy from renewable sources to propel the ship. This innovation has been shown to reduce the amount of fuel consumption and emission of harmful gases. Use of solar power for powering boats is also under development and enhancement by a German company named PlanetSolar (PlanetSolar.org). In May 2012, PlanetSolar became the first ever solar electric vehicle to circumnavigate the globe. Figure 1(C) shows the solar-powered boat, which is covered by 537square miles of solar panels that connect to one of the two electric motors in each hull. In a separate effort, solar power to transport large volumes of liquid has been developed by Australian company, Solarsailor, in its vessel called "Aquatanker" (SolarSailor.com). Figure 1(D) shows the Aquatanker with its 30-meter long sails, decked in photovoltaic panels, controlled automatically by a computer to angle the sails for maximum wind and solar efficiency. They are found to catch enough wind to reduce fuel costs by as much as 20% to 40% (SolarSailor.com).

In a completely new and innovative way of propelling ships, a Japanese sailor and environmentalist developed and sailed a wave-powered catamaran. His journey to date is the longest known voyage by a manned wave-powered boat (WavePropulsion.com). Figure 1(E) shows the system components of a wave-powered catamaran. Its propulsion is generated by two horizontal fins mounted beneath the bow of the ship. Incoming waves cause these fins to move up and down, producing dolphin-like kicks of thrust, which drives the ship forward.

Ireland-based B9 Shipping Company is working toward designing the world's first 100% fossil fuel-free cargo sailing ships. Figure 1(F) shows the futuristic wind powered cargo ship that employs a Dyna-rig sail propulsion system combined with an off-the-shelf Rolls-Royce engine powered by liquid bio-methane derived from municipal waste (B9 Shipping 2012). While these approaches are yet to be tested for actual freight transportation, yet they do indicate promising, sustainability-driven future trends in the maritime industry.

In many study initiatives and innovations described above, green initiatives are largely looked at in light of compliance and their accompanying tactical benefits. Sustainability is seldom seen as a competitive differentiator and is built as part of terminal operator's business strategy. In this paper, using established core competency framework, we provide a mechanism for coalescing sustainability initiatives of terminal operators in both short-term gains and long-term advantage. Past academic work has researched different techniques to reduce emissions but none has looked at it from a strategic viewpoint for building competency. To the best of the authors' knowledge, no other study or model has been proposed that builds a long-term competency for terminal operators by utilizing a combination of green/sustainable initiatives.

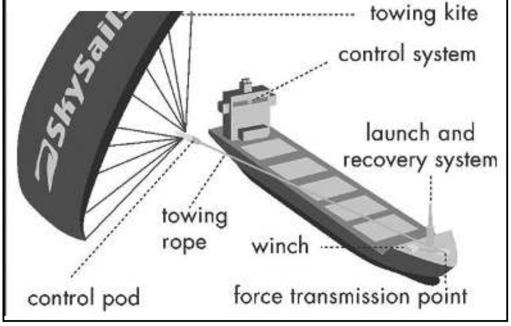
Core competency is defined next.

CORE COMPETENCY

C. K. Prahalad and Gary Hamel (Prahalad and Hamel 1990) defined core competency as a central practice of combining a company's resources and skills to distinguish them from others in the market. It is said that even though a core competency can take various forms, it must fulfill three key criteria: (1) be difficult for competitors to imitate, (2) can be adopted across functional units/markets, and (3) provide value to the customer.

Figure 1: Green Innovations in Maritime

A) Skysails

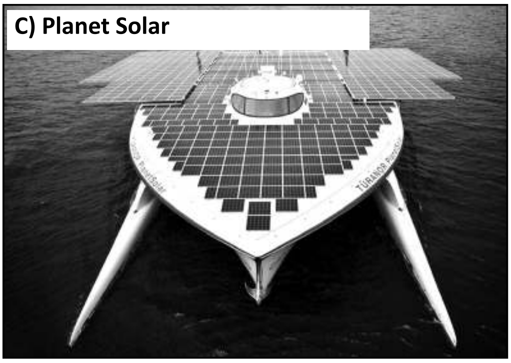


http://www.vos.noaa.gov/MWL/apr_09/skysails.shtml

B) EcoMarine Power

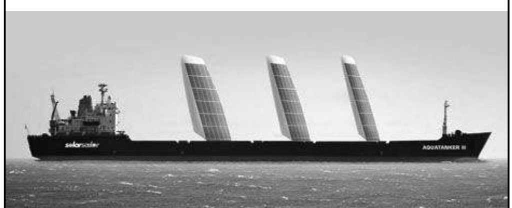
http://www.eeweb.com/blog/greg-atkinson

C) Planet Solar



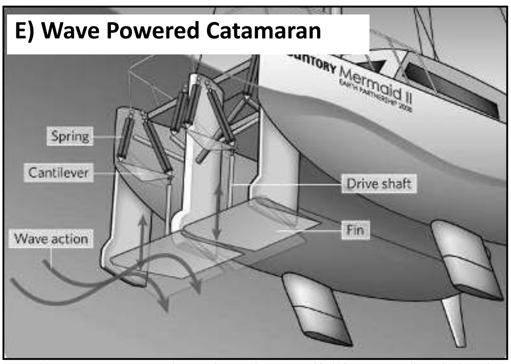
http://www.arch2o.com/planet-solar-boat/

D) SolarSailor Aqua-tanker



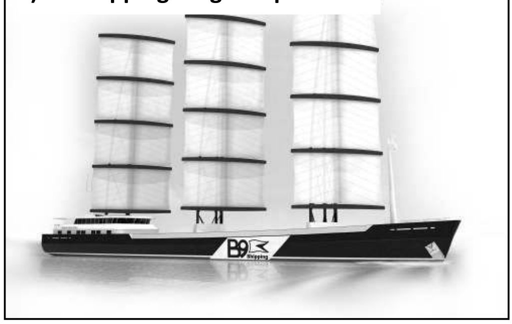
http://www.treehugger.com/solar-technology/solar-sailor-sun-sails-to-be-fitted-to-chinese-cargo-ships.html

E) Wave Powered Catamaran



http://www.nature.com/news/2008/080820/full/454924a/box/3.html

F) B9 Shipping Cargo Ship



http://www.cleanechnica.com/2012/06/22/b9-cargo-ship-uses-no-fossil-fuel-only-sails/

Past research has shown that competencies can typically be grouped under three basic types: technological know-how, reliable processes, and close relationships with external parties (Mascarenhas et al. 1998). Technological know-how represents using machines, equipment, software/tools and materials for gaining competency. Reliable processes indicate constructing a practice that may remain with the company for a long time. It is a methodology that is dependable, consistent, and time-tested. Lastly, strategies that are relationship focused and may build strong and trustworthy relationships between different industry stakeholders can develop a strategic competency.

We now examine and discuss some of the best known initiatives for energy and emission reduction in marine terminals worldwide. Consistent with core-competency literature, these practices are later classified as` technology-centric, process-centric and relationship-centric.

Transforming Green Initiatives to Strategic Competencies in Sustainability

Utilizing a recent report by Drewry Shipping Consultants (Drewry Research and Advisory Organization 2012), the top-five global terminal operators are identified (Table 1). The five terminal operators - Port of Singapore Authority (PSA), Hutchison Port Holdings (HPH), A.P. Moller (APM), Dubai Ports World (DPW) and China Ocean Shipping Company (COSCO) account for 29% of the world's throughput (by equity). Attention is given to only the top five operators, in the expectation they will provide a spectrum of initiatives, ranging from small to large/complex ideas. Smaller operators often tend to involve only a subset of possible initiatives.

Table 1: Top Ten Global/International Terminal Operators' Equity Based Throughput, 2012

Ranking	Operator	Million TEU	% share of world throughput
1	PSA International	50.9	8.2%
2	Hutchison Port Holdings	44.8	7.2%
3	APM Terminals	33.7	5.4%
4	DP World	33.4	5.4%
5	COSCO Group	17.0	2.7%
6	Terminal Investment Limited (TIL)	13.5	2.2%
7	China Shipping Terminal Development	8.6	1.4%
8	Hanjin	7.8	1.3%
9	Evergreen	7.5	1.2%
10	Eurogate	6.5	1.0%

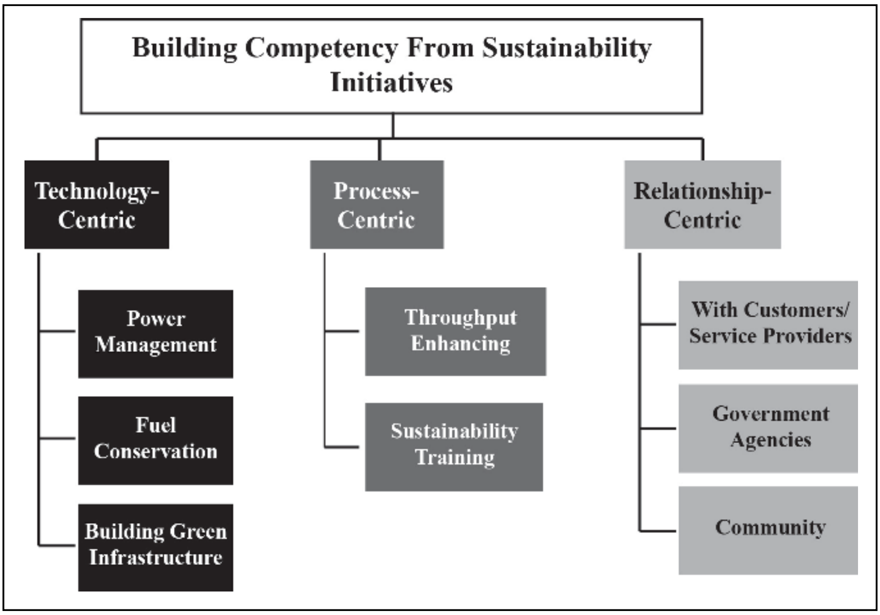
Source: Drewry Maritime Research, http://www.drewry.co.uk/news.php?id=232

To perform the study, the following approach is adopted:

- Using existing literature, trade reports, news articles and terminal operator's website, prepare an exhaustive list of green initiatives undertaken globally by top terminal operators. We believe that global initiatives can provide a useful benchmark and encourage adoption/testing of these initiatives in other locations where they are not currently being used. We caution the reader that an absence of a terminal operator's name or example from a specific country vis-à-vis a particular initiative, does not necessarily imply they are not pursuing it; it merely shows that we could not confirm it through publicly available sources. To keep track of initiatives by operator(s), a three-letter code is appended (i.e., PSA, HPH, APM, DPW, and COSCO). Our compiled list with its references is available at: https://sites.google.com/site/ukierinexgift/project-definition/paper-submissions (Mittal et al. 2014).
- Consistent with the core competency literature, classify all green initiatives into three broad categories: technology-centric, process-centric, and relationship-centric.
- Within each broad category, aggregate the initiatives (iteratively) into logical *strategic competency* groupings. In doing so, care is taken to ensure that these competencies *have potential* to (a) be deployed across location/markets, (b) add value to customer, and (c) not be easily imitated by competitors. Figure 2 presents the complete categorization.

We next explain these categories of green initiatives adopted by global terminal operators.

Figure 2: Categorizing Sustainability Initiatives



Technology-Centric Competencies (TCs)

Initiatives adopting novel and smart technologies fall into this category. It includes installation of state-of-the-art machines, embracing cutting-edge tools/techniques, and using alternate sources of energy to prevent or reduce carbon emissions. TCs are relatively easy and quick to implement. They deliver faster visible returns. However, their ease and quickness in deployment make them easily replicable by competitors. Later, we will discuss mitigating factors that can help elevate TCs to be core competencies. The three TCs uncovered here were:

Power Management Technologies. Initiatives that focus on deploying technologies to reduce/ moderate the energy consumption in a terminal. They result in lowering of electricity bills, which leads to reduction in operator's operational costs. Customers accrue benefit from increased efficiency and cost savings due to the deployment of these technologies. While it's possible that these savings may not be directly passed onto the customer in monetary terms, reduced emissions and greener operations provide an improved customer service experience. Indeed, today's shippers and freight-forwarding companies increasingly aim to reduce their freight supply chain carbon footprint (U.S. EPA Webpage). They need to improve environmental performance and reduce carbon emissions throughout their supply chains. Given that marine terminals are one of shippers' key supply-chain links, reduction in carbon emissions at terminals becomes an imperative customer service priority for terminal operators. Additionally, port personnel and neighboring communities experience an increase in wellness and quality-of-life through adoption of such initiatives.

Power management initiatives are, for the most part, easy, quick and inexpensive to implement. They are generally deployable across locations/facilities and not difficult for the competitors to imitate. Examples include:

- Installation of voltage optimization units to systematically control the equipment's voltage input. For example, DPW terminals installed PowerSines ComEC voltage optimisation system in its units that supplied power to its refrigerated and frozen containers to extend equipment's life, reduce energy consumption and waste, and lower emissions [DPW].

- Use of lower-watt flood lights on lighting towers and switching-off terminal lights during operations downtime to help save energy and costs [HPH].
- Replacement of fluorescent lamps with LEDs, use of motion-sensor lights, and employing precision cut lenses (Prismalence) to help reduce lighting energy consumption while maintaining illumination/visibility [PSA, DPW].

Fuel Conservation Technologies. These are initiatives that focus on deploying technologies to improve fuel economy, increase power, lower emissions, and reduce maintenance downtime for the terminal operator. Ensuing benefits translate to increased customer value via improved speed, reliability, and reduced cost. Fuel conservation technologies are easy and quick but can sometimes be expensive to implement. They can be imitated especially if competitor is willing and able to commit resources. Some examples are:

- Installation of electrified Rubber Tired Gantry (RTG) cranes or eco-RTG cranes to reduce the amount of diesel fuel needed, resulting in lower emissions. These cranes require shorter maintenance intervals and fewer stoppages for refueling, resulting in shorter downtime and cost reduction [PSA, APM, DPW, HPH].
- Vehicles used in ports or yards that move and stack freight containers are called drive straddle carriers. Replacement of these mechanical drive straddle carriers with hybrid diesel-electric drive machines that consume approximately 20% less fuel and emit carbon up to 90% less than the conventional mechanical drive, diesel-only machines [APM, DPW, HPH].
- Installation of variable speed drives (that provide soft-start capabilities and decrease electrical stress and line voltage sags associated with full voltage motor start-ups) in RTG and quay cranes to regulate speed and torque of equipment, resulting in reduced fuel consumption and pollution and lowered operating costs [PSA, HPH, APM, COSCO].

Green Infrastructure Technologies. Technology-driven initiatives that aim to build green infrastructure such as eco-friendly buildings, electrical sub-stations, and windmills in the port terminal. Their objective is to reduce air emissions and help the company build its positive image among its employees, customers, government agencies, the broader community, and society at large. These technologies, while ubiquitous, can be costly to implement. Nevertheless they offer long-term, sustained benefits due to cost savings from reduced energy consumption, lower maintenance costs, tax credits from the government, and increased health of the employees. If proven reliable and financially viable, they can be adopted across facilities/locations of the organization. The chief barrier to imitation for these is the capital investment required. Some examples of green infrastructure technology are:

- Enabling shore-side powering (cold ironing) for berthed vessels. Terminal operators adopt the technology because of its long-term benefits on human health, marine wildlife, and the eco-system around the port facility. Regulatory requirements, pressure from environmentalists, and community groups play a significant role in the adoption of cold ironing. On June 21, 2004, the Port of Los Angeles and China Shipping Container Line announced the grand opening of the West Basin Container Terminal, the first container terminal in the world to use Alternative Maritime Power. Beginning Jan. 1, 2014, California mandated that at least half of all container ships run on shore-side electricity at berth (Port of Long Beach Website).
- Constructing buildings that allow use of natural day lighting. For example, PSA Singapore uses the Sola-tube day lighting system, which captures daylight by redirecting low-angle sunlight and rejecting overpowering midday sunlight for consistent lighting throughout the day [PSA].
- Constructing windmill farms at the terminal to power terminal activities. For example, APM terminal operates a €12.5 million power distribution network at the Rotterdam container terminal with electricity generated solely by wind power [APM].

- Deploying automated guided vehicles (AGV) for transporting containers between the harbor quay and the storage area. AGVs require laying sensors, wires, and tapes on the floor to control unmanned machines in the terminal area. The AGVs help increase efficiency and reduce material handling costs. The first automated terminal in the U.S., an APM Terminal in Portsmouth, Virginia, is still the most automated facility in this country [APM, PSA].
- Installing solar panels on roofs of terminal buildings to power water heaters, and traffic lights and charging RTG crane batteries to reduce energy consumption and emissions [PSA, HPH, APM, DPW, COSCO].
- Using ultra-low sulfur diesel (ULSD, which is 97% cleaner than the standard diesel fuel) for all cargo carrying equipment in the terminals [PSA, HPH].

Process-centric Competencies (PCs)

Initiatives that improve existing or develop new innovative practices fall in this category. It includes modifying, upgrading, and schooling procedures and methodologies for lowering emissions in the terminal. Due to inherent difficulty in changing and modifying processes, PCs are more difficult to implement than TCs. Implementation of PCs across units/locations is generally more complex as they need to be adapted to the idiosyncratic environment of a unit/location. Due to these complexities, PCs are difficult to imitate by the competitors. The PCs uncovered by our analysis are:

Throughput Enhancing Processes. Refer to improving practices that increase terminal productivity. These initiatives include developing coordination among activities, managing traffic, optimizing routing, improving layout, and allocating appropriate resources to increase terminal's throughput and reduce its waste, costs, and emissions. Through these initiatives, customers experience dual benefits of improved service and reduced costs. Throughput enhancing initiatives require time, commitment, and diligence. Once successfully implemented, they can be adopted across the operator's different facilities. Imitation by competitors is not straightforward since it requires time, effort, and dedication to develop and implement these practices. Some examples are:

- Coordinating and streamlining berthing, ship planning, yard planning, resource allocation and gate operations at the terminal to improve productivity, efficiency, and overall serviceability. For example, PSA terminal operator in Singapore adopted a Computer Integrated Terminal Operations System (CITOS) to manage their equipment and people seamlessly, flexibly, and in real time [PSA].
- Continuously monitoring the number and movement of trucks in the terminal to help relieve congestion and minimize truck turnaround time. For example, terminal operators deploy advance booking systems such as Truck Appointment Management System (TAMS) to help avoid unnecessary/delayed visits [PSA, APM]. DPW implemented Optical Character Recognition (OCR) technique to enable faster gate-ins for the truckers [DPW]. They install truck positioning systems under the Gantry cranes to reduce container transfer time between the crane and the truck when being off-loaded from the ships [DPW].
- Creating dedicated storage areas for empty containers or modifying yard layout to maximize terminal's space utilization [PSA, APM].
- Determining optimal routes and dispatches for transporters, such as straddle carriers and terminal tractors, to help lower labor, fuel, and maintenance costs and emissions at the terminal and thereby increase terminal's productivity [DPW].
- Employing Automated Guided Vehicles for material handling that utilizes lasers to transport containers between the quay and container yard efficiently and reliably, without any human driver [PSA].
- Utilizing non-road intermodal transportation at the terminal for speedy transfer of containers from the facility. Launching barge-rail links between the port terminals and neighboring cities

helps reduce truck traffic, increases speed of container transfer, and lowers emissions [PSA, APM, DPW].

Sustainability Training Processes. These initiatives created a workforce that is well trained in eco-friendly practices. It involves educating, motivating, and training employees in methods of maintaining/enhancing the quality of air, land, and water environment at the workplace**.** These initiatives require planning, effort, and commitment. Transition pains and lack of reliability during the pilot phase can pose further challenges to terminal operators. Once pilot successes have been firmly established, these initiatives can be deployed across the operator's different functions, facilities and locations. Imitation by competitors is difficult as it requires a shift in mind-set coupled with determination and dedication. Some examples are:

- Training crane operators to operate machines/equipment in a way that reduces waste and improves operational efficiency of the equipment [DPW, PSA, HPH].
- Training employees by various operations-based, technical, IT, and managerial courses to enhance and deepen their knowledge of the equipment and operations [PSA].
- Training support staff by organizing programs such as Basic Education for Skills Training (BEST), Worker Improvement through Secondary Education (WISE), and Critical Enabling Skills Training (CREST) to increase their productivity [PSA].
- Educating staff by providing company's sustainability report and environment-related information via portal website and WLAN to make them aware of best practices, policies, guidelines, and company's performance on carbon reduction strategies [COSCO].
- Institutionalizing and incentivizing policies and measures to develop a sustainable environment in the facility. Some terminal operators establish practices that promote eco-friendly mindset among employees, encouraging them to recycle and conserve resources to help create a greener environment [PSA, HPH].

Relationship-centric Competencies (RCs)

These initiatives involve forging relationships that may help port terminal operators function more effectively and efficiently. RCs tend to be the most complex, requiring significant deployment time and effort. Returns are rarely immediate. However, once an organization builds a reputation and capability to forge such relationships, these can be leveraged across locations. Due to the above mentioned reasons, RCs are difficult for competitors to imitate. Based on our research, the following RCs were found:

With Customers/Service Providers. This involves initiatives that develop and deepen partnerships between the terminal operator and its customers, such as railroad companies, shipping lines, and container freight service providers. A strong relationship helps in streamlining the activities, prevent delays, minimize points of conflict, and increase work productivity while keeping the environment green. These partnership initiatives take time to develop and yield returns. Some examples are:

- DPW and Etihad rail collaborated to develop an intermodal rail terminal in Jebel Ali Port to enable a highly efficient and eco-friendly way to transfer containerized freight arriving at the port. This brought substantial benefits to the involved stakeholders, and the UAE economy as a whole [DPW].
- PSA Antwerp and Naviland Cargo collaborated to increase the terminal's hinterland rail connectivity, which resulted in improved quality of operations and increased satisfaction among customers [PSA].
- APM Terminal in Gothenburg developed a rail system called "Railport Scandinavia" to collaborate with inland dry-harbors to help customers drop off and collect their containers

locally. This helped streamline operations, aggregate in-and-out-bound shipping, use greener mode of transportation, and improve throughput and reliability [APM].

With Government Agencies. These initiatives built relationships between the governing agencies/port authority and the terminal operator. A strong relationship with these agencies builds public image, improves success of future ventures, and transforms a (traditionally) adversarial relationship to one of trust and cooperation. Such initiatives take time to develop and are forged by an attitude of focusing on shared benefits. Some examples include:

- Incheon Port Authority (IPA) and PSA International (PSA) shared information and ideas in the area of port operations, technology, and best practices, gaining better understanding and unveiling opportunities for port development in the Incheon area [PSA].
- APM Terminal in Jamaica built a unique collaboration with U.S. Customs to help expedite the cargo inspection process, which benefited Jamaican exporters by increasing their sales, serviceability, and revenues [APM].

Community Alliances. This involved initiatives that connected the terminal operator with its surrounding community to develop a sustainable and thriving environment. By nature, these alliances require mutual trust and time to develop. However, through its actions, once a company develops a reputation of being community-oriented, this competency can be deployed more easily at other locations; other communities then become likely to trust a time-tested organization with a strong culture of developing community alliances. These initiatives are difficult for a competitor to imitate since it requires well-documented historical results. Some examples are:

- Creation of natural environment by planting trees in the terminal area. For example, one of HPH ports planted 34,000 mangroves to offset the construction of a terminal expansion. In another instance, APM Terminals in Virginia, USA, set aside over 150 acres of undeveloped forest and wetlands. They recreated 27 acres of wetlands by planting nearly 200,000 wetland plants.
- Building relationships with the local community. PSA in Singapore set up a $16 million endowment fund to award bond-free scholarships to Singapore citizens. These scholarships aim to provide the lower-income families with financial assistance to attain formal qualifications and/or technical skills [PSA].
- Deploying high-efficiency air and diesel filters in port equipment to clean up emissions from older, dirtier diesel engines, which may demonstrate their commitment to clean air for the community [HPH, APM].
- Organizing community outreach through environmental protection activities such as Earth hour, recycling programs, painting competitions, scholarships, and green essay competitions [HPH].

Key Insights from the Core Competency Qualitative Framework

From the above list of initiatives, we can infer that terminal operators participate in sustainability through a range of initiatives. Beginning with tree plantation within their terminals, to applying the latest fuel-saving technologies in equipment, lighting, and buildings, improving traffic flow within the terminal, educating staff, and organizing green awareness programs are undertaken. Strategic benefits of these green initiatives for terminal operators are improved energy use, reduced air emissions and pollution, better human health, reduction in functional and operational costs, and an ability to promote the company's image as green by becoming environment-friendly. Sustainability initiatives can provide companies/facility-operators a competitive advantage (over competitors) with lowered operational costs, increased productivity, and better pricing/service for its customers.

The issue is that terminal operators often look at green initiatives as only initiatives without positioning them strategically. They venture into sustainability initiatives in an *ad hoc* fashion.

These initiatives are often undertaken with an ROI mindset and rarely looked at in a strategic way as a source of competitive advantage. Indeed, tremendous opportunity is lost by attending to narrow and short-term goals. Terminal operators are better served by not having a unidimensional focus on Return-on-Investment (ROI), as it can cloud their ability to look at strategic benefits of an investment. Indeed, initial cost of investment should not be viewed as a deterrent in situations where it positions the organization to gain long-term competitive advantage that can yield rich dividends in new market entry, brand recognition, relationship with government agencies, and capturing market share.

Through our analysis, we find that it is important for terminal operators to view similar initiatives cumulatively. Aggregation of (a group of) similar initiatives into (a small number of) competencies enables operators to gain clarity on prioritizing investments and measuring strategic benefits. We recommend this as an important step for all terminal operators.

Historically, sustainability initiatives across industries have been driven by technological advances. Due to this, a technology-biased mindset for sustainability is often developed. Not surprisingly, terminal operators, too, seem to reflect this prevalent technology-driven sustainability paradigm. However, by utilizing the existing literature on core competencies, we show that a portfolio of sustainability competencies that encompass technology, processes, and relationships are better positioned to offer long-term strategic competitive advantage than simply focusing on technology-centric competencies alone.

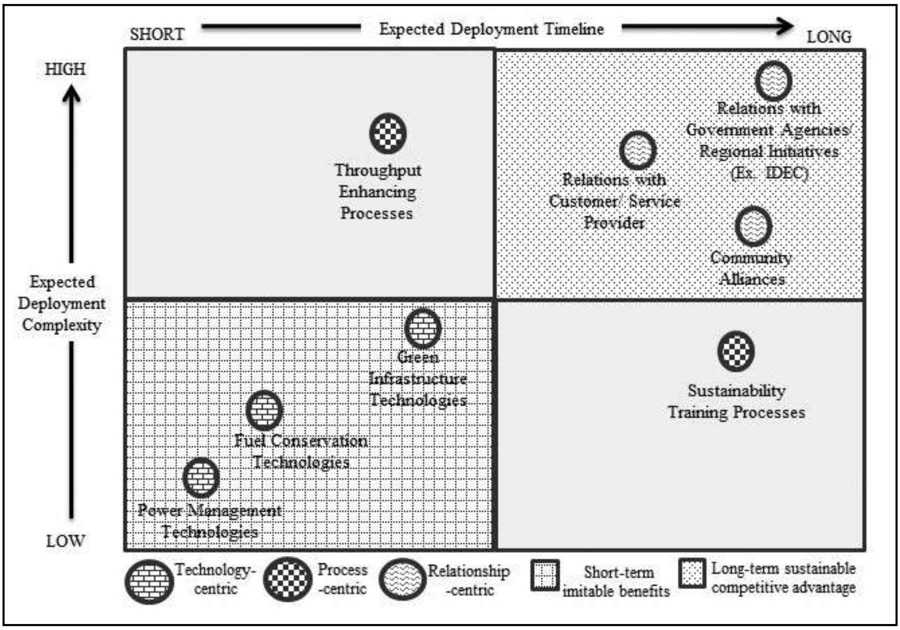
Technology-centric competencies (power, fuel, and green) are relatively less difficult to deploy and helps organizations receive positive reinforcement by yielding quick returns. Due to this ease in deployment, they can often be imitated by competitors. Process-centric competencies require more time/commitment. Bringing change in existing practices requires time, willingness, planning, training, communication, and coordination, as well as local cultural awareness. Altering policies and implementing new processes is a complex, delicate, and challenging task, making these more difficult to imitate by competitors. Relationship-centric competencies are the most complex and time consuming to develop. Long-term strategic partnerships with customers, government agencies, and communities build on a history of mutual trust, shared goals, and successes. Typically, competitors have a difficult time imitating such relationships, especially if they lack historical strength in the area of forging partnerships.

To calibrate the imitation difficulty/ease, we plot these competencies on a graph in Figure 3. Y-axis shows the Expected Deployment Complexity and X-axis shows the Expected Deployment Timeline. Expected Deployment Complexity captures the intrinsic difficulty in successfully implementing these competencies.Expected Deployment Timeline refers to the *likely* time it would take for an organization to develop these competencies.

Over time, "softer" competencies improve through organizational learning. For an organization, expertise gained by experience, the "actual deployment time" and "actual deployment complexity," may reduce vis-à-vis the corresponding expected values. For example, over time, a terminal operator that has spent significant time/resources in training its workforce in the area of sustainability can develop reliable processes in this area.

Synergistic interaction of TCs, PCs, and RCs offer the greatest potential of sustained benefits and competitive advantage to marine terminal operators. It is important that the three categories of competencies should not be looked at in isolation. For example, at a particular marine terminal, fuel-conservation technology (a TC) was installed that automatically switched off crane engines when not in use. Despite the implementation of this technology, in practice, savings were not being realized. Further investigation showed that crane operators, to avoid the inconvenience of switching on engines multiple times, developed a practice of incorporating pseudo moves (such as shaking the joystick) that kept the engine running. Changing this practice required training of crane operators (a PC) to align their behavior with the sustainability mission of the organization. With that training in place, the deployed fuel conservation technology was able to realize its intended goal. Further,

Figure 3: Classification of Green Initiatives on a Core Competency Framework



crane operators started to actively contribute by suggesting new, innovative ideas that advanced the sustainability goals. Similarly, showing a deep commitment to sustainability technology and practices (TCs and PCs), over time builds strong external relationships with customers, government agencies, and community at large (RCs).

A strategic view of sustainability supported with synergistic and diverse types of competencies can enable marine terminal operators to add value to their stakeholders while gaining significant and long-lasting competitive advantage.

CONCLUDING REMARKS

This work utilized available sustainability practices data of various marine terminal operators. With maritime transportation's continued expansion and its consequential environmental impact, immense opportunities exist for improving the sustainability-driven performance of this industry. The key roadblocks to long-term benefits from sustainability initiatives are: (a) short-term thinking, (b) focus on initiatives instead of business strategy, (c) ad hoc adoption of sustainability programs, (d) ignoring multiple stakeholder viewpoints, (e) rigid, irreversible outlook to decision making and (e) lack of judicious use of qualitative and quantitative data. We argue that a rigorous strategic framework can be very useful in addressing the aforementioned shortcomings, thereby improving the longevity and impact of these sustainability programs. This is one of the key contributions of this article.

Another key contribution of this work is in providing a bridge between strategic management and sustainability literatures. We show that core competence is a concept that is closely tied with sustainability because it offers a way for long-term competitive advantage (Javidan 1998). While this work focused on envisioning, developing, deploying, and deepening of sustainability competencies for marine terminal operators, the broad sustainability framework developed can be applied to any industry. Firms involved in developing or strategizing their sustainability practices could benefit from embracing the long-term, competitive-advantage argument formulated in this article.

There are several ways in which this work's contributions and impact can be extended. This work utilized available sustainability practices data of various marine terminal operators. To complement this study, it would be useful to do an in-depth longitudinal study of sustainability practices of leading multinational marine terminal operators. Such a study can help uncover the opportunities and challenges, and help frame structured theories from case studies as suggested in Eisenhardt's seminal research (Eisenhardt 1989).

From the human resource development standpoint, this research offers new areas of investigation in the arena of sustainability. Our work clearly shows that training and development of the workforce, if done strategically, can be a source of competitive advantage for organizations. It would be useful for human resource development scholars to see what practices can yield optimum results under different environmental and cultural factors. Further, it would be valuable to see how practices are transplanted across locations, allowing these competencies to be leveraged across markets.

Organizational behavior scholars may find opportunities to investigate the idea of building trust and relationship among partners around an issue that is truly bigger than them individually. The idea of sustaining the planet can, indeed, allow agencies/organizations to share a common ground where they can forge relationships that look beyond the singular profit-driven focus. Also, given that these relationships can have direct impact on the business strategy of an organization, the importance of this work cannot be overemphasized.

As with leading organizations in any industry, successful terminal operators cannot rely on their past laurels in sustainability to remain leaders in the market. Instead they should innovate, deepen and deploy these competencies in newer communities/geographical locations. The dynamic nature of these competencies needs to be understood and leveraged to ensure continued success (Innovation Excellence 2012). This requires a commitment from top leadership that is supported at all levels of the organization. Further research is needed to envision such a self-sustaining organizational structure that does not view sustainability as a fad or short-term-profit goal but as something that is embedded in the genetic code of the organization.

Finally, this work's greatest impact would be in encouraging organizations, across industries and geographic locations, to diligently and deeply investigate the central thesis of this work – *sustainability as a strategic business driver*. In doing so, deeper and far reaching insights can be gained – now and for generations to come. This promise of synchronizing organizational and societal needs in context of a sustained future on this planet that we inhabit is the sincere hope with which we present this work.

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Weights from a Safety Perspective for Interchange Lighting Prioritization

by Srinivas S. Pulugurtha and Ravishankar P. Narayanan

The focus of this paper is to research and update weights (values indicating the effect) to multiply ratings of selected factors used in the Total Design Process (TDP) for interchange lighting prioritization from a safety perspective. Results based on analysis using data collected at 80 interchanges along nine segments in North Carolina showed differences in weights for currently used factors such as freeway median width, freeway number of lanes and night-time traffic volume per lane. Results also showed that considering the number of night-time crashes by severity instead of night-to-day crash rate ratio, for prioritization of interchange lighting system installation or maintenance, would reduce the bias towards interchanges with fewer numbers of crashes and lead to better utilization of limited available transportation funds.

INTRODUCTION

Transportation statistics indicate that approximately 25% of travel occurs at night (dark light conditions, typically between 7:00 PM and 6:00 AM). However, more than 50% of fatalities occur during this time period (NHTSA 2012). Inadequate roadway lighting in addition to factors such as fatigue, driving under the influence of alcohol or drugs, distracted driving, speeding, and failure to reduce speed are the most common contributing factors of crashes at night.

Improved visibility through illumination increases the probability of a driver to correctly react to the hazard and take appropriate action while driving at night (AASHTO 2005). It is often the first strategy considered and well perceived by the traveling public for locations with high night-time crashes. Several researchers in the past have shown that roadway lighting or illumination helps reduce nighttime crashes on roads and improve safety (Walker and Roberts 1976; Lipinski and Wortman 1978; Schwab et al. 1982; Elvik 1995; Preston and Schoenecker 1999; Elvik and Vaa 2004; Isebrands et al. 2004; Isebrands et al. 2006; Bruneau and Morin 2005; Harwood et al. 2007; Wanvik 2009; Rea et al. 2009; Donnell et al. 2010; Bullough and Rea 2011; Bullough et al. 2013). However, it is very expensive to install the hardware for required or additional lighting. The maintenance and utility charges associated with roadway lighting can often be costly for smaller jurisdictions (Hallmark et al. 2008).

AASHTO (2005) and NCHRP Report 152 (Walton and Rowan 1974) provide several warranting and screening methods to assess and identify potential locations that require roadway lighting to improve safety. The NCHRP Report 152 emphasizes various geometric, operational, and environmental conditions, while AASHTO emphasizes exposure or average daily traffic (ADT).

Several state agencies in the United States use the Total Design Process (TDP) discussed in the NCHRP Report 152 (Walton and Rowan 1974) to assess and prioritize interchange lighting needs. The TDP is a method of assessing the cost-effectiveness of installing roadway lighting and establishing a priority index to determine if investing funds is justified. The priority index is a number (with no units; not comparable with other measures) computed by multiplying need (warrant) and benefit factors (traffic volume) and then dividing by the cost.

The warrant factor is computed using various geometric, operational, and environmental factors, and night-to-day crash rate ratio. The geometric factors include ramp type, cross-road channelization to facilitate, separate or regulated traffic into definite paths of travel using pavement markings and/or traffic islands, frontage roads, freeway lane width, freeway median width, number of freeway lanes, horizontal curve, grade, and sight distance. The operational factors include level-of-service and freeway volume, while environmental factors include percent development, offset to development from traffic lanes, freeway lighting, and cross-road approach lighting. The night-to-day crash rate ratio is defined as the percent of nighttime crashes to the percent of daytime crashes divided by the percent of nighttime traffic volume to the percent of daytime traffic volume.

Each factor considered in the computation of warrants is divided into a maximum of five different ratings (categories 1 to 5) based on the complexity that the driver might encounter due to the factor. The rating of the factor is multiplied by the difference of unlighted and lighted weight for the factor (values indicating the effect of factor under unlighted and lighted conditions) to obtain the warranting points related to the factor. The warranting points of all factors are summed to compute the total interchange warranting points. Based on the tool currently used by the North Carolina Department of Transportation (NCDOT), the maximum number of points an interchange could have for geometric, operational, environmental, and crash factors are 40.5, 30, 23.5, and 40, respectively.

The minimum warranting condition is the total effectiveness achieved by lighting a traffic facility with an average rating of 3 on the subjective scale of 1 to 5 for each factor. It is equal to 90 points and 60 points for complete interchange lighting and partial interchange lighting, respectively. It is generally agreed by practitioners that this 40-year-old document lacks several needed updates. The TDP does not account for various factors that range from nighttime crash severity to traffic composition (percent of heavy vehicles and ramp volume ratio defined as the ratio of ramp volume to the freeway through volume) and other design criteria (e.g., acceleration and deceleration lane lengths). Considering these factors is essential for better utilization of limited available transportation funds. Moreover, no documents pertaining to computation of the lighted and unlighted weights used in TDP could be found in the literature. These weights play a vital role in computing the warranting points and the priority index. There is a need to research current practices, update the state of knowledge, and develop an updated mechanism to prioritize interchanges that require better and enhanced lighting needs. The objectives of the paper, therefore, are to research weights from a safety perspective and develop an updated mechanism to prioritize interchange locations that require lighting.

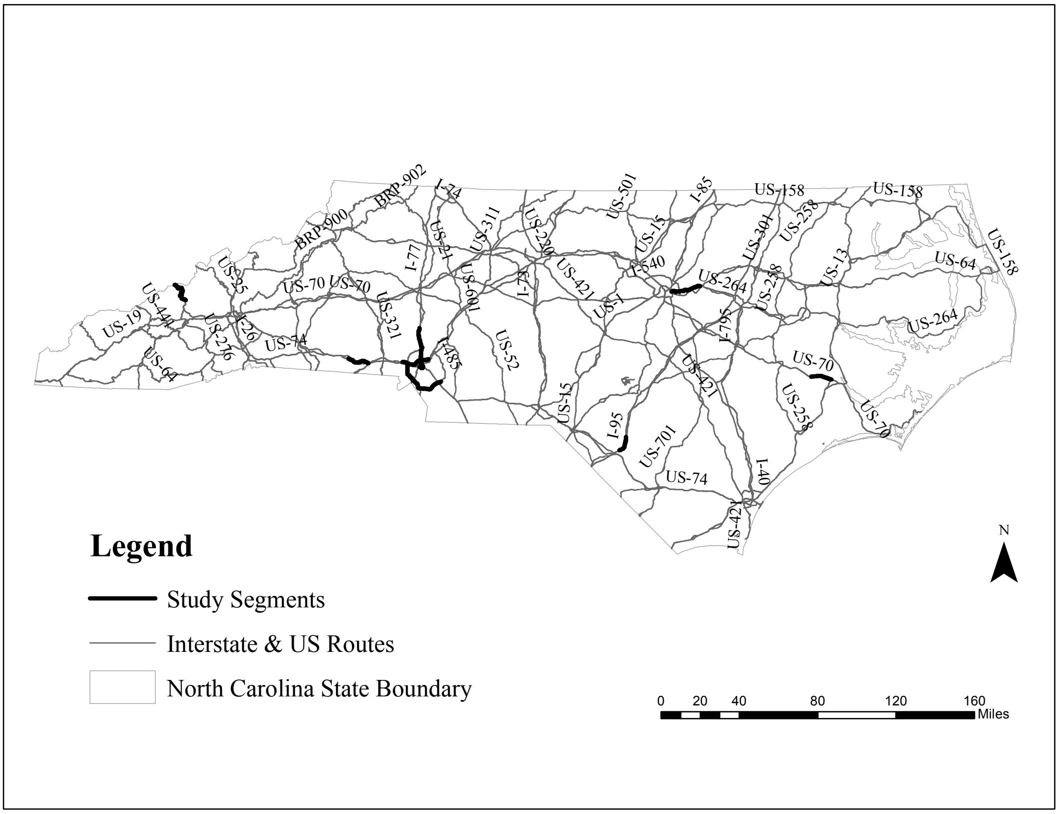
DATA AND RESEARCH METHOD

Nine study segments with full access control in North Carolina were selected to collect data, identify new factors, and compare results obtained from current and updated interchange lighting priority index tools (also referred to as current and updated tools, respectively). These nine study segments include six interstates and three U.S. routes. They are spatially distributed throughout the state of North Carolina (Figure 1). Further, the study segments were selected such that they are located in both rural and urban areas. Eighty interchanges were selected along these study segments for data collection and evaluation.

Interchanges were distinguished based on the exit number. Partial or full cloverleaf interchanges were considered as two separate interchanges. Ramps that have different exit numbers or connect different roads were also considered as separate interchanges.

Crash data from 2006 to 2011 were obtained for the selected interchanges from NCDOT. Traffic data were collected at 25 interchanges between 10:00 PM and 2:00 PM for at least half an hour through field visits. This was primarily done to observe if 25% of ADT (from NCDOT travel survey maps) occurs at night. Observed traffic data indicate that the nighttime traffic volume estimate is less than 15% of ADT at most of the selected interchanges. The percent of heavy vehicle volume at night was observed to be significantly higher (nearly 50% of traffic volume observed) at seven interchanges, with an overall average close to 25% of nighttime traffic volume. Ramp volumes were high at interchanges with a large number of developments. It was observed that ramp volume at

Figure 1: Selected Study Segments



interchanges with no developments within their proximity was less compared with ramp volume at interchanges with developments within their proximity.

Land use characteristics except business operation hours were identified using Google Earth. Most of the land uses within the vicinity of interchanges are residential and commercial developments. Freeway volume and ramp volume were comparatively high at interchanges in urban areas than at interchanges in rural areas, primarily due to commercial activity open at night in urban area. The urban areas also have residential developments near the freeway, resulting in a relatively higher ramp volume at night. All commercial establishments, except gas stations, near selected interchanges were found to be closed after 10:00 PM.

All geometric characteristics for each selected interchange were captured from Google Earth. The interchanges along the selected study segments have relatively flat terrain (less than 3% grade). None of the interchanges along the selected study segments have characteristics of a critical horizontal curve; all are reasonably straight sections.

All lighting characteristics except pole spacing were collected through field visits. Illuminance was measured using a luminance meter. Digital Illuminance / Light Meter LX1330B with a range of 0 to 20,000 foot-candle was used to measure the illuminance. Freeway lighting and cross-road lighting was differentiated as complete (illumination throughout or of all roadways in the interchange) and partial (illumination near or at some points critical to the driver). Type of roadway lights (High Pressure Sodium or any other type), presence of high mast lighting, and lighting from adjacent developments was also noted.

Identify New Factors, Their Categories and Ratings

The crashes at interchanges are typically associated with merging, diverging, and weaving maneuvers. Providing adequate acceleration and deceleration lane lengths will provide ample time for drivers to complete these maneuvers, reduce the number of crashes, and enhance safety at interchanges. The lack of roadway lighting further aggravates the likelihood of nighttime crashes. Therefore, these two factors were considered for further analysis and possible inclusion in the updated tool. Acceleration or deceleration lane length of 750 ft. is generally considered adequate for design purposes. The acceleration and deceleration lane lengths were therefore divided into three categories: 0 to 250 ft., 250 ft. to 750 ft., and greater than 750 ft. The 0 to 250 ft. is the most critical situation. Hence, it was given a rating of 5 in the updated tool. The 250 ft. to 750 ft. is relatively safer than 0 to 250 ft. and was given a rating of 3. As greater than 750 ft. is safest for acceleration or deceleration, it was given a rating of 1.

The placement of signboard also has an effect on diverging maneuvers at interchanges. A distance of one mile for signboard placement from the interchange is generally considered adequate for design purposes. If the signboard is placed at a distance less than one mile from the interchange, the time available for the driver to identify the path and make a decision to diverge from the freeway traffic is relatively less. The lack of roadway lighting at interchanges where signboards are placed close to the interchange would worsen the situation. Therefore, the distance of signboard placement from the interchange was considered as vital for improving safety at interchanges and was examined for further analysis and possible inclusion in the updated tool. The distance of signboard placement from the interchange was divided into three categories: 0 to 1,320 ft., 1,320 ft. to 5,280 ft., and greater than 5,280 ft. The signboard placement distance greater than 5,280 ft. is considered safest and was given a rating of 1. The signboard placement distance category 2,640 ft. to 5,280 ft. is relatively unsafe and was given a rating of 3, while signboard placement distance category 0 to 1,320 ft. was given a rating of 5 as it is more unsafe.

Nighttime crash severity is one major factor that was not considered widely while prioritizing interchanges for roadway lighting. Fatal crashes result in higher monetary costs than all other types of crashes. Severe or fatal injury crashes also result in substantial social costs that far exceed the less severe injury and property damage only (PDO) crash costs. The lack of roadway lighting limits visibility at interchanges and increases the probability of getting involved in severe crashes. Improving roadway lighting at interchanges with higher number of severe crashes also yields substantial benefits. Further, night-to-day crash rate ratio may be more biased toward interchanges with fewer numbers of crashes or low traffic volume. Considering nighttime crash severity would help better prioritize and allocate funds for interchange lighting installations. Nighttime crash data were, therefore, categorized into three categories: fatal and injury type “A,” injury types “B” and “C,” and PDO. The maximum number of nighttime fatal and injury type “A” crashes at the selected 80 interchanges from 2006 to 2011 is equal to 3. The fatal crashes were hence divided into three categories. Three or more nighttime fatal and injury type A crashes were given a rating of 5. One to two nighttime fatal and injury type A crashes were given a rating of 3, while zero nighttime fatal and injury type A crash was given a rating of 1. Likewise, the average number of nighttime injury type B and C crashes at the selected 80 interchanges from 2006 to 2011 is equal to 10. Therefore, nighttime injury type B and C crashes were categorized as 0 to 10, 10 to 20, 20 to 30, 30 to 40, and greater than 40 with ratings of 1, 2, 3, 4, and 5, respectively. Similarly, the average number of nighttime PDO crashes at the selected 80 interchanges from 2006 to 2011 is equal to 20. Thus, nighttime PDO crashes were categorized as 0 to 20, 20 to 40, 40 to 60, 60 to 80, and greater than 80 with ratings of 1, 2, 3, 4, and 5, respectively.

Illumination at interchanges generally would improve security and safety. An illuminance index equal to 0.7 foot-candle is considered adequate while inadequate levels result in a lack of visibility at night and could be probable cause of crashes under nighttime conditions. The illuminance index was therefore divided into three categories: less than 0.4 foot-candle, 0.4 foot-candle to 0.7 foot-candle, and greater than 0.7 foot-candle. An illuminance index less than 0.4 foot-candle was given a rating of 5 while illuminance index 0.4 foot-candle to 0.7 foot-candle was given a rating of 3. The rating was given as 1 if the illuminance index was greater than 0.7 foot-candle.

Traffic composition is another important factor that could have a bearing on the number of crashes at interchanges. Safety problems could be further aggravated due to the presence of heavy vehicles or truck traffic. As traffic data observed indicate, on average, 25% of nighttime traffic volume is heavy vehicles at the selected interchanges, the percent of heavy vehicles was categorized as 0 to 10%, 10% to 20%, 20% to 30%, 30% to 40%, and greater than 40% with ratings of 1, 2, 3, 4, and 5, respectively.

The ramp volume is divided by the freeway through volume to compute the ramp volume ratio. A higher ramp volume ratio indicates a higher number of vehicles carrying out weaving maneuvers (conflicting situations), which could contribute to increasing number of crashes at the interchange. The lack of roadway lighting worsens the condition and results in higher crash costs in such situations. The ramp volume ratio was categorized as 0 to 0.1, 0.1 to 0.2, 0.2 to 0.3, 0.3 to 0.4, and greater than 0.4 with ratings of 1, 2, 3, 4, and 5, respectively.

The new factors, categories, and ratings were presented to the Project Panel, comprising engineers from NCDOT. Feedback and input received was used to finalize the information and considered for further analysis.

Analyze Crash Data to Determine Unlighted and Lighted Weights

The lighted and unlighted weights used in the current tool were computed based on various field studies, literature, and collective judgments as stated by the authors of NCHRP Report 152 (Walton and Rowan 1974). Adequate details could not be found on the computation of unlighted and lighted weights used in the current tool. Since the previous study was performed more than four decades ago, there is a need to re-visit, research and document a method for computation of unlighted and lighted weights.

Crash data obtained from NCDOT were used to determine the effect of each factor on the number of crashes by light condition. The area within 0.3 miles (an influence area of 1,500 ft. including the acceleration or deceleration lane) from an onramp or off-ramp was considered as interchange influence area. Crashes occurring within 0.3 miles of both onramp and off-ramp of an interchange were therefore attributed to the interchange. These crashes within the interchange influence area could be due to merging, diverging, or weaving maneuvers.

The crashes occurring within the interchange influence area were identified for all the 80 selected interchanges along the study segments. Descriptive analysis was then conducted to tabulate these crashes by each factor provided in the interchange lighting priority index tool. Lighted and unlighted weights were then computed for freeway median width, number of freeway lanes, nighttime traffic volume per lane, ramp type, sight distance at cross-road intersections, percentage development, and cross-road approach lighting and freeway lighting. Lighted and unlighted weights for factors such as cross-road channelization to facilitate, separate, or regulate traffic into definite paths of travel using pavement markings and/or traffic islands, freeway lane width, freeway horizontal curve, freeway grade, level of service and offset to development from roadway were not computed as these were same for all the selected interchanges.

For freeway median width factor, the number of crashes at each interchange was processed and summarized for 4 ft. to 12 ft., 12 ft. to 24 ft., 24 ft. to 40 ft., and greater than 40 ft. median width categories. Table 1 shows the number of crashes by light condition and freeway median width categories. The number of nighttime crashes under unlighted conditions is greater than the number of crashes under lighted conditions when no freeway lighting is provided. As the number of crashes in the 4 ft. to 12 ft. freeway median width category is comparatively less (only two selected interchanges in this category), the number of crashes in the 12 ft. to 24 ft. freeway median width category was considered critical and used to compute the lighted and unlighted weights. The lighted weight was considered as 1. The unlighted weight was computed as the number of nighttime crashes per interchange with no freeway lighting for 12 ft. to 24 ft. freeway median width category (equal to 37.09) divided by the number of nighttime crashes per interchange with complete freeway lighting for the same freeway median width category (equal to 28.45) plus 1. The unlighted weight is, therefore, [(37.09 / 28.45) + 1] = 2.30, whereas the lighted weight is 1.00 for freeway median width category.

Table 1: Crashes by Lighting Condition and Freeway Median Width

Median Width (ft.)	Freeway Lighting	# Crashes Under Lighted Condition	# Crashes Under Unlighted Condition	# Interchanges	# Lighted Crashes per Interchange	# Unlighted Crashes per Interchange
4 to 12	Complete	0	0	0	0.00	0.00
	Partial	0	0	0	0.00	0.00
	No	2	43	2	1.00	21.50
	Total	2	43	2	1.00	21.50
12 to 24	Complete	313	192	11	28.45	17.45
	Partial	290	226	9	32.22	25.11
	No	88	408	11	8.00	37.09
	Total	691	826	31	22.29	26.65
24 to 40	Complete	126	91	6	21.00	15.17
	Partial	248	230	4	62.00	57.50
	No	134	206	4	33.50	51.50
	Total	508	527	14	36.29	37.64
>40	Complete	61	166	5	12.20	33.20
	Partial	48	122	3	16.00	40.67
	No	53	653	30	1.77	21.77
	Total	162	941	38	4.26	24.76

For the number of freeway lanes factor, the number of crashes at each interchange was processed and summarized for less than or equal to 4 freeway lanes, 4 to 6 freeway lanes, and greater than 6 freeway lanes categories. Table 2 shows the number of crashes by light condition and number of freeway lanes categories. From Table 2, the number of crashes (sum of complete, partial, and no freeway lighting) generally increased as the number of freeway lanes increased. Moreover, the number of nighttime crashes under unlighted conditions is greater than the number of crashes under lighted conditions when no freeway lighting is provided. This could be attributed to the fact that higher number of lanes would result in greater exposure and probably sharper weaving maneuvers. Unlighted roadway aggravates the problem by making it difficult for the driver to identify the exit ramp and make a decision promptly. As the number of crashes is highest for the greater than 6 freeway lanes category, the lighted and unlighted weights for number of freeway lanes were determined based on the number of crashes by light condition for this category. The lighted weight was considered as 1. The unlighted weight was computed as the number of nighttime crashes per interchange with no freeway lighting for the greater than 6 freeway lanes category (equal to 37.86) divided by the number of nighttime crashes per interchange with complete freeway lighting for the same freeway lanes category (equal to 31.27) plus 1. The unlighted weight is, therefore, [(37.86 / 31.27) + 1] = 2.21, whereas the lighted weight is 1.00 for the same number of freeway lanes category.

Table 2: Crashes by Lighting Condition and Number of Freeway Lanes

# Freeway Lanes	Freeway Lighting	# Crashes Under Lighted Condition	# Crashes Under Unlighted Condition	# Interchanges	# Lighted Crashes per Interchange	# Unlighted Crashes per Interchange
4 or Less	Complete	116	101	8	14.50	12.63
	Partial	17	32	1	17.00	32.00
	No	49	616	24	2.04	25.67
	Total	182	749	33	5.52	22.70
6 or less and >4	Complete	40	10	3	13.33	3.33
	Partial	49	59	4	12.25	14.75
	No	94	429	16	5.88	26.81
	Total	183	498	23	7.96	21.65
>6	Complete	344	338	11	31.27	30.73
	Partial	520	487	11	47.27	44.27
	No	134	265	7	19.14	37.86
	Total	998	1090	29	34.41	37.59

Likewise, for the total nighttime traffic volume per lane factor, the number of crashes at each interchange was processed and summarized for less than 1,000, 1,000 to 2,000, 2,000 to 3,000, 3,000 to 4,000, and greater than 4,000 nighttime traffic volume per lane (estimated from ADT) categories. Table 3 shows the number of crashes by light condition and total nighttime traffic volume per lane. In the current tool, total nighttime traffic volume per lane greater than 4,000 is the most critical situation. The total number of unlighted crashes per interchange with no freeway lighting is highest for this category. Hence, the number of crashes corresponding to this critical situation was used to compute the unlighted weight. The lighted weight was considered as 1. The unlighted weight was computed as the number of nighttime crashes per interchange with no freeway lighting for greater than 4,000 nighttime traffic volume per lane category (equal to 58.71) divided by the number of nighttime crashes per interchange with complete freeway lighting for the same nighttime traffic volume per lane category (equal to 8.00) plus 1. The unlighted weight is, therefore, [(58.71 / 8.00) + 1] = 8.34, whereas the lighted weight is 1.00 for total nighttime traffic volume per lane category.

The same procedure was used to estimate the unlighted and lighted weights for other aforementioned factors as well as acceleration lane length, deceleration lane length, and signboard placement distance.

To estimate unlighted and lighted weights for crash severity, the crash data were processed and categorized into three categories: fatal and injury type A, injury types B and C, and PDO. Table 4 shows the number of crashes by light condition and severity categories. The number of nighttime crashes under unlighted conditions is greater than the number of crashes under lighted conditions for each severity type. This implies that roadway lighting reduces the number of crashes at interchanges.

Table 3: Crashes by Lighting Condition and Total Nighttime Traffic Volume per Lane

Nighttime traffic Volume per Lane	Freeway Lighting	# Crashes Under Lighted Condition	# Crashes Under Unlighted Condition	# Interchanges	# Lighted Crashes per Interchange	# Unlighted Crashes per Interchange
<1000	Complete	0	0	0	0.00	0.00
	Partial	0	0	0	0.00	0.00
	No	0	0	0	0.00	0.00
	Total	0	0	0	0.00	0.00
1000 - 2000	Complete	0	0	0	0.00	0.00
	Partial	0	0	0	0.00	0.00
	No	3	185	13	0.23	14.23
	Total	3	185	13	0.23	14.23
2000 - 3000	Complete	172	159	9	19.11	17.67
	Partial	58	78	4	14.50	19.50
	No	89	453	17	5.24	26.65
	Total	319	690	30	10.63	23.00
3000 - 4000	Complete	304	273	10	30.40	27.30
	Partial	277	260	6	46.17	43.33
	No	73	261	10	7.30	26.10
	Total	654	794	26	25.15	30.54
>4000	Complete	24	17	3	8.00	5.67
	Partial	251	240	6	41.83	40.00
	No	112	411	7	16.00	58.71
	Total	387	668	16	24.19	41.75

Table 4: Crashes by Lighting Condition and Severity

Crash Type	# Crashes under Lighted Condition	# Crashes under Unlighted (Dark) Condition	Total # Crashes
Fatal & injury type “A”	28	32	60
Injury types “B” & “C”	422	622	1,044
Property Damage Only (PDO)	889	1,634	2,523

Different scaling levels (100, 10, and 1) were used to derive meaningful weights for the three crash categories. The unlighted weight for fatal and injury type A crash category was computed as 100 times the number of unlighted fatal and injury type A crashes (equal to 32) divided by the total number of fatal and injury type “A” crashes at the selected interchanges (equal to 60). The lighted weight was computed by subtracting the unlighted weight from 100. The unlighted weight is, therefore, $[100 \times (32 / 60)] = 53$, whereas the lighted weight is $(100 - 53) = 47$ for fatal and injury type A crash category. Subtracting 47 from 53 and then multiplying with a rating of 5 gives 30 warranting points (maximum) for this crash severity category.

The unlighted weight for injury type B and C crash category was computed as 10 times the number of unlighted injury type B and C crashes (equal to 622) divided by the total number of injury type B and C crashes at the selected interchanges (equal to 1,044). The lighted weight was computed by subtracting the unlighted weight from 10. The unlighted weight is, therefore, $[10 \times (622 / 1{,}044)]$

= 6, whereas the lighted weight is (10 - 6) = 4 for injury type B and C crash category. Subtracting 4 from 6 and then multiplying with a rating of 5 gives 10 warranting points (maximum) for this crash severity category.

The unlighted weight for PDO crashes was computed as the number of unlighted (dark) PDO crashes (equal to 1,634) divided by the total number of PDO crashes at the selected interchanges (equal to 2,523). The lighted weight was computed by subtracting the unlighted weight from 1. The unlighted weight is, therefore, (1,634 / 2,523) = 0.65 and lighted weight is (1 - 0.65) = 0.35 for PDO crash category. Subtracting 0.35 from 0.65 and then multiplying with a rating of 5 gives 1.5 warranting points (maximum) for this crash severity category.

Overall, a maximum of 30 points, 10 points, and 1.5 points are allocated for fatal and injury type A, injury type B and C, and PDO crash categories, respectively. The sum (30 + 10 + 1.5 = 41.5) is relatively close to the maximum of 40 points allotted for safety factor in the current tool. It should be noted that maximum warranting points are allocated if the rating is equal to 5.

The ratio of crashes under unlighted condition to lighted condition was used in the computation of unlighted and lighted weights for illuminance index, percent of heavy vehicles, and ramp volume ratio.

Table 5 compares the unlighted and lighted weights for factors used in the current tool and those estimated from this research.

Table 5: Summary of Lighted and Unlighted Weights

Factor	Current Tool			Updated Tool		
	Unlighted Weight (A)	Lighted Weight (B)	Diff. (A-B)	Unlighted Weight (A)	Lighted Weight (B)	Diff. (A-B)
Factors in the Current Tool						
Ramp Type	2	1	1	2.09	1	1.09
% Development	2	0.5	1.5	2.76	1	1.76
Cross-road Approach Lighting	3	2	1	2.06	1	1.06
Freeway Lighting	5	3	2	2.23	1	1.23
Freeway Median Width	1	0.5	0.5	2.30	1	1.30
# Freeway Lanes	10	8	2	2.21	1	1.21
Total Night-time traffic Volume per Lane	6	1	5	8.34	1	7.34
New Proposed Factors						
Deceleration Lane Length	Not applicable			2.07	1	1.07
Acceleration Lane Length				2.15	1	1.15
Signboard Placement				2.34	1	1.34
Fatal and Injury Type “A”				53	47	6
Injury Type “B” and “C”				6	4	2
PDO				0.65	0.35	0.30
Illumination				0.72	0.28	0.44
% Heavy Vehicles				0.72	0.28	0.44
Ramp Volume Ratio				0.72	0.28	0.44

DISCUSSION

The current tool used by NCDOT was updated by including the new factors, their categories and ratings, and unlighted and lighted weights. Table 6 summarizes interchange ID, interchange name, and selected data elements for 41 selected interchanges without lighting systems. The geometric conditions, traffic characteristics, and crashes varied for the selected interchanges.

As nighttime traffic volume data are not available, NCDOT assumes it as 25% of the freeway ADT at the interchange in the current tool. The percent of nighttime traffic volume divided by daytime traffic volume is, therefore, 25% / 75% = 1/3. This typically results in a night-to-day crash rate ratio equal to three times the ratio of the number of nighttime crashes to the number of daytime crashes.

Figure 2 shows warranting points from the current and updated tool for selected interchanges without lighting systems. The interchange ID is represented on the x-axis while warranting points are represented on the y-axis. TDP priority index could not be computed or compared for these interchanges due to lack of details pertaining to cost estimates.

The effect of new factors and weights on warranting points identified from this research other than crash severity seem to be marginal. This is because the difference in unlighted and lighted weights is not high enough to see noticeable effects at a macroscopic level.

However, the computed warranting points using the updated tool for 17 interchanges out of 41 selected interchanges without lighting systems was observed to be greater than warranting points computed from the current tool (Figure 2). At least one severe crash or over 100 nighttime total crashes occurred during the study period at more than 50% of these interchanges. The remaining 24 interchanges without lighting systems had computed warranting points from the updated tool that were less than computed values from the current tool.

From Table 6, overall, 36 out of the 41 interchanges without lighting systems have a night-to-day crash rate ratio less than 3 (or night-to-day crash ratio less than 1). It was observed equal to 3 at one interchange, equal to 4.5 at two interchanges, equal to 6 at one interchange, and a very high value at one interchange (all crashes occurred at night). While one interchange (US-64 / S New Hope Rd) with a night-to-day crash rate ratio equal to 4.5 had 0 fatal, 0 injury type A, 0 injury type B, 1 injury type C, 2 PDO nighttime crashes and 2 daytime crashes – 5 total crashes, the second interchange (US-70 / Tuscarora Rhems Rd) had 0 fatal, 0 injury type A, 0 injury type B, 2 injury type C, 13 PDO nighttime crashes and 10 daytime crashes – 25 total crashes. The interchange (US-70 / NC-41) with a night-to-day crash rate ratio equal to 6 had 0 fatal, 0 injury type A, 1 injury type B, 0 injury type C and 3 PDO nighttime crashes while the total number of crashes observed at this interchange was equal to 6. On the other hand, I-277 / Kenilworth Ave had 0 fatal, 1 injury type A, 5 injury type B, 7 injury type C and 17 PDO nighttime crashes and 130 daytime crashes – 160 total crashes with a night-to-day crash rate ratio equal to 0.69. This clearly indicates that using a night-to-day crash rate ratio could result in biased results (toward interchanges with fewer numbers of crashes).

Table 6: Summary of Crash Data for Selected Interchanges without Lighting System

IID	Interchange	ALL	DLL	SBPD	NTC						DTC	TC	CRR	LI	%HV	RVR
					K	A	B	C	PDO	Total						
1	I-40 / Cold Springs Creek Rd	1	1	1	0	0	2	4	27	33	56	89	1.77	0.1	66.4	0.0
2	I-85 / I-485	3	3	1	0	0	7	17	63	87	118	205	2.21	0.1	25.2	0.1
3	I-85 / I-77	3	3	1	2	0	10	14	32	58	121	179	1.44	3.6	30.8	0.3
4	I-485 / Providence Rd	3	3	3	0	2	2	5	28	37	97	134	1.14	0.1	28.9	0.2
5	I-485 / Johnston Rd	3	3	3	0	0	2	6	48	56	147	203	1.14	0.1	11.0	0.1
6	US-64 / I-540	3	3	3	0	0	0	0	1	1	1	2	3.00	0.1	6.2	0.3
7	US-64 / Knightdale Rd	2	3	1	0	0	1	4	16	21	35	56	1.80	0.6	9.6	0.2
8	US-64 / N Arendell Ave	2	2	1	0	0	2	1	31	34	74	108	1.38	0.1	15.4	0.2
9	US-70 / NC-41	2	2	1	0	0	1	0	3	4	2	6	6.00	0.1	21.0	0.2
10	US-70 / Clarks Rd	2	1	1	0	0	2	5	18	25	36	61	2.08	0.1	12.4	0.5
11	US-70 / Country Club Rd	2	1	3	0	0	0	0	0	0	0	0		1.7	0.0	0.1
12	US-74 / NC161	3	1	3	0	0	0	0	12	12	19	31	1.89	0.1	16.9	0.1
13	US-74 / Oak Grove Rd	3	1	3	1	0	0	5	14	20	27	47	2.22	0.1	18.4	0.1
14	US-74 / Shelby Rd	2	1	3	2	1	1	3	10	17	31	48	1.65	0.1	33.0	0.1
15	I-77 / W 5th St	2	2	2	2	7	20	79	185	293	610	903	1.44	1.7	12.7	0.3
16	I-85 / US-321	1	1	1	0	0	3	15	36	54	138	192	1.17	0.1	35.3	0.1
17	I-85 / NC-279	3	2	2	0	1	5	13	15	34	87	121	1.17	0.2	35.3	0.1
18	I-85 / S Main St	3	3	3	0	0	6	13	48	67	197	264	1.02	0.2	35.3	0.1
19	I-85 / NC-7	3	3	3	0	1	4	15	38	58	126	184	1.38	0.1	35.3	0.1
20	I-85 / McAdenville / N Main St	3	3	3	2	0	4	6	35	47	94	141	1.50	0.1	35.3	0.1
21	I-85 / NC-273	2	3	1	0	0	3	11	91	105	233	338	1.35	0.1	35.3	0.1
22	I-277 / Kenliworth Ave	3	3	1	0	1	5	7	17	30	130	160	0.69	7.3	11.8	0.1
23	I-277 / US-74	2	2	1	0	1	5	7	12	25	57	82	1.32	2.3	11.8	0.1
24	I-485 / Lawyers Rd	1	1	1	0	0	0	0	22	22	31	53	2.13	0.1	23.5	0.2
25	I-485 / Idlewild Rd	3	2	2	0	0	0	4	33	37	65	102	1.71	0.1	23.5	0.2

Table 6 (continued)

IID	Interchange	ALL	DLL	SBPD	NTC						DTC	TC	CRR	LI	%HV	RVR
					K	A	B	C	PDO	Total						
26	I-485 / Old Monroe Rd	3	3	3	0	0	1	4	20	25	66	91	1.14	0.1	23.5	0.2
27	I-485 / Rea Rd	3	3	3	0	0	0	10	22	32	0	32	>10	0.1	23.5	0.2
28	I-485 / NC-51	3	3	3	0	0	2	11	36	49	102	151	1.44	0.4	23.5	0.2
29	I-485 / Pineville Rd	2	3	1	0	0	4	21	103	128	284	412	1.35	0.1	23.5	0.2
30	US-64 / S New Hope Rd	2	2	1	0	0	0	1	2	3	2	5	4.50	0.3	10.4	0.2
31	US-64 / Hudge Rd	2	2	1	0	0	0	0	2	2	4	6	1.50	0.2	10.4	0.2
32	US-64 / Smithfield Rd	2	1	1	0	0	0	0	3	3	9	12	1.00	0.2	10.4	0.2
33	US-64 / Eagle Rock Rd	2	1	3	0	0	0	0	4	4	11	15	1.09	0.2	10.4	0.2
34	US-64 / Rolesville Rd	3	1	3	0	0	5	6	26	37	71	108	1.56	0.1	10.4	0.2
35	US-64 / Lizard Lick Rd	3	1	3	0	0	2	6	26	34	71	105	1.44	0.1	10.4	0.2
36	US-70 / Tuscarora Rhems Rd	2	1	3	0	0	0	2	13	15	10	25	4.50	0.1	11.1	0.3
37	US-70 / US-17 Bypass	3	3	1	0	0	0	0	0	0	2	2	0.00	0.1	11.1	0.3
38	US-70 / NC-43	3	3	1	0	0	0	0	0	0	0	0		0.1	11.1	0.3
39	US-70 / Glenburnie Rd	2	2	2	0	0	0	0	0	0	0	0		0.2	11.1	0.3
40	US-70 / US-70 Business Rd	1	1	1	0	0	0	0	0	0	0	0		0.9	11.1	0.3
41	US-74 / NC216	1	1	1	1	1	0	1	8	11	18	29	1.83	0.2	22.8	0.1

Note 1. IID is Interchange ID.

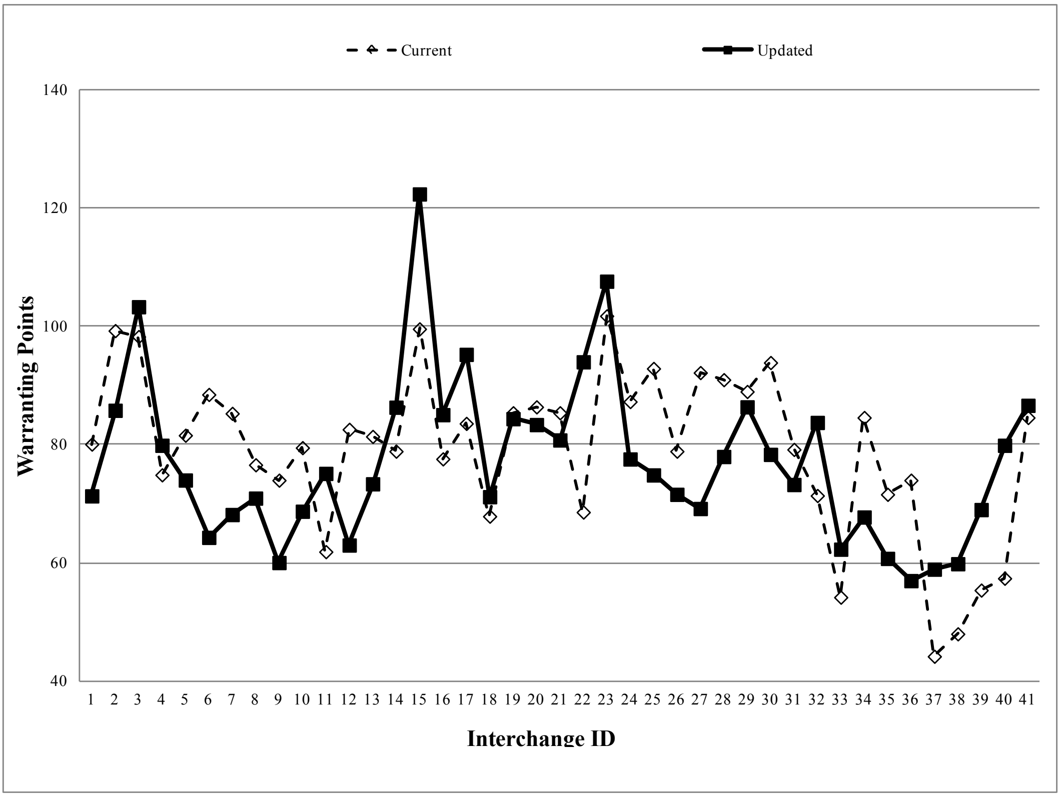
Note 2. ALL, DLL and SBPD are acceleration lane length, deceleration lane length, and signboard placement distance, respectively. 1, 2, 3 for acceleration lane length and deceleration lane length indicate < 250 ft, 250 to 750 ft and > 750 ft, respectively. Likewise, 1, 2, 3 for signboard placement distance indicate < 1,320 ft, 1,320 to 2,640 ft and 2,640 to 5,280 ft, respectively.

Note 3. NTC, DTC and TC are nighttime, daytime, and total number of crashes, respectively. K, A, B, C, and O are fatal, injury type A, B and C, and PDO crashes, respectively.

Note 4. CRR is night-to-day crash rate ratio. It is defined as the percent of nighttime crashes to the percent of day-time crashes divided by the percent of nighttime traffic volume to the percent of daytime traffic volume.

Note 5. LI, %HV and RVR are luminous index, % heavy vehicles, and ramp volume ratio, respectively.

Figure 2: Warranting Points for Selected Interchanges



Interchanges such as I-85 / I-77 and I-77 / W 5th St with fatal and more severe injury crashes have seen an increase and have more than 100 warranting points using the updated tool in comparison to the current tool. On the other hand, interchanges such as US-64 / S New Hope Rd and US-64 / I-540 have 94 and 89 warranting points, respectively, using the current tool (primarily due to a high night-to-day crash rate ratio) but have seen a decrease in warranting points using the updated tool.

CONCLUSIONS

Most of the interchanges with night-to-day crash rate ratio greater than 3 (used in the current tool) have seen fewer, less severe injury, or PDO crashes. Using crash severity would reduce the bias toward interchanges with fewer numbers of crashes and assign higher priority to interchanges with fatal and severe crashes. As fatal and severe injury crashes result in substantial social costs that far exceed the property damage only crash costs, incorporating crash severity into the TDP further increases the economic justification for improved visibility.

A comparison of warranting points using the current and updated tool indicates a decrease in warranting points at interchanges with fewer numbers of crashes or less severe crashes using the updated tool. In general, warranting points increased and are higher based on the updated tool for interchanges with more severe crashes. Therefore, it is recommended to consider the number of crashes by severity instead of the night-to-day crash rate ratio for prioritization using the TDP.

While other considered new factors and weights developed from this research seem to have an effect on warranting points, the difference when compared with the warranting points from the current tool seem to be marginal. This is due to the small difference in unlighted and lighted weights, and, the standard design characteristics of the study interchanges.

Overall, the enhancements and updates to the interchange lighting priority index tool could be efficiently used to prioritize interchanges based on safety in addition to other critical factors pertaining to geometric, traffic, and environmental conditions at the location.

Providing lighting at obsolete sections because of no traffic at night, due to closure of business or change in land use, is cost prohibitive. Field observations indicate that most businesses except gas stations in urban areas at the selected interchanges are closed by 10:00 PM. The nighttime traffic volume is less than 15% of ADT. This suggests that using 25% of ADT or values obtained from traffic forecasters in the Statewide Planning Branch as nighttime traffic volume may result in overestimating warranting points.

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Disclaimer

The contents of this report reflect the views of the authors and not necessarily the views of the university. The authors are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of either a NCDOT or the Federal Highway Administration at the time of publication. This report does not constitute a standard, specification, or regulation.

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Analyzing Severity of Vehicle Crashes at Highway-Rail Grade Crossings: Multinomial Logit Modeling

by Wei (David) Fan, Martin R. Kane, and Elias Haile

The purpose of this paper is to develop a nominal response multinomial logit model (MNLM) to identify factors that are important in making an injury severity difference and to explore the impact of such explanatory variables on three different severity levels of vehicle-related crashes at highway-rail grade crossings (HRGCs) in the United States. Vehicle-rail and pedestrian-rail crash data on USDOT highway-rail crossing inventory and public crossing sites from 2005 to 2012 are used in this study. A multinomial logit model is developed using SAS PROC LOGISTICS procedure and marginal effects are also calculated. The MNLM results indicate that when rail equipment with high speed struck a vehicle, the chance of a fatality resulting increased. The study also reveals that vehicle pick-up trucks, concrete, and rubber surfaces were more likely to be involved in more severe crashes. On the other hand, truck-trailer vehicles in snow and foggy weather conditions, development area types (residential, commercial, industrial, and institutional), and higher daily traffic volumes were more likely to be involved in less severe crashes. Educating and equipping drivers with good driving habits and short-term law enforcement actions, can potentially minimize the chance of severe vehicle crashes at HRGCs.

INTRODUCTION

Fatalities resulting from motor vehicle crashes is the fifth leading cause of death in the United States. Data from the National Highway Traffic Safety Administration indicate that since 1949 more than 30,000 (40,000 average) fatalities result from motor vehicle crashes every year. However, the current trend shows this number is declining. For example, a 1.9% decrease in crash-related fatalities was observed in 2011 as compared with 2010. Nonetheless, crash-related injuries are still large in number. In 2011, an estimated 2.22 million people were injured in motor vehicle traffic crashes and 2.24 million in 2010 (NHTSA 2012). Fatal crashes on highway-rail grade crossings (HRGCs) contributed to 261 deaths in 2010 and 251 in 2011 (FRA 2012).

HRGCs are conflict points between highway users and rail equipment (e.g., locomotive, freight car, caboose, or service equipment car operated by a railway company), which have contributed to a considerable amount of crashes in U.S. history. Though the trend of highway user crashes with rail equipment is showing a decrease in numbers, much has yet to be done to improve the safety of HRGCs. Unlike highway traffic crashes, a significantly high percentage of vehicle-rail crashes lead to fatality and injury to vehicle users. For example, data in the past eight years (2005-2012) indicate that 8.55% of vehicle-rail crashes were fatal and 26.68% resulted in injury (FRA 2012). However, in the case of highway traffic crashes, the percentage of fatal crashes is no more than 2% (NHTSA 2012).

Despite the fact that highway user-rail crashes had significant impacts on highway user safety, the subject still receives little attention and is under-cited. An understanding of the factors contributing to the levels of injury severity is an important step toward making the transportation system safer and more attractive. Responsible jurisdictions may use the results of this research to derive road user safety measures and policies.

One of the most important tasks in improving road safety is to uncover influential factors and then to develop countermeasures. The relationship between the injury severity of traffic crashes and factors such as driver and passenger characteristics, pedestrian age and gender, vehicle type, environmental conditions, traffic, and geometric conditions has attracted much attention. A better understanding of this relationship is necessary and very important for improving facility design so that crashes can be reduced. It is important to note that reducing crash frequency and reducing crash-injury severity may necessitate different strategic approaches. The development of effective countermeasures requires a thorough understanding of the factors that affect the likelihood of a crash occurring or, given that a crash has occurred, the characteristics that may mitigate or exacerbate the degree of injury sustained by crash-involved road users. To gain such an understanding, safety researchers have applied a wide variety of methodological techniques over the years.

Numerous studies have applied statistical models for crash injury severity studies. Among them, the ordered probit, ordered logit, and their variations are the most often used models. Savolainen et al. (2011) briefly discussed and summarized a wide range of methodological tools applied to study the impact of various factors on motor vehicle crash injury severities. As presented in the paper, ordered logit and probit, multinomial logit, binary logit and binary probit, and nested logit are some of the frequently used statistical methodologies. In particular, logistic regression has been widely applied to model crash severity levels. Variables such as elements of geometric design, traffic operational measures, and environmental conditions are considered as independent variables to estimate the severity. Savolainen et al. (2011) also applied the logistic regression modeling approach (specifically an unordered logit model) to estimate the three levels of highway user crash severity on HRGC as a function of various factors involved. The explanatory variables were obtained from the USDOT crossing inventory and crash data.

This purpose of this study is to analyze the severity of vehicle crashes at USDOT public HRGCs from 2005 to 2012, and to investigate the impact of various factors involved in the crashes. The remainder of this paper is organized as follows. The second section presents a literature review on existing studies regarding vehicle crash severity modeling. The third describes the MNL modeling methodology. The fourth section discusses the data assembly and analysis of the research. Section five presents numerical results and discussion. The sixth section discusses the conclusions and recommendations are also made.

LITERATURE REVIEW

Several studies have been conducted to model crash severity and investigate the impacts of various factors involved in the crashes. Mercier et al. (1999) conducted a study (using data from the Iowa Department of Transportation for 1986 to 1993) and tested the hypothesis that older drivers and passengers would suffer more severe injuries than younger adults in the presence of broadside and angle collisions of automobiles on rural highways. Logistic modeling, Hierarchical Regression Analysis, and Principal Components Regression, were analysis tools applied. Injury severity levels, fatal, major, and minor, were considered as dependent categorical variables. Some of the independent variables considered were occupant age, occupant position relative to point of impact, and protection. According to the study, age-related variables were generally more significant predictors of injury severity for females than for males. It was also identified that use of lap and shoulder restraints reduces injury severity and is less certain for females. For females only, air bags deployed were reported as significant injury severity predictors.

By using sequential binary logistic regression, Dissanayake and Lu (2002) modeled crash severity for single-vehicle fixed object crashes involving young drivers using data from the Florida Traffic Crash Database for the two-year period (1997 and 1998). The five crash severity categories considered were no injury, possible injury, non-capacitating injury, incapacitating injury, and fatal. As reported in the study, factors such as alcohol or drug influence, ejection in the crash, point of impact, rural crash locations, existence of curve or grade at the crash location, and speed of vehicle significantly increased the probability of more severe crashes. On the other hand, restraint device usage and drivers being male were reported to reduce the chance of high severity crashes. It was also indicated that factors such as weather condition, residence location, and physical condition have no significant relation in the model.

Duncan et al. (1998) conducted a study to investigate car occupant injury severity in two-vehicle passenger car-truck rear-end collisions by using an ordered probit model. The 1993-95 Highway Safety Information System (HSIS) data for collisions between heavy trucks and passenger cars in North Carolina were used for analysis. As reported in the study, factors such as darkness, high speed differentials, high speed limits, grades, being in a car struck to the rear, driving while drunk, and being female increased the passenger vehicle occupant injury severity. On the other hand, factors such as snowy or icy roads, being in a child restraint, and congested roads decreased the severity level. It was also indicated that interaction effects of cars being struck to the rear with high speed differentials and car rollovers were significant and increased the injury severity.

Donnell and Mason (2004) conducted a study and developed median-related crash severity models using data collected from Pennsylvania Department of Transportation between 1994 and 1998. Three crash severity classes, fatal, injury, and property damage only (PDO), were considered as independent variable outcomes. Both ordinal and nominal response logistic regression models were developed in the study. As indicated in the report, the ordinal response model gave better results for cross-median crashes. On the other hand, the nominal response model gave better results for median-barrier crashes. Furthermore, variables such as highway surface conditions, use of drugs or alcohol, presence of an interchange entrance ramp, horizontal alignment, crash type, and average daily traffic volume were reported to have some significant positive or negative effects on crash severity.

By using paired comparison analysis and ordered probit model, Renski at al. (1999) conducted a study to test the hypothesis that a speed limit increase will result in an increase in driving speed and produce higher crash severity. The study was focused on single-vehicle crashes on interstate roadways in North Carolina. As reported in the study, increasing speed limits from 89 to 97 km/hour (55 to 60 mph) and from 89 km/hour (55 mph) to 105 km/hour (65 mph) increased the probability of sustaining minor and non-capacitating injuries. However, the study indicated that increasing speed limits from 105 km/hour (65 mph) to 113 km/hour (70mph) did not show a significant effect on crash severity.

Huang et al. (2002) investigated the effects of road diets in which four-lane undivided roads were converted into three lanes. A road diet, also called a lane reduction or road rechannelization, is a technique in transportation planning whereby a road is reduced in number of travel lanes and/or effective width in order to achieve systemic improvement. Twelve road diets and 25 comparison sites in California and Washington cities were analyzed in the study. A before and after analysis was conducted and it was reported that road-diet crashes that occurred during the "after" period were observed to be about 6% lower than that of the comparison sites.

Khattak (2001) conducted a study that investigated the effect of vehicle technologies on crash injury severity. The North Carolina 1994-1995 HSIS crash data were used for the analysis. Three separate ordered probit models were developed for the three drivers, Driver 1 (leading), Driver 2 (striking), and Driver 3 (striking in a three-vehicle crash). As indicated in the study, in a two-vehicle rear-end collision the leading driver is more likely to be injured, whereas in a three-vehicle collision the driver in the middle is more likely to be injured. It was also stated that being in a newer vehicle protects the driver in rear-end collisions. Moreover, the study showed the benefit of technological improvements on driver safety.

Mercier at al. (1997) performed a study and tested the hypothesis that older drivers and passengers would suffer more severe injuries than younger adults in the presence of head-on collisions of automobiles on rural highways. Study data were drawn from the Iowa Department of Transportation's accident files from 1986 through part of 1993. Logistic modeling, Hierarchical Regression Analysis, and Principal Components Regression were applied. Injury severity levels, fatal, major, and minor, were considered as dependent categorical variables (which take on one of a limited number of possible values). The independent variables considered included, among others, occupant age, occupant position relative to point of impact, and level of protection. As stated in the study, age was an important factor in predicting injury severity for both men and women. The study concluded that older drivers and passengers experienced more severe injury than any of the other age groups. Use of lap and shoulder devices was reported to be more important for men than women while the reverse was true for deployed air bags.

Chira-Chavala et al. (1996) investigated the characteristics and probable causes of light rail transit system crashes and developed a crash severity model for the Santa Clara County Transit Agency. A binary logit model was applied to predict the probability of injury accident as a function of explanatory variables such as speeds before collision of light rail vehicles and motor vehicles and movement of the motor vehicle before collision. As reported in the study, left-turn vehicle movements, higher speeds of the motor vehicle or the LRV, and accidents occurring during peak hours increased the probability of injury crashes.

Chen and Jovanis (2000) developed and tested the variable-selection procedure that avoids problems occurring due to the presence of a large number of potential factors, the complex nature of crash causes and outcomes, and a large number of categories in crash-severity modeling. Bus-involved crash data for Freeway 1 in Taiwan from 1985 through 1993 were used. The procedure consisted of the chi-squared automated interaction detection (CHAID) method to collapse categories. Person chi-square test was used to assess the relationship between dependent and independent variables and log-linear modeling techniques. As indicated in the study, the log-linear model showed that late-night or early-morning driving increased the risk of severe injury crashes for bus drivers. It was also stated that bus crashes involving a large truck or tractor-trailers increased the risk of severe injury crashes.

By using an ordered probit model, Khattak at al. (2002) explored factors contributing to more severe older driver (age 65 and above) crash injury severity by analyzing 1990-1999 crash data from Iowa. According to the study, older male drivers are more prone to injury as compared with older female drives. It was stated that older drivers under the influence of alcohol experienced more severe injuries. It was also indicated that older driver injuries involving farm vehicles are more severe as compared with other vehicle types.

Xie et al. (2009) conducted a study that demonstrated application of a Bayesian ordered probit model in drivers' injury severity analysis. In the Bayesian probit model, prior distributions such as means and variances were included, reflecting the analysts' prior knowledge about the data. Comparisons were made between Bayesian ordered probit and conventional ordered probit models. As reported in the study, for large data size, model fitting results obtained from the Bayesian and the conventional probit model have no significant differences. It was also reported that for small sample size, a Bayesian probit model produced parameter estimates with better prediction performance than the conventional ordered probit model.

Some recent research efforts were also made to the joint estimation of two dependent variables that were closely related to each other in order to improve the efficiency of uncovering the influential factors. For example, Ye et al. (2009) developed a simultaneous equations model of crash frequency by collision type for rural intersections. Ye et al. (2013) developed and presented a similar multivariate Poisson regression to model the crash frequency by severity level for freeway sections in this paper. Along this same line, a generalized Poisson model was developed to assess the effects of demographic factors, driving habits, and medicinal use on elderly driver automobile crashes (Famoye et al. 2004). Likewise, several multivariate Poisson-lognormal regression models were presented for jointly modeling crash frequency by severity and applied to a case study in California

(Park and Lord 2007). The results showed promise toward the goal of obtaining more accurate estimates by accounting for correlations and over-dispersion (Park and Lord 2007).

Gitelman and Hakkert (1997) developed a method to evaluate road-rail crossing safety with limited accident statistics when the need for grade separation was discussed using available Israeli accident data. Austin and Carson (2002) developed an alternate highway-rail crossing accident prediction model using negative binomial regression, which showed great promise. Saccomanno et al. (2004) developed risk-based models for identifying high-rail grade crossing blackspots (i.e., crossings with unacceptable risks of involving high expected collision frequencies or consequences or both). Miranda-Moreno et al. (2005) compared the relative performance of three alternative models for ranking locations for safety improvement, which included the traditional negative binomial model, the heterogeneous negative binomial model, and the Poisson lognormal model. These models were calibrated using a sample of Canadian highway-railway intersections with an accident history of five years. It was concluded that the choice of model assumptions and ranking criteria can lead to considerably different lists of hazardous locations. Saccomanno et al. (2007) conducted a research study of estimating countermeasure effects for reducing collisions at highway-railway grade crossings. Park and Saccomanno (2007) developed a propensity score method to reduce treatment selection bias for estimating treatment effects. The model was also applied to Canadian highway-railway grade crossings data to estimate reductions in collisions due to upgrades in warning devices. It was shown that the propensity score method could be used to reduce treatment selection bias. Hu et al. (2010) investigated key factors and developed a generalized logit model to estimate the accident severity at railroad grade crossings in Taiwan.

As discussed, crashes occurring at HRGCs have a significant effect on highway user safety, and the importance of conducting research in such areas is evident. However, compared with the amount of work on general highway traffic crashes, this subject receives relatively less attention, although some research efforts have been made in this particular area. As such, the objective of this research is to explore the impacts of various factors contributing to different levels of crash severity to vehicle users as a result of vehicle-rail crashes on HRGCs. A nominal response multinomial logit model with three levels of severity was used to model the impact of various factors that include vehicle driver characteristics, environmental factors, railroad crossing characteristics, highway characteristics, land use type, and more. The three levels of responses considered were fatality, injury, and no injury. The SAS PROC LOGISTICS procedure was used to develop the model.

METHODOLOGY

The MNLM formulation is well discussed by Long (1997). If y is the response variable with J nominal (i.e., categorical) outcomes (which takes on one of a limited number of possible values), then the assumption of the multinomial logit model is that category 1 through J are not ordered (i.e., not arranged in an increasing or decreasing order). Also, let $\Pr(y=m|x)$ be the probability of observing outcome m given the independent variable x. The model for y is constructed as follows:

- Assume that $\Pr(y=m|x)$ is a linear combination $x\beta_m$. The vector $\beta_m = (\beta_{0m \ldots}\ \beta_{km \ldots}\ \beta_{Km})$ contains the intercept β_{0m} and coefficients of β_{km} for the effects of x_k on outcome m.
- To ensure non negativity for the probabilities, the exponential of $x\beta_m$ is used.
- For the probabilities to sum to 1, divide $\exp(x\beta_m)$ by $\sum_{j=1}^{J} \exp(x_i\beta_j)$.

$$(1)\quad \Pr(y_i = m|x_i) = \frac{\exp(x_i\beta_m)}{\sum_{j=1}^{J} \exp(x_i\beta_j)}$$

Though the probability sum is 1, the set of parameters that generates the probabilities is not identified since more than one set of parameters can generate the same probabilities. In order to identify the set of parameters that generate the probabilities, a constant must be imposed. By imposing one of the parameter estimates to be equal to zero (assume β_1=0), the model can be written as follows:

(2) $\Pr(y_i = 1|x_i) = \frac{1}{1 + \sum_{j=2}^{J} \exp(x_i \beta_j)}$

(3) $\Pr(y_i = m|x_i) = \frac{\exp(x_i \beta_m)}{1+\sum_{j=2}^{J} \exp(x_i \beta_j)} \qquad for\, m > 1$

The parameter estimates are determined using maximum likelihood estimation. If the observations are independent, the likelihood eq. (4) is given by:

(4) $(\beta_2, \ldots . \beta_J | y, x) = \prod_{i=1}^{N} P_i$

Where P_i is the probability of observing whether values of y was actually observed for the i^{th} observation. Combining the eq. (1) with this eq. (4) in place of P_i the likelihood eq. (5) can be written as:

(5) $L(\beta_2, \ldots \beta_J | y, x) = \prod_{m=1}^{J} \prod_{y_{i=m}} \frac{\exp(x_i \beta_m)}{\sum_{j=1}^{J} \exp(x_i \beta_j)}$

Where $\prod y_{i=m}$ is the product over all cases for which y_i is equal to m. Taking logs, we may obtain the log likelihood function, which can be maximized with numerical methods to estimate the β's.

The overall model fitness can be compared by using the model's log-likelihood at convergence with the log-likelihood of a naive model (model with all coefficients set to zero, which is equivalent to assigning equal probability for all outcomes). It is also possible to compare a model with only alternative constants (assigning probability to outcomes equal to the observed share of the outcomes in the dataset).

(6) $\rho^2 = 1 - \frac{LL(\beta)}{LL(0)}$

Where LL (β) represents the log-likelihood at model convergence, LL(0) represents the log-likelihood of a naïve model (without information). The ρ^2 goes from 0 (for no improvement in the log-likelihood) to 1 for a perfect fit. A value for ρ^2 larger than 0.1 indicates meaningful improvement (Long 1997).

The marginal effect or partial change can be determined by taking derivative of Eq. (1) with respect to x_k as described in the following eq. (7).

(7) $\frac{\partial Pr(y=m|x)}{\partial x_k} = \Pr(y = m|x) [\beta_{km} - \sum_{j=1}^{J} \beta_{kj} \Pr(y = j|x)]$

Marginal effect is the slope of the curve relating x_k to $\Pr(y=m|x)$, holding other variables constant. Variables are held at their means, possibly with dummy variables at 0 or 1.Though the computation of the change in the probability is important to interpret the effects of the MNLM, it has limitations. Firstly, the discrete change indicates the change for a particular set of values of the independent variables, which means at different levels of these variables, the changes will be different. And the second limitation is that it measures the discrete change, which does not indicate the changes among the dependent outcome due to infinitely small changes in independent variables (Long 1997).

An odds ratio can also be used in the interpretation of the developed model. The odds ratio is defined as the ratio of the odds of those with the risk factor to the odds for those without the risk factor. Generally, the odds ratio associated with a one-unit increase in the risk factor can be computed by the exponential function of the regression coefficient of that risk factor (SAS 2008).

DATA ASSEMBLY AND ANALYSIS

Vehicle-rail crash data on the USDOT public crossing sites from 2005 to 2012 are used in this study. In order to acquire more explanatory variables, the USDOT highway-rail crossing inventory was also included. The crash data and the crossing inventory data were merged based on the USDOT identification number. The SAS PROC SQL was used to merge and clean the data (i.e., removing data errors). After the data merging and cleaning process, a total of 7,414 records were obtained and used in the modeling stage. The data used to create the data set were obtained from the Federal Railroad Administration (2012).

Table 1 presents the descriptive statistics of some of the variables from such HRGC crash and inventory data. As shown, the distribution of vehicle-rail crash severity is 6.80%, 26.63% and 66.58% for fatal, injury, and no injury, respectively. This distribution of crash severity indicates 33.43% of vehicle crashes at HRGC sites lead to fatality or injury. The majority (78.64%) of vehicle-rail crashes at HRGC sites occurred when the rail equipment struck the vehicle while the remaining (21.36%) were when the vehicle struck the rail equipment. It is shown in the table that a majority (53.09%) of vehicles involved in the vehicle-rail crashes are cars, and the majority (71.01%) of vehicle crashes occurred in clear weather conditions.

The HRGC sites where crashes occur are located in different development areas. As one can see from Table 1, 32.37% of the crossings are located in open space areas, 21.51% in residential areas, and 28.10% in commercial areas. The rest are found in industrial and institutional development areas. The majority (74.99%) of the HRGCs cross two-lane highways. Descriptive statistics of other variables are also shown in the table. All variables that are available in the database are considered in this study. Some of the continuous variables are converted into categorical variables and the MNLM is applied to estimate the model parameters.

RESULTS AND DISCUSSION

Many variables obtained from the crossing inventory and crash data were used in developing the nominal response MNLM. During the final preferred model development process, some of the variables were found to be statistically insignificant and hence removed in a stepwise manner. PROC LOGISTIC procedure was applied with significance level being 0.1 to retain some of the variables.

Tables 2 and 3 present the results obtained from this study. In this modeling, three vehicle-rail crash severity levels (fatal crashes, injury crashes, and no injury crashes) were considered as the dependent variable. Among the three crash severity levels, no injury crashes were considered the base case. Therefore, coefficients estimated for the explanatory variables are values representing the relative effect of contributing factors on fatal or injury crashes compared with no injury crashes. Positive estimates in the model indicate that the chance of injury or fatal crash increases as the value of the independent variables increases, while negative estimates indicate that the chance of injury or fatal crash decreases as the value of the independent variables increases.

As shown in Table 2, some of the variables are not statistically significant. However, since the main interest of this paper is to examine how the chance of injury and fatal (both) crash increases or decreases (separately or simultaneously) corresponding to a one-unit change in the value of the independent variables, for the sake of facilitating interpretation of the results, those variables were still retained in the model if at least one of variables/factors in the same parameter category was significant in at least one of the models (injury and/or fatality). This actually induces reduction in efficiency of the model. Furthermore, a 90% confidence level was considered instead of 95% (Tay et al. 2011).

Table 1: Descriptive Statistics of Variables from HRGC Crash and Inventory Data

Variable	Category	Frequency	Percent
Crash Characteristics			
INJURY (crash severity level)	3=Fatal crashes	504	6.80
	2=Injury crashes	1974	26.63
	1=No Injury crashes	4936	66.58
TYPACC (Type of accident)	1=Train struck vehicle	5830	78.64
	2=Vehicle struck train	1584	21.36
Vehicle Characteristics			
TYPVEH (Type of vehicle)	1=Auto	3936	53.09
	2=Truck	542	7.31
	3=Truck trailer	1298	17.51
	4=Pickup truck	1317	17.76
	5=Van	306	4.13
	6=Bus	10	0.13
	7=School Bus	5	0.07
VEHSPD (Vehicle speed)	1=<40km/hour (<25mph)	6312	85.14
	2=40-72km/hour (25-45mph)	830	11.20
	3=>72km/hour (>45mph)	272	3.67
(AADT) (Average annual daily traffic)	1=<10,000	6525	88.01
	2=10,000-20,000	602	8.12
	3=20,000-30,000	177	2.39
	4=>30,000	110	1.48
Train Characteristics			
TRNSPD (Train speed)	1=<40km/hour (<25mph)	2999	40.45
	2=40-72km/hour (25-45mph)	2549	34.38
	3=>72km/hour (>45mph)	1866	25.17
Vehicle Driver Characteristics			
DRVAGE	1=<25 Years	1186	16.00
	2=25-60 Years	3978	53.66
	3=>60 Years	1029	13.88
	Missing	1221	16.47
DRIVGEN (Vehicle driver gender)	1=Male	5645	76.14
	2=Female	1769	23.86
Highway Characteristics			
HWYPVED (Highway surface type)	1=Paved	6042	81.49
	2=Unpaved	1372	18.51
HWYSGNL (Highway signal)	1=Not present	7215	97.32
	2=Present	199	2.68

Table 1 (continued)

Variable	Category	Frequency	Percent
TRAFICLN (No. of traffic lane)	1=1 Lane	644	8.69
	2=2 Lanes	5560	74.99
	3=3 Lanes	87	1.17
	4=4 Lanes	872	11.76
	5=≥5 Lanes	251	3.39
Environmental Characteristics			
DEVELTYP (Development area type)	1=Open space	2400	32.37
	2=Residential	1595	21.51
	3=Commercial	2083	28.1
	4=Industrial	1226	16.54
	5=Institutional	110	1.48
WEATHER (Weather condition)	1=Clear	5265	71.01
	2=Cloudy	1406	18.96
	3=Rain	445	6
	4=Fog	107	1.44
	5=Sleet	15	0.2
	6=Snow	176	2.37
TEMP (Temperature)	1=<10°C (50°F)	2074	27.97
	2=10°-27°C (50°-80°F)	3624	48.88
	3=>27°C (80°F)	1716	23.15
NEAREST (Intersecting IN or Near city)	1=In city	4244	57.24
	2=Near city	3170	42.76
Crossing Characteristics			
XSURFACE (Crossing surface type)	1=Timber	2049	27.64
	2=Asphalt	3015	40.67
	3=Asphalt & Flange	445	6
	4=Concrete	920	12.41
	5=Concrete & Rubber	266	3.59
	6=Rubber	413	5.57
	7=Metal	3	0.04
	8=Unconsolidated	256	3.45
	9=Other	47	0.63
XBUCK (Cross bucks)	1=Not Present	2348	31.67
	2=Present	5066	68.33
FLASH (Flashlight)	1=Not present	3475	46.87
	2=Present	3939	53.13
GATES (Gates)	1=Not Present	6371	85.93
	2=Present	1043	14.07

Table 2: Multinomial Logistic Model Regression Results

Parameter	Injury		Fatal	
	Estimate	P-value	Estimate	P-value
Intercept	-1.1553*	<.0001	-4.4843*	<.0001
VEHSPD (Ref:<40km/hour (<25mph))				
40-72km/hour (25-45mph)	0.6457*	<.0001	0.7110*	<.0001
>72km/hour (>45mph)	0.9211*	<.0001	1.6351*	<.0001
TYPVEH (Ref: Auto)				
Truck	0.0581	0.6299	0.0846	0.6604
Truck-trailer	-0.1967*	0.0316	-1.5297*	<.0001
Pick-up truck	0.1480*	0.0766	0.0385	0.7808
Van	0.0756	0.6144	-0.2670	0.3401
Bus	0.7259	0.4470	-9.9575	0.9790
School bus	1.0507	0.2969	-10.0643	0.9820
TYPACC (Ref: vehicle struck rail equipment)				
Rail equipment struck vehicle	-0.1107	0.1476	0.6935*	<.0001
TEMP(Ref: <10°C (50°F))				
10°-27°C (50°-80°F)	0.1029	0.1654	0.0671	0.6081
>27°C (80°F)	0.2520*	0.0034	0.1148	0.4494
WEATHER (Ref: Clear)				
Cloudy	-0.0399	0.6056	-0.0438	0.7463
Rain	-0.1611	0.2240	-0.4313	0.1130
Fog	0.0295	0.9021	-1.2110	0.1003
Sleet	0.4891	0.4086	-10.7328	0.9568
Snow	-0.6097*	0.0087	-0.6858	0.1285
TRNSPD (Ref: <40km/hour (<25mph))				
40-72km/hour (25-45mph)	0.6274*	<.0001	1.7280*	<.0001
>72km/hour (>45mph)	0.6433*	<.0001	2.7725*	<.0001
DRIVGEN (Ref: Female)				
Male	0.3848*	<.0001	0.2965*	0.0176
DEVELTYP(Ref: Open space area)				
Residential	-0.1907*	0.0231	-0.1882	0.1913
Commercial	-0.3342*	<.0001	-0.3510*	0.0171
Industrial	-0.4128*	<.0001	-0.1197	0.5122
Institutional	-0.4649*	0.0666	-0.5219	0.2897

Table 2 (continued)

Parameter	Injury		Fatal	
	Estimate	P-value	Estimate	P-value
XSURFACE(Ref: Timber)				
Asphalt	-0.2094*	0.0043	-0.4813*	0.0002
Asphalt & Flange	-0.1327	0.3229	-0.6683*	0.0143
Concrete	0.0793	0.4405	0.0422	0.8002
Concrete & Rubber	0.0897	0.6240	0.5610*	0.0428
Rubber	0.0745	0.6092	-0.3451	0.2467
Metal	-0.4770	0.7027	-10.1543	0.9825
Unconsolidated	-0.3027*	0.0669	-0.1017	0.6871
Other	-0.2763	0.4752	-0.3334	0.6653
AADT(Ref:<10,000)				
10,000-20,000	-0.0882	0.4556	-0.4342*	0.0698
20,000-30,000	-0.5348*	0.0184	-0.8054*	0.0755
>30,000	-0.2838	0.2595	-0.9880*	0.0788
DRIVAGE(Ref:<25 Years)				
25-60 Years	0.0727	0.3548	0.2983*	0.0452
>60 Years	0.2706*	0.0069	1.2399*	<.0001
Number of observation= 7,414, ρ^2=0.011, $\chi 2$ for likelihood ratio =943.787, P-value for chi square= 0.000				

Based on the parameter estimates obtained in Table 2, the MNL models can be written as follows. Note that the information about driver under the influence or not is unavailable in the dataset and thus not included in the analysis.

$$(8)\quad \log\left[\frac{P(Y = Fatal)}{P(Y = No\ Injury)}\right] = -4.4843 + 0.7110X_1 + 1.6351X_2 - 1.5297X_3 + 0.0385X_4 + 0.6935X_5 + 0.11 \\ - 0.6858X_7 - 1.2110X_8 + 1.7280X_9 + 2.7725X_{10} + 0.2965X_{11} - 0.1882X_{12} \\ - 0.3510X_{13} - 0.1197X_{14} - 0.5219X_{15} - 0.4813X_{16} - 0.1017X_{17} - 0.6683X_{18} \\ + 0.5610X_{19} - 0.4342X_{20} - 0.8054X_{21} - 0.9880X_{22} + 0.2983X_{23} + 1.2399X_{24}$$

$$(9)\quad \log\left[\frac{P(Y = Injury)}{P(Y = No\ Injury)}\right] = -1.1553 + 0.6457X_1 + 0.9211X_2 - 0.1967X_3 + 0.1480X_4 - 0.1107X_5 + 0.25 \\ - 0.6097X_7 + 0.0295X_8 + 0.6274X_9 + 0.6433X_{10} + 0.3848X_{11} - 0.1907X_{12} - \\ - 0.4128X_{14} - 0.4649X_{15} - 0.2094X_{16} - 0.3027X_{17} - 0.1327X_{18} + 0.0897X_{19} \\ - 0.5348X_{21} - 0.2838X_{22} + 0.0727X_{23} + 0.2706X_{24}$$

Where:

X_1 = Vehicle speed category (1 if vehicle speed is 40-72 km/hour (25-45 mph), 0 otherwise)

X_2 = Vehicle speed category (1 if vehicle speed is >72 km/hour (>45 mph), 0 otherwise)

X_3 = Vehicle type indicator (1 if vehicle is truck-trailer, 0 otherwise)

X_4 = Vehicle type indicator (1 if vehicle is pick-up truck, 0 otherwise)

X_5 = Accident type indicator (1 if rail equipment struck vehicle, 0 otherwise)

X_6 = Temperature indicator (1 if temperature is greater than 27°C (80°F), 0 otherwise)

X_7= Weather indicator (1 if snowy weather, 0 otherwise)

X_8= Weather indicator (1 if foggy weather, 0 otherwise)

X_9 = Train speed category (1 if train speed is 40-72 km/hour (25-45 mph), 0 otherwise)

X_{10} =Train speed category (1 if train speed is >72 km/hour (>45 mph), 0 otherwise)

X_{11}= Vehicle driver gender indicator (1 if male, 0 otherwise)

X_{12} =Development area type indicator (1 if residential, 0 otherwise)

X_{13}= Development area type indicator (1 if commercial, 0 otherwise)

X_{14}= Development area type indicator (1 if industrial, 0 otherwise)

X_{15}= Development area type indicator (1 if institutional, 0 otherwise)

X_{16}= HRGC surface type (1 if surface is asphalt, 0 otherwise)

X_{17}= HRGC surface type (1 if surface is unconsolidated, 0 otherwise)

X_{18}= HRGC surface type (1 if surface is asphalt and flange, 0 otherwise)

X_{19}= HRGC surface type (1 if surface is concrete and rubber, 0 otherwise)

X_{20}= Traffic volume indicator (1 if AADT is 10,000-20,000, 0 otherwise)

X_{21}= Traffic volume indicator (1 if AADT is 20,000-30,000, 0 otherwise)

X_{22}= Traffic volume indicator (1 if AADT is >30,000, 0 otherwise)

X_{23}= Vehicle driver age indicator (1 if age is 25-60 years, 0 otherwise)

X_{24}= Vehicle driver age indicator (1 if age is >60 years, 0 otherwise)

In particular, it should be noted that by dropping insignificant variables (one at a time) through conducting a series of tests, the preferred model may actually be different from the above models. However, again, since the main interest of this paper is to examine how the chance of injury and fatal (both) crash increases or decreases (separately or simultaneously) corresponding to a one-unit change in the value of the independent variables, for the convenience and consistency of illustration purposes, the MNL models developed in eqs. (8-9) are used as the final preferred models. Based on the above MNL model eqs. (8-9), the marginal effect/value is also determined and presented in Table 3. As can be seen in Table 3, the sum of marginal effect is zero, which satisfies the requirement that the sum of probability is 1. Using the values in the first row of Table 3 as an example, as vehicle speed changes from category (<40 km/hour [<25 mph]) to category (40-72 km/hour [25-45 mph]), the probability of fatal and injury crashes increases by 0.028 and 0.135, respectively, while the probability of no injury crashes decreases by -0.163. The marginal effect for the remaining variables provides a great deal of valuable information for interpreting results.

As shown in Table 2, vehicle speed was one among several explanatory variables that are considered and used to estimate the vehicle-rail crash severity level. Vehicle speed was categorized into three levels (<40 km/hour [<25 mph], 40-72km/hour [25-45mph], and >72 km/hour [>45 mph]). According to the result, two speed categories (40-72 km/hour [25-45 mph] and >72 km/hour [>45 mph]) were statistically significant and had higher probability of resulting in injury and fatal crashes. It was also shown that the parameter estimate for vehicle speed category three (>72 km/hour [>45 mph]) was higher than vehicle speed category two (40-72 km/hour [25-45 mph]). This indicates that higher vehicle speed has a detrimental effect of increasing the chance of fatal and injury crashes. In this regard, reducing vehicle speed will definitely help in reducing the chance of more severe vehicle-rail crashes at HRGCs.

Table 3: Marginal Effects Results

Variable	P(Fatal)	P(Injury)	P(No injury)
Vehicle speed (40-72 km/hour [25-45 mph])	0.028	0.135	-0.163
Vehicle speed (>72 km/hour [>45 mph])	0.026	0.323	-0.349
Vehicle type (truck-trailer)	0.020	-0.316	0.296
Vehicle type (pick-up)	0.009	0.005	-0.014
Accident type (rail equipment struck vehicle)	-0.022	0.148	-0.125
Temperature (>27^{o}C (80^{o}F))	0.014	0.019	-0.033
Weather (snow)	-0.026	-0.131	0.157
Weather (foggy)	0.028	-0.254	0.226
Train speed (40-72 km/hour [25-45 mph])	0.005	0.349	-0.353
Train speed (>72 km/hour [>45 mph])	-0.017	0.567	-0.550
Vehicle driver gender (male)	0.019	0.054	-0.073
Development area type (residential)	-0.009	-0.035	0.044
Development area type (commercial)	-0.015	-0.066	0.081
Development area type (industrial)	-0.025	-0.016	0.041
Development area type (institutional)	-0.020	-0.099	0.119
HRGC surface type (asphalt)	-0.004	-0.096	0.100
HRGC surface type (unconsolidated)	-0.018	-0.015	0.033
HRGC surface type (asphalt and flange)	0.006	-0.137	0.132
HRGC surface type (concrete and rubber)	-0.006	0.116	-0.110
Traffic volume (AADT 10,000-20,000)	0.003	-0.089	0.086
Traffic volume (AADT 20,000-30,000)	-0.018	-0.157	0.176
Traffic volume (AADT >30,000)	0.002	-0.201	0.199
Vehicle driver age (25-60 years)	-0.002	0.061	-0.059
Vehicle driver age (>60 years)	-0.009	0.254	-0.245

Likewise, train speed was categorized into three levels and also found to be statistically significant. Compared with train speed category one (<40 km/hour [<25 mph]), both higher train speed categories (40-72 km/hour [25-45 mph] and >45 mph) had increased probabilities of injury and fatal crashes. Like vehicle speed, higher train speed also has a detrimental effect of increasing the chance of fatal and injury crashes. As shown in Table 3, the marginal effect result indicates that probabilities of injury and fatal crashes increase as speed of vehicle increases. On the other hand, the probability of no injury crashes decreases as vehicle speed increases.

Seven vehicle categories (ranging from automobile to truck-trailer to school bus types) were considered in this study. Among these seven categories, both truck-trailers and pick-up trucks were found to be statistically significant. As shown in Table 2, truck-trailer vehicles were less likely to result in injury and fatal crashes as compared with automobiles. On the other hand, pickup trucks were more likely to result in injury and fatal crashes. The marginal effect result as shown in Table 3 indicates that truck-trailer vehicles increase the likelihood of fatal and no injury crashes while they decrease injury crashes; and that pickup trucks increase the likelihood of fatal and injury crashes and decrease that of no injury crashes. The reasons behind these interesting results are uncertain and need to be further investigated.

Two crash circumstances (rail equipment struck vehicle and vehicle struck rail equipment) were considered. The crash circumstance under which vehicle struck rail equipment was considered a reference (i.e., base) for comparison. As shown in Table 2, when rail equipment struck vehicle, crash severity was more likely to be fatal. On the other hand, this crash circumstance is less likely to result in injury crashes. Such results are expected and come as no surprise because fatal crashes are believed to be more likely when rail equipment struck vehicle.

Compared with low temperature (less than 10°C [50°F]), vehicle-rail crashes occurring at higher temperatures (greater than 27°C [80°F]) had increased the probability of injury and fatal crashes. As presented in Table 3, the marginal effect result also clearly indicates that higher temperature increases the chance of injury and fatal crashes while decreasing no injury crashes.

Regarding weather condition, snow and foggy conditions were found to be statistically significant. As presented in Table 2, snowy weather conditions were less likely to result in injury and fatal crashes as compared with clear weather conditions. Result also shows that foggy weather conditions were more likely to result in injury crashes but less likely to result in fatal crashes. This might suggest that, as compared with clear weather conditions, people are more likely to drive vehicles with caution under severe weather conditions (such as snow and foggy weather) and therefore the chance of resulting in more severe crashes is reduced.

Five different types of development area types were considered in this study. Compared with open space development areas, HRGCs located in commercial, residential, industrial, and institutional areas were less likely to result in injury and fatal crashes and they were all found to be statistically significant. The marginal effect results in Table 3 also confirm that HRGCs located in these development areas decrease the probability of injury and fatal crashes while the probability of no injury crashes increases. This might suggest that compared with open space development areas, vehicles are more likely to be driven with caution and therefore the probability of resulting in more severe crashes is reduced.

Various types of HRGC surfaces were investigated in this study. A timber crossing surface was considered a reference to which other crossing surface types are compared. As shown in Table 2, vehicle-rail crashes occurring on asphalt, asphalt and flange, and unconsolidated crossing surfaces were found to be less likely to result in injury and fatal crashes, and all these variables were found to be statistically significant. On the other hand, concrete and rubber crossing surface types were also found to be statistically significant; however, crashes occurring on such surfaces were more likely to be injury and fatal crashes. Similar results can also be seen in Table 3. This might indicate that compared with timber crossing surfaces, people are less likely to drive vehicles with caution on concrete surfaces and therefore the chance of resulting in more severe crashes is higher.

The Average Annual Daily Traffic (AADT) was also considered in order to investigate the effect of traffic volume on crash severity. The AADT was classified into four categories. The three AADT categories (i.e., AADT of 10,000-20,000, 20,000-30,000, and >30,000) were found to be statistically significant and they were less likely to result in injury and fatal crashes compared with category one (i.e., AADT less than 10,000). This probably suggests that compared with low traffic volume conditions, people are more likely to drive vehicles with caution under high traffic volume conditions and as a result, the chance of resulting in more severe crashes is reduced.

Finally, vehicle driver characteristics such as age and gender were considered in the study as explanatory variables. With respect to driver gender, male drivers were more likely to be involved in injury and fatal crashes as compared with female drivers and the variable was found to be statistically significant. The age of vehicle drivers is grouped into three categories. Vehicle driver age below 25 was considered a reference for comparison purpose. As shown in Table 2, driver age of 25-60 and above 60 years had higher probability of being involved in injury and fatal crashes. As shown in Table 3, the marginal effects confirm that vehicle drivers age 25-60 and above 60 years increase the probability of being involved in injury crashes while decreasing the probability of being involved in fatal and no injury crashes.

In addition to the model results of intercepts and slope coefficients for serious injury and fatality, the model can be interpreted by using the odds ratio, which is the exponential of parameter estimates obtained from the analysis. For example, the estimated coefficient for vehicle speed category three (i.e., >72 km/hour [>45 mph]) is 0.9211 and hence the relative effect of this speed category versus vehicle speed category one (i.e., <40 km/hour [<25 mph]) is =2.512. This indicates that the odds of vehicle crash severity being injury is 2.512 times higher if the speed of the vehicle is category three compared with that of vehicle speed category one. Similarly, the parameter estimate of vehicle driver age above 60 years, considering driver age below 25 years as a reference, is found to be 0.2706. So, the relative effect of drivers age above 60 years to age below 25 years on injury crashes is determined as =1.311. This indicates that the odds of injury crash severity versus no injury crashes are 1.311 times higher for drivers age above 60 years compared with those below 25 years. The odds ratio results of the rest of variables can also be interpreted in a similar fashion.

The probabilities of the three severity crashes (fatality, injury and no injury) can be predicted by using the following three eqs. (10-12).

$$(10)\quad P_{Fatal} = \frac{e^{equation(8)}}{[1 + e^{equation(8)} + e^{equation(9)}]}$$

$$(11)\quad P_{Injury} = \frac{e^{equation(9)}}{[1 + e^{equation(8)} + e^{equation(9)}]}$$

$$(12)\quad P_{No\ Injury} = 1 - (P_{Fatal} + P_{Injury})$$

The probability of the three different severity levels of vehicle-rail crashes are determined based on the parameters estimated for the indicator variables in the models as shown in eqs. (8-9) and the probability eqs. (10-12) shown above. Accordingly, the predicted average probability of fatal, injury, and no injury severity levels are 0.072, 0.299, and 0.629, respectively by using these equations. And the observed crash severity from the original data (as discussed and shown in the “Data Assembly and Analysis” section) was 0.069, 0.334, and 0.597 for fatality, injury, and no injury, respectively. Also as shown in Table 2, the ρ^2 determined for the model is 0.011, which indicates the model has some improvement over the naïve model (model without covariates).

CONCLUSION

Highway vehicle crash severity levels at HRGCs were modeled using MNLM in this paper. The three vehicle crash severity levels (fatality, injury, and no injury) were considered as dependent variables. Vehicle and vehicle user characteristics, environmental factors, type of development area, highway-rail crossing characteristics, highway traffic characteristics, vehicle speed, and train speed were the explanatory variables used in predicting crash severity levels. The analysis was conducted using SAS PROC LOGISTICS procedure. In order to retain some of the variables, those within 90% confidence level were considered statistically significant. Some of the variables were found to be statistically significant even at 95% confidence level.

As discussed in the paper, results indicate that as vehicle and/or train speeds increase, the chance of being involved in injury and fatal crashes at HRGCs also increases. Hence, reducing train and vehicle speeds at HRGCs will certainly minimize the chance of resulting in more severe crashes. It is noted that the majority of crashes occurred when rail equipment struck vehicles. In particular, this type of accident increases the chance of resulting in fatal crashes. As for vehicle types, truck-trailer vehicles are observed to decrease the probability of fatal crashes while pickup trucks increase such chances. It is also observed that male drivers above 25 years are more likely to be involved in injury and fatal crashes. Moreover, crashes occurring at higher temperatures are more likely to be injury and fatal compared with those occurring at low temperatures. Also, higher traffic volume (i.e., higher AADT) decreases the probability of resulting in injury and fatal crashes. Results seem to suggest that people are more likely to drive vehicles with caution at commercial/residential/industrial/institutional areas as opposed to open space development areas, under severe weather conditions (such as snow and foggy weather) compared with clear weather conditions, on non-concrete surfaces as opposed to concrete surfaces, and as a result, the chances of being involved in more severe crashes are reduced. In all, educating and equipping drivers with good driving habits (such as reducing speeds or stopping their vehicle completely regardless of a train being present or not) at HRGCs and short-term law enforcement actions, can potentially minimize the chance of resulting in more severe vehicle crashes at HRGCs.

Future research may be directed toward modeling the severity level at HRGCs using ordered logit, which can be modeled by the proportional odds models (McCullagh 1980) along with the conduct of a score test for proportional odds assumption (Strokes et al. 2000). Furthermore, future direction will be on developing a simultaneous equations model of crash frequency by severity level at HRGCs since this will improve the efficiency of uncovering the influential factors. Last but not least, the reasoning based on the empirical study results will need to be fully supported by field investigation evidences in the near future.

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Assessing the Effect of Compressed Work Week Strategy on Transportation Network Performance Measures

by Venkata R. Duddu and Srinivas S. Pulugurtha

The focus of this paper is on evaluating and assessing the effect of a compressed work week strategy (say, not working a day each week) on transportation network performance measures such as link-level traffic speed, travel time, and volume-to-capacity ratio using data gathered for the Charlotte metropolitan area, North Carolina. The results obtained indicate that reducing 15% to 20% of work commute during the morning peak hours using compressed work week strategy would increase traffic speeds by up to 5 mph on at least 64% of center-lane miles (sum of the length of the center line of all lanes of traffic for each selected link). It would also decrease the travel time by up to two minutes on at least 61% of center-lane miles.

INTRODUCTION

The rapid increase in the population had a catalytic effect on travel demand during the past few decades. The infrastructure and system capacity provided to promote this growth has not seen the same trend, resulting in congestion on roads in the urban transportation network. Traffic congestion leads to excessive usage of energy resources (fuel consumption), which in turn leads to an increase in the emission of various pollutants produced through the combustion of fuel. The loss of time due to traffic congestion results in huge economic losses. According to the Texas Transportation Institute (TTI) Urban Mobility Report, traffic congestion resulted in losses exceeding $121 billion to the United States in 2011 (TTI 2012). These losses include time lost and waste of fuel but do not involve the total environmental costs and other associated indirect costs.

Recurring congestion is observed mainly during morning and evening peak hours on any given weekday. This recurring congestion on road links during morning and evening peak hours could be attributed to traffic generated by people traveling to work. The estimates from 2009 National Household Travel Survey (NHTS) indicate that 17% of the total daily trips in the United States account for personal work-related trips (NHTS 2011). Studies conducted in the past also show that 44% of the commuting trips are from a suburban residence to a suburban job location. These commuters cause localized congestion but do not travel to the downtown area or central business district (Pisarski 1996).

Generally, the road links that are connected to and around the downtown area are relatively more congested with increased travel times during the peak hours. Therefore, traffic congestion during peak hours on the road links connected to the downtown area could be primarily attributed to the travelers who work in and around the downtown area.

The reduction of traffic on the road links around the downtown area may help decrease travel time, enhance regional economy, and achieve greater prosperity and health. The reduction of traffic and associated improvement in transportation network performance measures can be easily achieved by decreasing the total number of commuters (employees or workers) traveling to the downtown area on a given day during a given time period. Since a significant percent of these commuters travel longer distances (from suburban areas), the effects on transportation network performance measures may extend beyond the downtown area (may not be completely localized), in particular on freeways and expressways.

Strategies to reduce the total number of commuters traveling to their work during peak hours on weekdays include compressed work week and telecommuting. According to these strategies, a percentage of employees are allowed to work four days a week (instead of normal five days a week in the United States) or allowed to work one or multiple days a week from home. Allowing 20% of employees to work four days a week or one out of five days a week from home could potentially reduce congestion associated with work trips by 20%.

The aforementioned travel demand strategies (compressed work week and telecommuting) have the potential to reduce congestion on roads. However, their effectiveness in achieving the desired objective has not been documented widely in the literature. Questions such as "does the strategy help reduce travel demand and lower congestion on roads?" and "what should be the optimum or appropriate but realistic percentage of employees that should be part of the compressed work week strategy?" are critical and have yet to be completely addressed. The objective and primary focus of this research is to identify the percentage of employees that should be part of a compressed work week strategy to help achieve amicable traffic flow conditions by reducing congestion on routes in and around the downtown area.

The findings assist practitioners understand the change in transportation network performance measures with an increase in percentage of employees that are part of the strategy. It also helps practitioners set targets for successful implementation of such a strategy.

LITERATURE REVIEW

Several studies were conducted to examine the effect of a compressed work week strategy on employee behavior, employee attitude, and transportation network performance. Ronen and Primps (1981) researched organizational changes, employee behavior, and attitudes toward compressed work week strategy. Their study suggests that employees' attitudes and job attitudes are positive in implementing a compressed work week strategy. They concluded that implementing the strategy would decrease employee absenteeism.

Hines (1982) assessed that 13% to 21% of employers, who have 100 or more employees, could implement flexi-time, staggered work hours, or compressed work week strategy. Based on a wide-scale basis and analysis using Baltimore data, Hines observed that 1,300 to 7,600 daily trips can be eliminated from the roads to help the city in meeting travel, air quality, and energy objectives.

Jin and Wu (2011) examined the factors that influence people's telecommuting behavior using data from the 1995 Nationwide Personal Transportation Survey, and 2002 and 2009 NHTS. Findings from their study indicate that telecommuters usually had longer distance and travel time to work compared with non-telecommuters. While non-telecommuters drove less than telecommuters, frequent telecommuters drove significantly less than the other group.

The Washington State legislature passed the commute trip reduction law in 1991 (Washington State Department of Transportation 2013). A major goal of this law was to promote employer-based programs that would decrease the number of commute trips made by people driving alone to reduce traffic congestion, emissions, and fuel consumption. Strategies considered to achieve the goal included carpool, vanpool, transit, compressed work week, and telecommuting.

Hung (1996) researched and demonstrated that the amount of work commutes decreased after implementing the compressed work week strategy. Zhou et al. (2009) applied generalized ordered logit models to evaluate the effect of commute trip reduction activities, journey to work distance, job characteristics, and business type on telecommuting. Results indicate that longer journey time to work, promotion of telecommuting through employers, and commute trip reduction plays an important role in commuters telecommuting choices.

Legislators passed the Commute Trip Reduction Efficiency Act in 2006. This act required all local governments in urban areas with traffic congestion to develop programs that reduce drive-alone trips and vehicle miles traveled per capita. As a result of this act, three years after enabling the act, the State of Washington has observed a reduction of 30,000 morning weekday work-based trips (Washington State Department of Transportation 2013). Another observation was the reduction in traffic delays by 8% in the Central Puget Sound Region. The rush-hour commuters have saved about $59 a year in fuel and time. Similarly, by driving 154 million fewer miles since 2007, participants in the commute trip reduction programs have saved about three million gallons of gasoline in the years 2009-2010 and prevented about 69,000 metric tons of greenhouse gases from entering the atmosphere each year with a total monthly savings of about $30 million (Washington State Department of Transportation 2013).

Telecommuting allows commuters to work at home or close to home thereby eliminating some vehicle trips. According to past research, telecommuting reduces total trips (especially peak-period trips), generating positive effects on the environment (Hamer et al. 1991; Quaid and Lagerberg 1992; Choo et al. 2005).

Literature documents research on employee behavior and attitude toward compressed work week strategy. In general, reducing one complete work day a week without incorporating other policies (such as working extra hours on other days) may result in losses to the business. It will not help in the decrease of traffic on the remaining work days unless a proportionate percentage of traffic is reduced on each work day so as to not exceed the congestion levels. Also, a business firm or any organization may not afford to have all its employees adopt such a policy. There will be some employees who need to be on site (at the office) all days of the work week (due to the nature of their work). Likewise, there may be individuals who may not prefer to be part of the strategy due to their personal constraints; for example, if they have to work extra hours on other days to compensate for lost time. Such effects can only be assessed by hypothetically varying the percentage reduction and evaluating its effect on transportation network performance. However, none of the past researchers have discussed the variations in the traffic flow and transportation network performance measures in order to reduce congestion during peak hours by adopting a compressed work week strategy and reducing work trips.

METHODOLOGY

The methodology adopted to evaluate the changes in the transportation network performance measures upon implementing a compressed work week strategy includes the following steps.

- Gathering existing travel demand forecasting model data - base case scenario
- Defining compressed work week strategy and target reduction
- Generating new origin-destination (O-D) trip tables
- Identifying the changes in the traffic pattern

A brief description of each step is presented next.

Gathering Existing Travel Demand Forecasting Model Data - Base Case Scenario

The Charlotte Department of Transportation has developed a regional travel demand forecasting model that runs on TransCAD (Caliper Corporation 2004). The regional travel demand model is used to assess existing travel demand and future travel demand based on future projections of population and employment as well as incorporating any improvements to the transportation system (CRTPO 2014). The data and output from this model are the best and most reliable sources at the time of this writing for regional-level analysis such as the one discussed in this paper.

The regional travel demand forecasting model incorporates origin-destination (O-D) trip tables based on travel surveys and a spatial gravity model (Allen 2007). However, the surveys do not include information on commercial vehicles, medium trucks, and heavy trucks. The trips related to these vehicle types are evaluated from the Freight Planning Manual developed by Cambridge

Systematics for the United States Department of Transportation's Travel Model Improvement Program.

The development of O-D trip tables involves the first two steps of the traditional four-step transportation planning process: trip generation and trip distribution. The trip generation model estimates the number of trips entering and leaving each traffic analysis zone (TAZ) on the basis of that zone's demographic, land use, and socioeconomic characteristics. All trip ends are modeled as either trip productions or trip attractions. Trip productions are those trip ends that are associated with the home end (origin or destination) of a home-based trip or origin of a non-home-based trip, while trip attractions are trip ends that are associated with the non-home end (origin or destination) of a home-based trip or destination of a non-home-based trip. Trip distribution is based on the well-known spatial gravity model. The spatial gravity model helps estimate the number of trips from a given origin to a selected destination as a function of trip productions, trip attractions, friction factors and other calibration parameters. Using a mode choice model, the mode of transportation for each trip is determined as the third step.

All vehicle types are converted into passenger car units using the following equation (Allen 2007). The conversion is done primarily to account for the effect of heavy vehicles on transportation system capacity and operation performance.

PCU = SOV + POOL2 + POOL3 + COM + 1.5*MTK + 2.5*HTK

where,

PCU	= Total passenger car units
SOV	= Single occupancy vehicles
POOL2	= Two-person carpool vehicle trips
POOL3	= Three or more person carpool vehicle trips
COM	= Commercial vehicles
MTK	= Medium trucks
HTK	= Heavy trucks

In the above equation, heavy trucks (HTK) include all trucks with more than three axles such as tractor- and semi-trailers, dual trailers, and buses. Medium trucks (MTK) include trucks with three axles and six tires, and single-unit trucks as well as light-duty trucks with dual rear wheels. The commercial vehicles (COM) category includes all light-duty vehicles (passenger cars, light trucks, vans, and sports utility vehicles) used for delivery and other business purposes.

The regional travel demand forecasting model adopted a user equilibrium method for trip assignment as the fourth step. The user equilibrium method is an iterative process to achieve a convergent solution in which no travelers can improve their travel times by shifting routes (Caliper Corporation 2004).

The model parameters are calibrated and validated by the Charlotte Department of Transportation planners by comparing estimated traffic volumes with actual annual average daily traffic (based on field counts) for selected links. The model is regularly updated and maintained by the city planners.

The following equation is used to compute the travel time for each selected link in the network (Allen 2007).

$$T = T_f * \left(1 + \alpha \left(V/C\right)^{\beta}\right)$$

where, T is travel time accounting for congestion due to traffic volume, T_f is free flow travel time, V/C is volume-to-capacity ratio, and, α and β are coefficients established by the city planners. The travel times obtained from the above equation are used to compute traffic speed (distance divided by travel time) for each link in the network.

The data and outputs directly obtained from the calibrated regional travel demand forecasting model are considered and used to indicate the base case scenario. In this base case scenario, no reduction in the percentage of employees is considered.

Defining Compressed Work Week Strategy and Target Reduction

Reducing a work day for all employees may not help in achieving the free traffic flow in the downtown area on remaining working days. The strategy must therefore comprise five work days but resulting in a smaller percentage of trips on each day. A reduction of a small percentage of employees from each business firm or organization proportionally on each day may help in achieving this objective. This percentage of employees working in the downtown area may be part of telecommuting or working additional hours on the remaining work days so that the total numbers of hours worked per week stays the same.

The appropriate or optimum percentage of employees that should be part of the compressed work week strategy for improved network performance is not known and has to be estimated. According to the United States Bureau of Labor Statistics (1997), the percentage of full-time wage and salary employees with flexible work schedules on their principal job is estimated to be around 27.6%. Therefore, variations in traffic patterns were assessed from 0% to 30% for every 5% increase in the number of employees that are part of a compressed work week strategy.

The implementation and the effect of the compressed work week strategy could be localized. However, as a significant number of commuters travel longer distances, improvements in the transportation network performance measures may be seen on freeways, expressways and other major roads throughout the core urban area. For implementation, only downtown area where congestion is usually high during peak hours was considered for illustration of the method and evaluation of effectiveness of the compressed work week strategy. The entire urban area transportation network was considered for assessment of the transportation network performance measures. However, the method could be easily adopted or replicated to enhance transportation system performance for the entire study area (not just downtown) or other local areas with significantly high office activity.

Generating New Origin-Destination (O-D) Trip Tables

The O-D traffic patterns vary for morning and evening peak hours. Traffic volume could be high on links towards downtown during the morning peak hours, while traffic volume may be high on links away from the downtown during the evening peak hours. Only morning peak hours were considered for illustration of the method and possible merits due to implementing the compressed work week strategy in this paper.

New O-D trip tables were generated from the gathered O-D trip tables by deducting the selected percentage of employees from each TAZ depending upon the location and its characteristics. These O-D trip tables were also computed separately for both morning and evening peak hours.

To generate the new O-D trip tables, firstly, the TAZs in the downtown area were selected. The trip attractions to these TAZs from every other TAZ (if any) were reduced by selected percentage (say, 15%). Similarly, the trip productions from the selected TAZs to each and every other TAZ were reduced by the same percentage (15%). This would also ensure that trip attractions and trip productions after deducting the selected percentage of employees would be equal. This process was repeated for each percentage reduction in the number of employees to generate the respective set of O-D trip tables.

Identifying the Changes in the Traffic Pattern

From the new O-D trip tables, the link volumes of all the routes in and around the downtown area were computed using TransCAD software. The tools and algorithms/modules used by the Charlotte Department of Transportation-Planning Division, outlined in the "Gathering Existing Travel Demand Forecasting Model Data-Base Case Scenario" sub-section, were adopted while going through this process of travel demand forecasting.

TransCAD version 4.7 (Caliper Corporation 2004) was used to assign trips, adopting the user equilibrium method, to the transportation network in this paper. The traffic pattern, reduction in travel time, and increase in traffic speed on the road links were computed and compared to the base case scenario (zero percent reduction in the number of employees; compressed work week strategy is not implemented). The least possible percentage of reduction in the total number of employees was computed by observing the changes in travel time and traffic speed on the road links in the core urban area.

Overall, spatial maps were generated and analysis was performed to identify the reduction in the congestion levels on the links and routes in the core urban area by reducing the possible number of work trips proportionally on each day.

ANALYSIS AND RESULTS

Data for the Charlotte metropolitan area during the morning peak hours were obtained from the Charlotte Department of Transportation-Planning Division and used to illustrate the effect of the compressed work week strategy and identify the appropriate percentage of employees that need to be part of the strategy. As stated in the "Methodology" section, trips that are attracted to the downtown area from various TAZ's are reduced on a percentage basis starting with 5% to 30% with 5% equal intervals. These trips were assigned using TransCAD version 4.7 (Caliper Corporation 2004) to evaluate changes in traffic pattern with respect to traffic parameters such as average traffic speed, travel time, and volume-to-capacity ratio of each link.

Changes in Traffic Speed

Table 1 shows the change in traffic speed for every 5% reduction of work trips to the downtown area. The total center-lane miles (length of the center line of all lanes of traffic) of road links with an increase in traffic speed from 0-5 mph and greater than 5 mph are summarized for both away from downtown (AB) and toward downtown (BA) directions. From Table 1, the total center-lane miles with an increase in traffic speed are higher for links toward the downtown direction than when compared with away from the downtown direction of traffic flow, showing a decrease in traffic towards the downtown area. The total center-lane miles with an increase in traffic speed was observed to increase with the percentage reduction in trips to downtown area.

Figures 1 and 2 show the relation between the percentage of total center-lane miles by the percentage reduction in work trips for 0-5 mph and greater than a 5 mph increase in traffic speed, respectively. The percentage of total center-lane miles with an increase in traffic speed up to 5 mph increases with the percentage reduction in work trips (Figure 1). A substantial increase in the slope of the curve (increase in the percentage of center-lane miles with an increase in traffic speed greater than 5 mph) was observed from 5% reduction to 15% reduction. This was followed by a relatively constant slope up to 20% reduction in work trips, i.e., a 15%-20% reduction in work trips will be appropriate as the optimal percentage reduction of work trips to the downtown area to improve the traffic speed on the road links toward downtown (Figure 2).

Overall, reducing 15% to 20% of work commutes during the morning peak hours using a compressed work week strategy would increase traffic speed by up to 5 mph on at least 64% of center-lane miles. Though a higher percentage of reduction in work trips may yield better performance, the reduction of work trips greater than 20% may be a difficult task for the employers or transportation system managers to target.

Table 1: Center-Lane Miles with an Increase in Traffic Speed for Every 5% Reduction in Work Trips

% Reduction in Work Trips	Center-Lane Miles & Change in Traffic Speed						% of Center-Lane Miles	
	Away from Downtown (AB)			Towards Downtown (BA)				
	<= 0 mph	> 0 & <= 5 mph	> 5 mph	<= 0 mph	> 0 & <= 5 mph	> 5 mph	0-5 mph	> 5 mph
5	791.6	552.7	1.7	579.5	765.2	1.2	56.9	0.1
10	793.8	550.2	1.9	520.7	821.7	3.5	61.1	0.3
15	737.6	604.6	3.7	473.8	860.0	12.1	63.9	0.9
20	755.9	586.4	3.6	436.3	897.5	12.1	66.7	0.9
25	711.9	628.3	5.7	416.8	903.9	25.3	67.2	1.9
30	695.1	645.5	5.3	392.3	917.7	35.9	68.2	2.7

Figure 1: Center-Lane Miles by % Reduction in Work Trips (0-5 mph Increase in Traffic Speed)

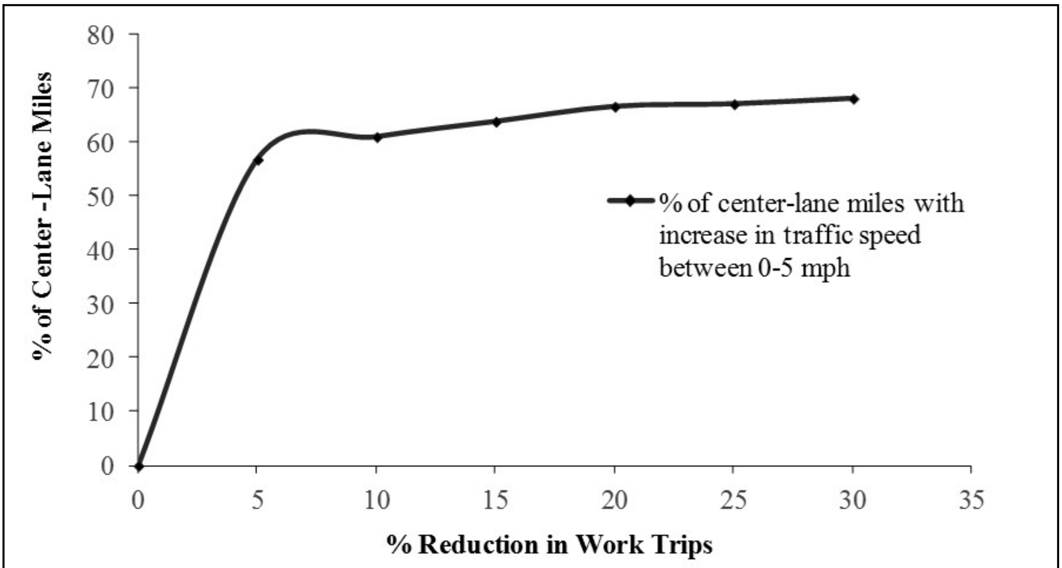
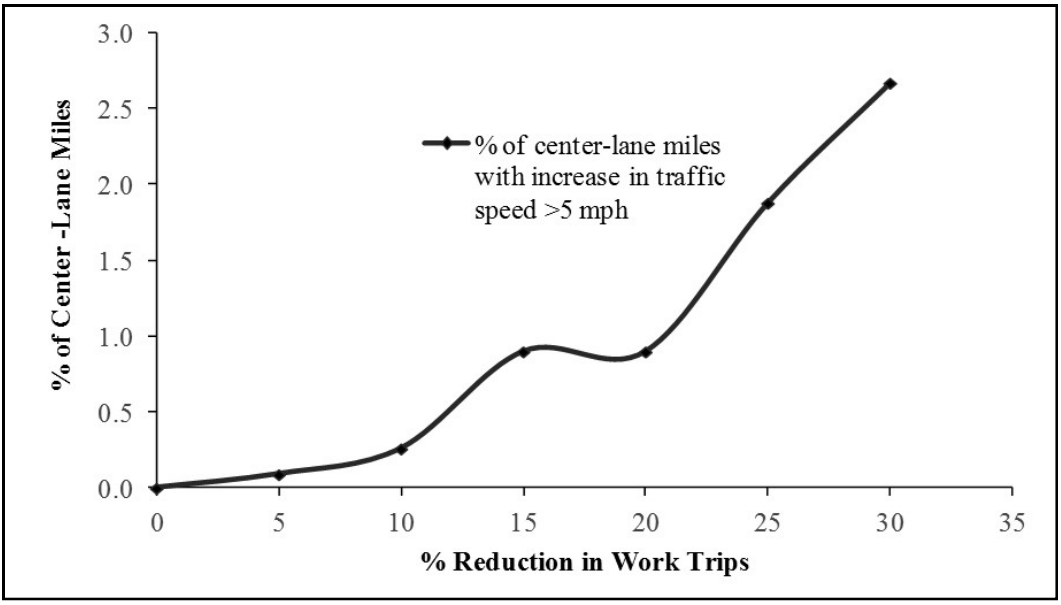


Figure 2: Center-Lane Miles by % Reduction in Work Trips (>5 mph Increase in Traffic Speed)



Changes in Travel Time

The change in total travel time is higher for away from downtown direction links than when compared with links toward the downtown direction of traffic flow, indicating a decrease in traffic toward the downtown area (Table 2). The total center-lane miles with a decrease in travel time is observed to increase with the percentage reduction in trips to the downtown area.

Figures 3 and 4 show the trend line between the percentage of center-lane miles by the percentage of reduction in work trips for 0-2 minutes and greater than a 2 minute decrease in travel time, respectively. The percentage of center-lane miles with a decrease in travel times up to two minutes increases with the percentage reduction in work trips (Figure 3). Similarly, a substantial increase in the percentage of center-lane miles with a decrease in travel time of more than two minutes was observed with the percentage reduction in work trips (Figure 4).

Overall, reducing 15% to 20% of work commute during the morning peak hours using the compressed work week strategy would decrease travel time by up to two minutes on at least 61% of center-lane miles. Even in this case, though a higher percentage of reduction in work trips may yield better performance, the reduction of work trips greater than 20% may be a difficult task for the employers or transportation system managers to target.

Changes in Volume-to-Capacity Ratio

Figure 5 shows the trends in volume-to-capacity ratio for the links with volume-to-capacity ratio greater than one. A substantial decrease in the percentage of center-lane miles with volume-to-capacity ratio greater than one is possible by reducing the number of work trips to the downtown area. The rate of decrease in volume-to-capacity ratio from 5% to 20% is greater than from 20% to 25% and 25% to 30%. Therefore, though a 25% or 30% reduction in the number of work trips yields better results (reduces volume-to-capacity ratio on the links toward the downtown area), the benefits seem to be relatively low or marginal. Based on this observation, a 15% to 20% reduction in the number of trips can be considered to reduce the volume-to-capacity ratio on the links toward downtown area.

Table 2: Center-Lane Miles with a Decrease in Travel Time for Every 5% Reduction in Work Trips

% Reduction in Work Trips	Center-Lane Miles & Change in Travel Time						% of Center-Lane Miles	
	Away from Downtown (AB)			Towards Downtown (BA)				
	<= 0 min	>0 & <2 min	> 2 min	<= 0 min	>0 & <2 min	> 2 min	0-2 min	> 2 min
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
5	851.4	493.7	0.8	640.5	705.4	0.1	52.4	0.01
10	853.9	491.2	0.8	572.8	773.1	0.1	57.4	0.01
15	795.6	550.0	0.3	524.4	821.4	0.1	61.0	0.01
20	808.3	536.9	0.7	482.7	863.1	0.1	64.1	0.01
25	768.1	576.7	1.1	466.4	879.3	0.3	65.3	0.02
30	757.4	587.9	0.7	445.8	899.9	0.3	66.9	0.02

Figure 3: Percent of Center-Lane Miles by % Reduction in Work Trips (0-2 Minutes Decrease in Travel Time)

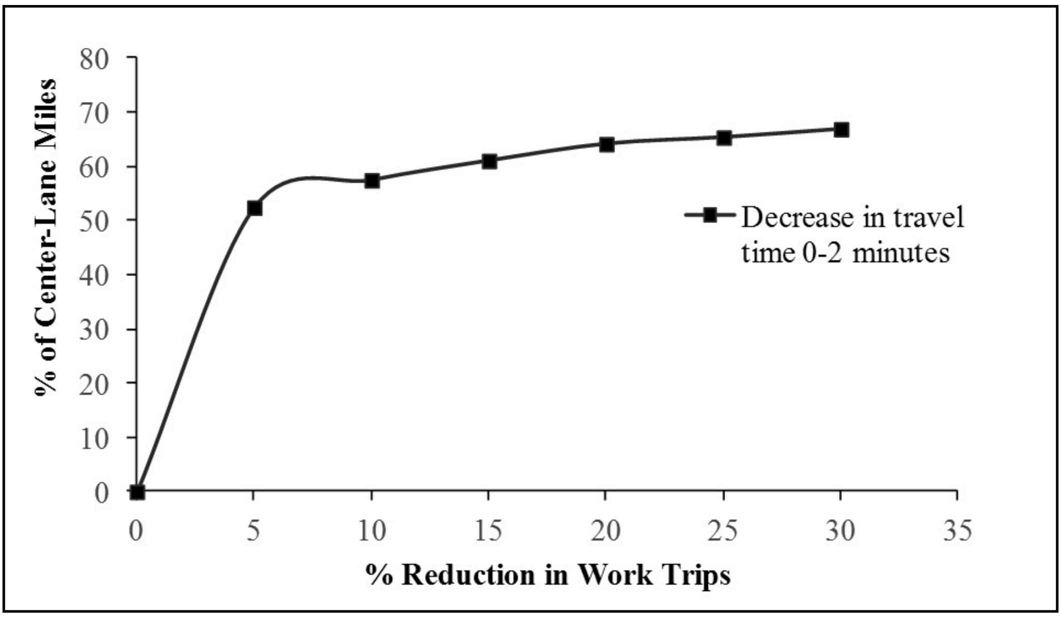


Figure 4: Percent of Center-Lane Miles by % Reduction in Work Trips (>2 Minutes Decrease in Travel Time)

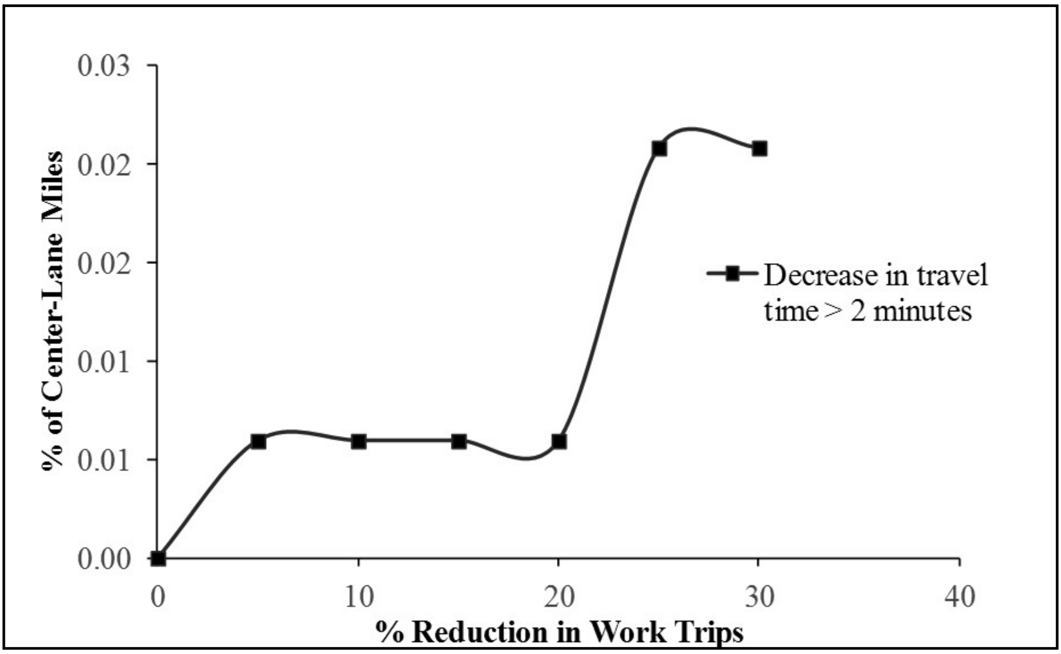


Figure 5: Percent of Center-Lane Miles with Volume-to-Capacity Ratio Greater Than One

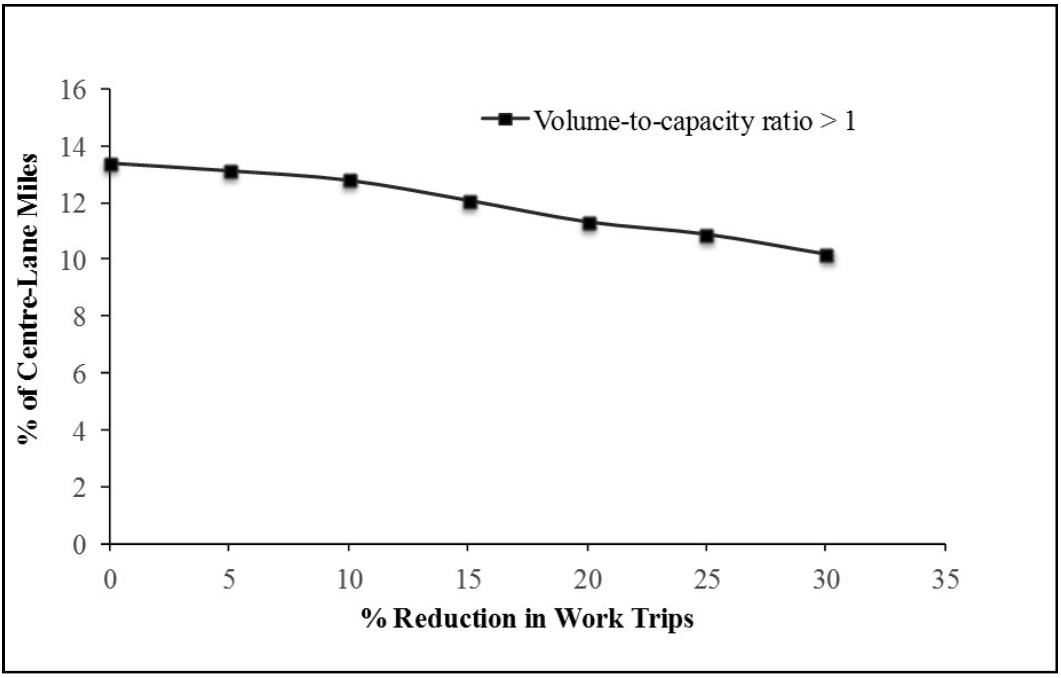


Figure 6 depicts the difference in traffic speed on the road links in the downtown area with a 15% decrease in the number of trips to the downtown area. The darker and thicker links in the figure indicate an increase in 3-5 mph and greater than 5 mph traffic speeds on the respective road links. There is an increase in traffic speeds on almost all the major links connecting the downtown area. An increase in traffic speed by 5 mph on some parts of Interstate-77 and US-74 Expressway (main freeways/expressways connected directly to the downtown area) was observed, which indicates a free movement of traffic toward downtown when compared with 0% reduction in trips to the downtown area (base case scenario). This increase in traffic speed along the major roads seems to extend well beyond the downtown area.

Figure 6: Difference in Traffic Speed Due to a 15% Reduction in Work Trips

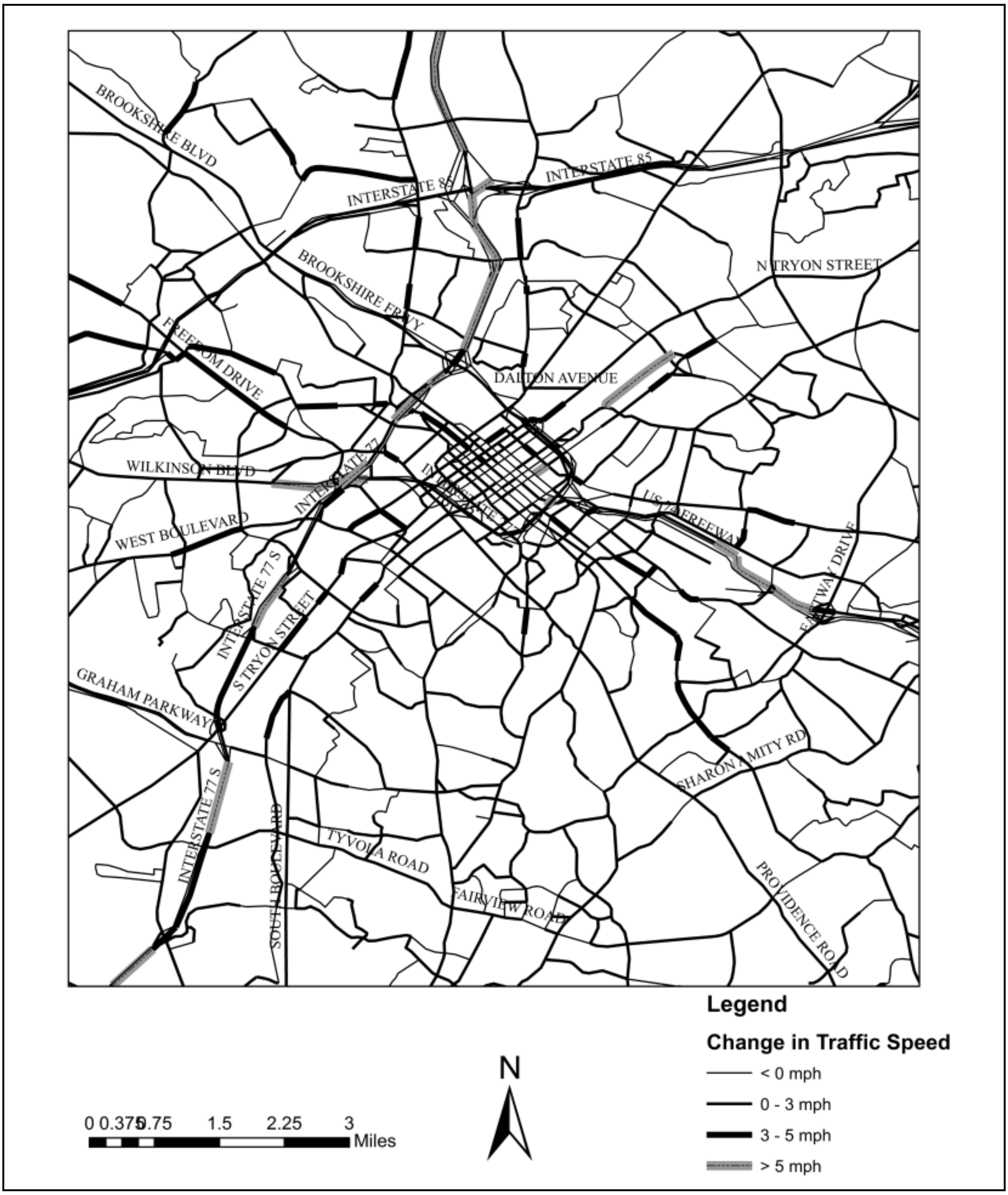


Table 3 shows the percentage of center-lane miles with an increase in traffic speed on road links for each category of speed limit. There is an increase in traffic speed on road links in AB direction (away from downtown) with lower speed limits. However, there is no change in traffic speed on the road links with high speed limits (freeways and expressways). This could be attributed to the fact that the links away from the downtown are less likely to be congested during the morning peak. The traffic speed on a majority of the freeway links in the BA direction (toward downtown) increased along with a substantial increase in the percentage of road links with lower speed limits when compared with the AB direction. Overall, there is an increase in traffic speeds on (44.41% + 0.51% + 0.27%) = 45.19% of the links in AB direction with a 15% decrease in the number of work trips to downtown area compared with (62.23% + 1.67% + 0.90%) = 64.80% of the links in the BA direction.

Table 3: Percent of Center-Lane Miles with an Increase in Traffic Speed for Each Category of Speed Limit

Category / Center-Lane Miles	Center-Lane Miles & Change in Traffic Speed				% of Center-Lane Miles			
	<= 0 mph	> 0 & <= 3 mph	> 3 & <= 5 mph	> 5 mph	<= 0 mph	> 0 & <= 3 mph	> 3 & <= 5 mph	> 5 mph
Away from Downtown (AB Direction)								
<= 35 mph	172.80	192.15	2.08	0.24	47.05	52.32	0.57	0.07
40 or 45 mph	357.53	357.18	4.59	2.95	49.50	49.45	0.64	0.41
50 mph	24.31	4.59	0.00	0.00	84.12	15.88	0.00	0.00
55 mph	141.37	43.82	0.17	0.51	76.06	23.58	0.09	0.27
65 mph	41.63	0.00	0.00	0.00	100.00	0.00	0.00	0.00
All	737.64	597.74	6.84	3.70	54.81	44.41	0.51	0.27
Towards Downtown (BA Direction)								
<= 35 mph	123.61	236.10	5.87	1.69	33.66	64.29	1.60	0.46
40 or 45 mph	191.69	517.44	7.97	5.15	26.54	71.64	1.10	0.71
50 mph	15.88	9.99	0.40	2.63	54.95	34.57	1.38	9.10
55 mph	122.07	52.91	8.27	2.62	65.67	28.47	4.45	1.41
65 mph	20.55	21.08	0.00	0.00	49.36	50.64	0.00	0.00
All	473.80	837.52	22.51	12.09	35.20	62.23	1.67	0.90

CONCLUSION

The compressed work week strategy helps relieve congestion during peak hours by increasing traffic speed and decreasing volume-to-capacity ratio, thereby decreasing travel time on links connected to the downtown area. Decreasing the number of work trips by 15% to 20% can be the ideal target percentage of reduction in work trips to have a substantial improvement in transportation network performance during peak hours. Though targeting more than 20% of employees through a compressed work week strategy continues to improve volume-to-capacity ratio, it is not suggested to have more than 20% of employees telecommuting as it might have a negative effect on economic productivity. Also, influencing work trips generated by more than 20% of employees may yield only marginal benefits (and not outweigh associated costs). Upon the reduction of trips by 15% to 20%, traffic speed on at least 64% of the center-lane miles can be increased by up to 5 mph and travel time on at least 61% of the center-lane miles can be reduced by up to two minutes.

Only offices in and around the downtown area were considered for evaluating the compressed work week strategy in this paper. Considering residential population in the downtown area or the entire core urban area may yield much larger benefits and merit an investigation.

The strategy and method discussed in this paper could be implemented to examine the effect of compressed work strategy on decentralized local areas or high office activity areas. It is highly likely that the results depend on network topology, existing travel demand, flow patterns, and congestion level. Evaluating the effectiveness of the compressed work week strategy using data for centralized and decentralized networks, different network topologies, types of networks (radial and grid patterns), detailed network characteristics, and levels of congestion would provide better insights and possibly lead to large-scale implementation of the strategy.

Implementing a compressed work week strategy might result in increased non-work trips, reducing its benefit. The development and assessment of a non-work-based model or activity-based model to examine its effect also warrants an investigation.

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What Matters Most in Transportation Demand Model Specifications: A Comparison of Outputs in a Mid-size Network

by T. Donna Chen, Kara M. Kockelman, and Yong Zhao

This paper examines the impact of travel demand modeling (TDM) disaggregation techniques in the context of medium-sized communities. Specific TDM improvement strategies are evaluated for predictive power and flexibility with case studies based on the Tyler, Texas, network. Results suggest that adding time-of-day disaggregation, particularly in conjunction with multi-class assignment, to a basic TDM framework has the most significant impacts on outputs. Other strategies shown to impact outputs include adding a logit mode choice model and incorporating a congestion feedback loop. For resource-constrained communities, these results show how model output and flexibility vary for different settings and scenarios.

BACKGROUND

Transportation directly provides for the mobility of people and goods, while influencing land use patterns and economic activity, which in turn affect air quality, social equity, and investment decisions. Driven by the need to forecast future transportation demand and system performance, Manheim (1979) and Florian et al. (1988) introduced a transportation analysis framework for traffic forecasting using aggregated data that provide the basis for what is known as the four-step model: a process involving trip generation, then trip distribution and mode choice, followed by route choice. Aggregating demographic data at the zone level, the four-step model generates trip productions based on socioeconomic data (e.g., household counts by income and size) and trip attractions primarily based on jobs counts. The model then proportionally distributes trips between each origin and destination (OD) zone pair based on competing travel attractions and impedances, under the assumption that OD pairings with higher travel costs draw fewer trips. Trips between each OD pair are split among a variety of transportation modes, allocating trips to private vehicle, transit, or other modes based on each mode's relative utility. Finally, the route choice step assigns trips between each OD pair for each mode onto the network links offering the lowest generalized route cost (typically based on travel times and, if applicable, tolls).

While the four-step model framework remains popular among most planning organizations today, transportation demand modeling (TDM) techniques have grown progressively more sophisticated. In particular, the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 linked air quality objectives to transportation plans and pushed transportation planners to improve their basic three-step and four-step transportation models to meet federal mandates. Driven by the need for air quality forecasts and evaluation of project alternatives, advanced TDMs in larger regions range from incorporating various levels of behavioral disaggregation within the traditional, trip-based, four-step model framework to microsimulation of individuals' itineraries and activity-based approaches to patterns of travel behavior. Such advanced TDMs recognize that travel decisions are made at the level of individuals and reflect choice behavior under specific circumstances, rather than statistical associations at an aggregate, zone, or group level. Under the United States' 2012s Moving Ahead for Progress in the 21st Century (MAP-21) legislation, TDMs have become an essential tool for tracking and analyzing current and future congestion levels, in efforts to achieve travel time goals. However, transportation planning practices in smaller (and typically less polluted and congested) communities are generally much less sophisticated, due to a lack of data and other resources and/or lack of urgency and regulatory requirements. In some states, like Texas (TTI 2011) and Illinois (Ullah et al. 2011), smaller MPOs rely on their state's department of transportation (DOT) for their local TDM framework, and those may lack behavioral disaggregation (e.g., no user class differentiation or time-of-day segmentation). In a 2004 survey of MPOs, 49% of regions with population under 200,000 rely on the state to develop travel demand models (Wachs et al. 2007).

Once considered a problem in major metropolitan areas, growing congestion is also plaguing smaller communities (populations under 250,000) across the U.S. and around the world. It is also a serious issue in developing countries, where there is substantial growth in private vehicle ownership. For example, between 1982 and 2005, total travel delay in 306 small- to medium-sized U.S. communities increased from 0.8 to 4.2 billion person-hours (Shrank and Lomax 2007). For these communities, with few (to no) modeling staff members on hand, there is a pressing need to identify which TDM modeling improvement strategies offer the most effective predictive capabilities in various scenarios. The data and specification sophistication requirements of any modeling improvements typically require added time and dollar expenditures, which are serious constraints on almost all communities. Furthermore, as transportation systems evolve to become more complex systems, possibly introducing various congestion pricing schemes (e.g., static and dynamic tolling scenarios) and alternative modes of transit and para-transit (e.g., bus rapid transit, car sharing, and bike sharing), these communities need to be aware of the most meaningful opportunities for behavioral disaggregation to reflect such transport system strategies.

This paper evaluates a suite of improvement strategies, as applied to a basic three-step TDM, based on their predictive power and behavioral flexibility. Examining the predictive performance of these strategies relative to top-model results can illuminate model sensitivity, feasibility, and versatility. Smaller communities can use the case study results presented here (for the Tyler, Texas, metropolitan statistical area, with 214,821 persons, according to 2012 American Community Survey results) to assess the value of adding the following strategies to their existing TDMs:

- Impacts of adding a mode choice sub-model, via logit and fixed-share specifications
- Impacts of a multi-period time-of-day analysis, versus a 24-hour (one-time-of-day) analysis
- Impacts of incorporating multiple classes of users across income levels and trip purposes in the route choice step, versus a single class, aggregate trip table
- Impacts of using an outer ("full") feedback loop (of travel time estimates back to trip distribution), for iteration of equilibrium flows and travel times

This study uses the Tyler network simply to demonstrate a set of traffic analysis zones with actual demographic characteristics and roadway links and nodes with realistic speed and capacity attributes. The simulations vary demand and network designs and travel costs significantly, so the results of this work are not intended to provide a future forecast of this particular region.

BASE CASE SPECIFICATION AND MODEL IMPROVEMENTS

The base-case scenario that serves as the starting point in this analysis is a simple 24-hour vehicle-trip-based model with trip generation, trip distribution, and traffic assignment (just three steps), for three trip purposes. The analysis considers various additions to this straightforward base model, including a mode-choice step, disaggregation of time-of-day periods and user classes, and implementation of an outer feedback loop that updates travel times and costs for every OD pair (back to the trip distribution step), as discussed in more detail below.

Time-of-Day Considerations

In congested networks, time-of-day (TOD) considerations are critical in TDMs because of driver responses to congestion (including alternative routes and alternative departure time choices). The relative utility of a tolled route depends largely on toll charges and perceived travel time savings, both of which can vary by TOD. While 75% of large MPOs assign at least two TOD periods in their models, many smaller MPO regions (with population between 50,000 and 200,000) assign average daily (24-hour) travel (Wachs et al. 2007). Typically, TOD segmentation is incorporated into TDMs after the mode choice step to reflect generalized travel costs that vary across different TODs (Parsons Brinckerhoff et al. 2012). Time-of-day segmentation into four periods (morning peak, mid-day, afternoon peak, and off peak) is common, but a simple peak-versus-off-peak distinction can also be quite effective when congestion is not excessive (Hall et al. 2013).

For this analysis, two types of time-of-day segmentation are considered. The first is a simple (two-period) peak (6 to 9 a.m. and 3 to 6 p.m.) versus off-peak (9 a.m. to 3 p.m. and 6 p.m. to 6 a.m.) structure. This setup may be sufficient in network settings where congestion is not excessive or highly variable. The second time-of-day segmentation setup considered here consists of four periods: AM peak (6 to 9 a.m.), midday (9 a.m. to 3 p.m.), PM peak (3 to 6 p.m.), and off-peak (6 p.m. to 6 a.m.). Hourly distributions for personal and commercial trip making in the modeling scenarios used here are based on TransCAD 6.0's default rates for home-based work (HBW), home-based non-work (HBNW), home-based other (HBO), and non-home based (NHB) trip purposes, which are based on Sosslau et al.'s (1978) NCHRP Report 187. Average auto occupancy rate assumptions are based on the U.S. 2009 National Household Travel Survey (NHTS) values (Santos et al. 2011), with auto occupancy rates of 1.1, 1.75, and 1.66 (persons per passenger vehicle) for HBW, HBO, and NHB trip purposes, respectively.

Mode Choice

While more than 90% of large MPOs include a mode choice step in their models, only 25% of small to medium MPOs incorporate mode choice (Wachs et al. 2007). Perez et al. (2012a) recommends that mode choice be incorporated in all TDMs, preferably via a logit or nested logit specification. However, modelers seem to agree that, for small- and medium-sized communities, a simpler approach (such as a fixed-shares model based on travel distance) can also be effective (Hall et al. 2013). For these reasons, two mode-choice models were tested in this evaluation. The first is the fixed-share model, where preference for non-motorized (e.g., walking and cycling) modes and transit fall with trip distance, as shown in Table 1.

Table 1: Fixed-Share Mode Splits

Trip Distance	Auto Share	Transit Share	Non-motorized Share
< 1 mile	75%	5%	20%
1–5 miles	94%	5%	1%
> 5 miles	98%	2%	0%

According to the 2012 American Community Survey (U.S. Census Bureau 2012), the auto share estimates assumed here are close to Tyler's work-trip mode splits, where respondents reported relying on personal motorized vehicles for approximately 92% of their commute trips. The transit share assumptions used here, however, are more reflective of a region with a more extensive and better-used transit system. In Tyler, there are only four bus-service routes, and the actual transit share for work trips is less than 1%.

The second mode-choice model used here is a multinomial logit (MNL) model to split trips across auto, transit, and non-motorized (bike/walk) travel modes. The systematic utility functions for each of the modes used in this simplified MNL model are based only on the three modes' competing travel times. The parameters used are shown in the following equations, and they yield mode splits similar to those in the fixed-share (Table 1) setting.

(1) $V_{auto} = -0.2 \times AutoTT$

(2) $V_{transit} = -2.5 - 0.2 \times TransitTT$

(3) $V_{nm} = -1.0 - 0.2 \times NmTT$

where V_{auto}, $V_{transit}$, and V_{nm} represent the competing modes' (systematic) utility values and *AutoTT*, *TransitTT*, *NmTT* represent the travel times associated with each mode (i.e., auto, transit, and non-motorized modes). Both mode-choice model specifications shown above reflect a network with fairly low shares of transit and non-motorized modes, typical of many U.S. settings. To appreciate whether auto shares may significantly affect model performance, another MNL mode choice model was tested (with higher alternative-specific constants for the non-auto modes), to deliver a "High Transit" scenario, with parameters shown in the following equations. In this scenario, approximately 25% of trips under five miles were made by transit or non-motorized modes.

(4) $V_{auto} = -0.2 \times AutoTT$

(5) $V_{transit} = -1.0 - 0.2 \times TransitTT$

(6) $V_{nm} = -0.5 - 0.2 \times NmTT$

Table 2 directly contrasts the mode splits for all trips between the first MNL model with higher auto mode shares (Scenario Mode Choice 2) and the second MNL model with lower auto mode shares (Scenario High Transit).

Table 2: MNL Mode Choice Splits

Scenario	Auto Share	Transit Share	Non-motorized Share
Mode Choice 2	98.0%	1.4%	0.6%
High Transit	86.4%	12.5%	1.1%

User Class and Values of Time

The utility of a tolled route varies by time of day (due to changing congestion levels and potentially changing toll rates) and its competitive appeal should reflect some heterogeneity in travelers and trips. Those who value time highly are more likely to pay tolls to save travel time than those who value time relatively less. The model's response to tolls becomes more accurate with more stratification in value of travel time (VOTT) (Perez et al. 2012b), as demand estimates smooth to reflect more realistic travel patterns. Current best practices in user class segmentation vary widely. The Ohio DOT segments traveler classes based on household income and trip purpose (commute versus other), while the Oregon DOT segments only work trips by (three) income levels (Hall et al. 2013). In their managed lanes guide (for the FHWA), Perez et al. (2012a) recommended class segmentation across a *minimum* of four travel purposes, three income groups, and three to four vehicle types (e.g. auto, truck, commercial vehicle). For toll revenue estimation, URS (2010) distinguishes three trip purposes (home-based work, home-based non-work, and non-home-based trips) for person trips and three vehicle classes (light-, medium-, and heavy-duty trucks) for commercial trips. Within the truck fleet, Slavin et al. (2012) recommend that owner-operator and fleet-driven trucks be distinguished, due to notable differences in average VOTTs. On a per-mile basis, heavy-duty vehicles add more to pavement deterioration and congestion than a light-duty vehicle, and are thus tolled at significantly higher rates (Balducci and Stowers 2008).

This analysis compared the following four types of user class segmentation, using distinct VOTTs:

- 2-Class Setup: Light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs)
- 4-Class Setup: LDVs segmented by three income categories and HDVs
- 7-Class Setup: LDVs segmented by three income categories and two (personal) trip purposes and HDVs
- 8-Class Setup: LDVs segmented by three income categories and two (personal) trip purposes and HDVs segmented by for-hire versus privately owned carrier status

The base scenario here with a 2-class setup is typical of less sophisticated modeling frameworks, such as that in Texas (TTI 2011) and Georgia (FHWA 2013). The single-class LDV VOTT is assumed to be $12 per hour, based on the Austin, Texas, (five-county metro population of 1.8 million) Capitol Area Metropolitan Planning Organization value (CAMPO 2010). In reality, Tyler's median household income is 18% lower than that of Austin ($42,279 versus $51,596, according to the 2007-2011 American Community Survey's five-year estimates). So a $12/hour LDV VOTT value may be biased high for a (smaller-region) setting, but the purpose of this work is not to mimic Tyler's traffic patterns; it is to evaluate different model specifications, for a range of settings (with more and less transit use, more and less congestion, and different user classes, for example).

For the 4-class VOTT segmentation, the three LDV classes are segmented by household income, as shown in Table 3 "VOTT for All Trip Purposes" column. For the 7-class and 8-class VOTT setups, VOTT assumptions vary by income class and trip purpose, as shown in Table 3. These values are roughly derived from USDOT-suggested values (USDOT 2011).

Table 3: VOTTs per Vehicle by Traveler Income and Trip Purpose Segmentation

Household Income (per year)	**VOTT for All Trip Purposes**	**VOTT for Work Trips**	**VOTT for Non-work Trips**
< $30,000	$8/hour	$10/hour	$6/hour
$30,000–$75,000	$12/hour	$14/hour	$10/hour
> $75,000	$16/hour	$18/hour	$14/hour

Using data from the 2010 American Community Survey for the Tyler region, 37% of households fall into the low-income group, 36% fall in the medium-income group, and 27% fall into the high-income group, as defined by the income thresholds shown in Table 3.

For heavy trucks, the single-class HDV VOTT is assumed to be $40 per (truck) hour, based on values from four larger Texas MPOS: Austin, Dallas-Fort Worth, Houston, and San Antonio (Hall et al. 2014). Though there are many classifications among heavy-duty trucks that can affect VOTT, this study disaggregates by fleet ownership, as recommended by Slavin et al. (2012). Past studies (e.g., Smalkoski and Levinson [2005] and Kawamura [2000]) have estimated significantly higher VOTTs of for-hire carriers than for private carriers. FHWA (2000) found that private carriers handled 55% of the total tons carried by the trucking industry, with for-hire carriers handling the remaining 45%. Based on Smalkoski and Levison (2005) and Kawamura (2000), in the 8-user-classes scenario examined here, for-hire carriers (assumed to be 45% of the HDVs) were assigned a $60/hr VOTT and private carriers (assumed to be 55% of the HDVs) were assigned a $20/hr VOTT.

Congestion Feedback Loop for Behavioral Convergence

The most sophisticated TDMs in use today apply outer feedback loops in order to equilibrate model outputs, ultimately achieving convergence and a unique, stable transport-system solution (of travel times and flows, for example). While Perez et al. (2012a) emphasize the importance of incorporating *full*-model feedback in achieving a stable equilibrium solution in regions with congestion, actual modeling practices vary. Like in the case of time-of-day disaggregation, congestion feedback is a common practice among large MPOs (more than 80% include feedback) but less common in small MPOs (Wachs et al. 2007). Such feedback helps ensure consistency between model inputs (in the form of travel time and cost assumptions) and model outputs (in terms of updated times and costs, and associated flows).

This work evaluates the convergence improvement of introducing an outer feedback loop, for link-level travel times, using average travel times between successive model iterations. This loop recycles the congested network's lowest-impedance (lowest generalized cost) routes, travel times, and costs (for all OD pairs and all traveler types) resulting from the network assignment step back to the trip distribution step. This feedback ensures consistency, allowing the travel patterns to reach a behavioral equilibrium (in theory) and the system of model equations to achieve convergence. Convergence of the iterative model system is determined by calculation of the percent root-mean squared-error (%RMSE) term for differences in upstream generalized travel costs (as used in the trip distribution phase: GC'_j) and the assignment-based (outputted) generalized travel costs: GC°_j), as shown in the following equation:

$$(7)\quad \%\mathrm{RMSE} = \frac{\sqrt{\sum_j \left(GC^{\mathrm{t}}{}_j - GC_j^{t-1}\right)^2 / (\#OD\ Pairs)}}{\sum_j (GC^{t-1}) / (\#OD\ Pairs)} 100$$

where *j* indexes the 204,304 OD pairs in the Tyler zone system, and generalized travel costs (GC) are typically for a single mode (the auto mode here) at a single time of day (such as AM peak period).

Convergence is established here when the %RMSE summed over all OD pairs is 1% or less as recommended by Slavin et al. (2012). In this study, as in general practice, the %RMSE for convergence is calculated for a single time of day (when multiple periods exist) for a specific mode (e.g., the AM peak period for auto mode, as used here).

MODELING SCENARIOS

Tyler Network and Trip Generation

Tyler, Texas, was chosen as the demonstration setting and network for these modeling scenarios, due to the city's medium size (approximately 215,000 persons). The region's 2002 network includes 452 zones, 1,475 nodes, and 2,291 bi-directional links. For non-commercial personal travel, vehicle-trip generation was performed using standard NCHRP Report 365 rates (Martin and McGuckin 1998) for each of three personal-trip purposes (HBW, HBO, and NHB trips), as is standard in TransCAD 6.0. The person-trip attraction rates are calculated as functions of the number of households (HH), whether a zone is in the central business district (CBD), and the numbers of retail, service, and basic (non-retail and non-service) jobs in the zone, as shown in the following equations, from Martin and McGuckin (1998):

(8) HBW Attractions in all zones = 1.45 × Jobs (in zone)

(9) HBO Attraction in CBD zones = (2.0 × CBD Retail Jobs) + (1.7 × Service Jobs) + (0.5 × Basic Jobs) + (0.9 × HHs)

(10) HBO Attraction in non-CBD zones = (9.0 × non-CBD Retail Jobs) + (1.7 × Service Jobs) + (0.5 × Basic Jobs) + (0.9 × HHs)

(11) NHB Attraction in CBD zones = (1.4 × CBD Retail Jobs) + (1.2 × Service Jobs) + (0.5 × Basic Jobs) + (0.5 × HHs)

(12) NHB Attraction in non-CBD zones = (4.1 × non-CBD Retail Jobs) + (1.2 × Service Jobs) + (0.5 × Basic Jobs) + (0.5 × HHs)

For commercial-truck trips, an average of trip rates provided by the Northwest Research Group for Southern California and for Seattle's MPO (the Puget Sound Regional Council) was used here, based on NCHRP Report 716 (Cambridge Systematics 2012). Productions and attractions were calculated as functions of the total number of households and total number of jobs, as shown in the following equations:

(13) Truck trip Productions = (0.014 × HHs) + (0.062 × Jobs)

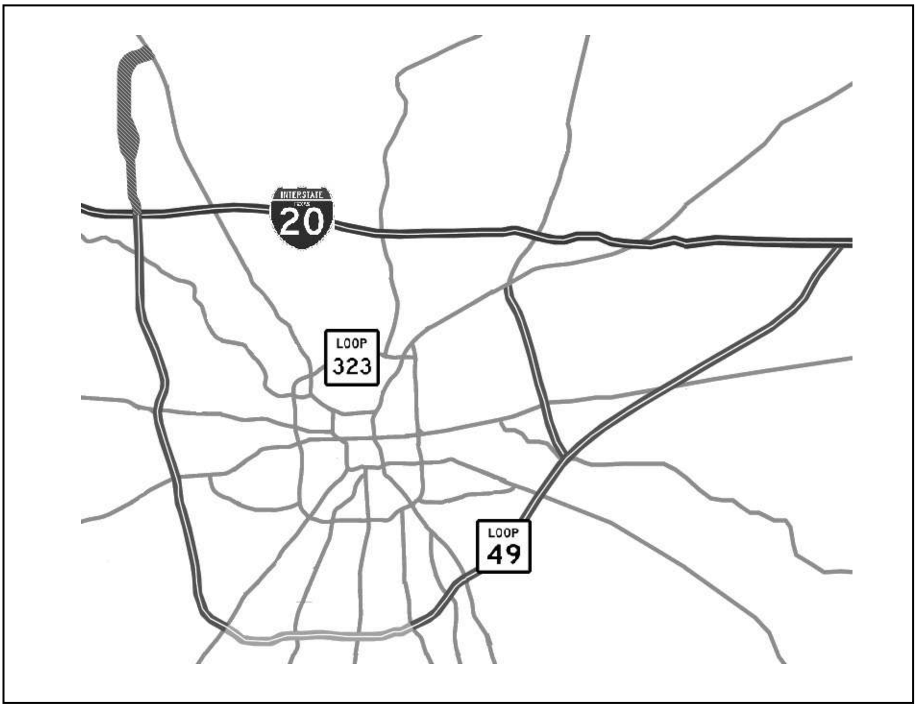
(14) Truck trip Attractions = (0.020 × HHs) + (0.065 × Jobs)

Trip distribution for three trip purposes (HBW, HBO, and NHB) was done via a gravity model using friction factors generated from Martin and McGuckin's (1998) gamma impedance function, the default parameters in TransCAD 6.0. The impedance term provides a structure for measuring relative spatial separation (such as travel distance, time, and cost) of trips between origins and destinations. Here, the gravity model is doubly constrained by productions and attractions in each zone, for each of the three trip purposes.

While Loop 49 is Tyler's current toll corridor, its distance from the region's downtown and current traffic volumes (below 2000 AADT on at least two segments) make the route an unsuitable candidate for testing the sensitivities of the previously described criteria. For example, any percentage change in Loop 49's low flows may easily overstate the sensitivity of such results to the alternative modeling approaches being tested here. For this reason, Loop 323, which is a 19.7-mile four- to six-lane major arterial about three miles from the region's primary downtown, was used as a (hypothetical) tolled corridor to test the alternative model specifications. Loop 323 is one of the most congested corridors in the region, due to its relative abundance of retail destinations and proximity to existing urban development.

Texas' current distance-based toll rates *average* between \$0.12 to \$0.23 per mile for passenger vehicles with toll tags (transponders or RFID chips). But minimum toll charges of \$0.25 and \$0.19 apply at each mainlane gantry and ramp gantry, respectively. This minimum-charge situation means that some tolls are as high as \$0.40 per mile for very short intra-city trip segments on the tolled facility (Hall 2014). Therefore, for purposes of this paper's test scenarios, distance-based tolls of \$0.20 per mile for autos and \$0.55 per mile for trucks are assumed to apply.

Figure 1: Loop 49 and Loop 323 Locations in the Tyler, Texas, Highway Network



SCENARIO RESULTS

The various model improvements discussed previously were incorporated into test runs on the Tyler network using TransCAD 6.0. Martin and McGuckin's (1998) daily trip generation and attraction values were increased 50% (by applying a 1.5 multiplier on all trip attraction rates) to better characterize a moderately congested network. Those volumes were then increased another 50% (or 125% versus Tyler's 2002 trip-making levels) to help reflect a severely congested network, with all results shown in Table 4. As a reference, the trip counts on Loop 323 on the moderately congested network are about 80% of the actual 2012 daily traffic volumes (Hall 2014), whereas traffic counts on Loop 323 in the severely congested network case are about 120% of the 2012 trip counts.

As described earlier, the base model is a non-tolled 24-hour assignment setup with a single user class, no mode-choice step (private vehicle-trips only), a 0.001 network assignment convergence (gap) criterion[1] (as currently used in the Texas DOT's model framework) and no outer feedback loop. Experts (e.g., Boyce and Xie [2012], Slavin et al. [2012], and Morgan and Mayberry [2010]) recommend convergence as defined by gaps of 10^{-4} or less, which is the network assignment gap defined in all scenarios other than the base model. Building on this base model, two alternative base models (Base Alt 1 and Base Alt 2) that recognize two user classes (commercial trucks and LDVs) were also considered, the first without tolls and the second tolled. From these alternative base-case models, the model improvements were first tested individually and then in various combinations (of two or more enhancements/extensions), with full-network and Loop-323-only VMT, vehicle-hours traveled (VHT) values, and toll revenues compared with the base model's values (as shown in Tables 4 and 5). Results of 36 scenarios are shown in Tables 4 and 5 (18 for each of the two trip generation or general congestion levels). Additional scenarios with more congestion and overall lower and higher VOTTs were also run, and are discussed briefly below. Since Loop 323 is the only true ring road in Tyler with no true substitute route, to test the different models' performances

Table 4: Network and Tolled Route Metrics with Moderate Congestion Across All Scenarios

							Network Results				Loop 323 Results				
SCENARIO	**Toll**	**# Times of Day**	**# of User Classes**	**Mode Choice**	**NA Conv.**	**Fdbk. Loop**	**VHT (hrs)**	**% Change**	**VMT (10^6 miles)**	**% Change**	**VHT (hrs)**	**% Change**	**VMT (miles)**	**% Change**	**Toll Revenue**
Base	N	1	1	-	0.001	N	159,266	-	4.662	-	10,793	-	436,920	-	$91,753
Base Alt 1	N	1	2	-	0.0001	N	162,953	2.32%	4.736	1.57%	11,028	2.18%	445,900	2.06%	$93,639
Base Alt 2	Y	1	2	-	0.0001	N	161,065	1.13%	4.683	0.46%	10,785	-0.07%	436,501	-0.10%	$91,665
Time-of-day 1	Y	2	2	-	0.0001	N	164,000	2.97%	4.736	1.57%	11,059	2.47%	446,193	2.12%	$93,700
Time-of-day 2	Y	4	2	-	0.0001	N	179,308	12.58%	4.742	1.71%	11,040	2.29%	444,739	1.79%	$93,395
User Class 1	Y	1	4	-	0.0001	N	159,918	0.41%	4.689	0.58%	10,917	1.15%	441,683	1.09%	$92,753
User Class 2	Y	1	7	-	0.0001	N	159,443	0.11%	4.757	2.02%	10,818	0.23%	437,917	0.23%	$91,963
User Class 3	Y	1	8	-	0.0001	N	151,341	-4.98%	4.496	-3.56%	10,376	-3.86%	420,498	-3.76%	$88,305
Mode Choice 1	Y	1	2	Fixed-share	0.0001	N	153,261	-3.77%	4.606	-1.22%	10,730	-0.58%	434,653	-0.52%	$91,277
Mode Choice 2	Y	1	2	MNL	0.0001	N	159,966	0.44%	4.464	-4.24%	10,473	-2.96%	421,688	-3.49%	$93,216
High Transit	Y	1	2	MNL	0.0001	N	139,623	-12.33%	4.434	-4.89%	10,251	-5.02%	416,094	-4.77%	$87,380
Feedback Loop	Y	1	2	-	0.0001	Y	151,445	-4.91%	4.464	-4.24%	10,473	-2.96%	421,688	-3.49%	$88,554
Comb. 1	Y	4	2	-	0.0001	N	179,308	12.58%	4.742	1.71%	11,040	2.29%	444,739	1.79%	$93,395
Comb. 2	Y	4	4	-	0.0001	N	178,057	11.80%	4.596	-1.43%	10,516	-2.57%	438,946	0.46%	$92,179
Comb. 3	Y	4	7	-	0.0001	N	169,104	6.18%	4.550	-2.41%	10,437	-3.30%	414,405	-5.15%	$87,025
Comb. 4	Y	4	7	Fixed-share	0.0001	N	168,186	5.60%	4.322	-7.30%	10,412	-3.53%	410,872	-5.96%	$86,283
Comb. 5	Y	4	7	MNL	0.0001	N	166,120	4.30%	4.512	-3.22%	10,503	-2.69%	399,549	-8.55%	$83,905
Comb. 6	Y	4	7	MNL	0.0001	Y	158,515	-0.47%	4.406	-5.50%	9,779	-9.39%	380,283	-12.96%	$79,859

Table 5: Network and Tolled Route Metrics with Severe Congestion Across All Scenarios

							Network Results				Loop 323 Results				
SCENARIO	**Toll**	**# Times of Day**	**# User Classes**	**Mode Choice**	**NA Conv.**	**Fdbk. Loop**	**VHT (hours)**	**% Change**	**VMT (10^6 miles)**	**% Change**	**VHT (hours)**	**% Change**	**VMT (miles)**	**% Change**	**Toll Revenue**
Base	N	1	1	-	0.001	N	458,246	-	7.068	-	16,497	-	636,701	-	$133,707
Base Alt 1	N	1	2	-	0.0001	N	473,362	3.30%	7.178	1.55%	16,871	2.27%	648,374	1.83%	$136,159
Base Alt 2	Y	1	2	-	0.0001	N	471,066	2.80%	7.170	1.43%	16,768	1.64%	643,386	1.05%	$135,111
Time-of-day 1	Y	2	2	-	0.0001	N	479,311	4.60%	7.187	1.68%	17,122	3.79%	652,769	2.52%	$137,081
Time-of-day 2	Y	4	2	-	0.0001	N	589,349	28.61%	6.467	-8.51%	17,212	4.33%	651,264	2.29%	$136,765
User Class 1	Y	1	4	-	0.0001	N	458,012	-0.05%	7.105	0.52%	16,695	1.20%	642,965	0.98%	$135,023
User Class 2	Y	1	7	-	0.0001	N	457,218	-0.22%	7.081	0.18%	16,539	0.26%	638,037	0.21%	$133,988
User Class 3	Y	1	8	-	0.0001	N	428,706	-6.44%	6.832	-3.34%	15,895	-3.65%	615,310	-3.36%	$129,215
Mode Choice 1	Y	1	2	Fixed-share	0.0001	N	408,950	-10.76%	6.866	-2.86%	15,978	-3.14%	620,322	-2.57%	$130,268
Mode Choice 2	Y	1	2	MNL	0.0001	N	456,687	-0.34%	7.137	0.97%	16,667	1.03%	645,199	1.33%	$135,492
High Transit	Y	1	2	MNL	0.0001	N	351,149	-23.37%	6.710	-5.07%	15,499	-6.05%	603,100	-5.28%	$126,651
Feedback Loop	Y	1	2	-	0.0001	Y	446,640	-2.53%	6.905	-2.31%	16,284	-1.29%	634,394	-0.36%	$133,223
Comb. 1	Y	4	2	-	0.0001	N	589,349	28.61%	6.467	-8.51%	17,212	4.33%	651,264	2.29%	$136,765
Comb. 2	Y	4	4	-	0.0001	N	548,934	19.79%	6.088	-13.87%	16,485	-0.07%	622,974	-2.16%	$130,825
Comb. 3	Y	4	7	-	0.0001	N	575,722	25.64%	6.192	-12.40%	16,838	2.07%	638,324	0.25%	$134,048
Comb. 4	Y	4	7	Fixed-share	0.0001	N	558,760	21.93%	6.195	-12.36%	15,749	-4.53%	604,288	-5.09%	$126,900
Comb. 5	Y	4	7	MNL	0.0001	N	568,192	23.99%	6.090	-13.84%	16,710	1.29%	644,111	1.16%	$135,263
Comb. 6	Y	4	7	MNL	0.0001	Y	541,834	18.24%	5.789	-18.10%	15,978	-3.15%	600,330	-5.71%	$126,069

in a network with substitute routes, additional scenarios were also examined where Loop 323 was changed to a tolled four-lane freeway facility with the existing arterial links converted to parallel frontage roads. It is important to note that currently the land use along arterial Loop 323 is heavily commercial with abundant driveway access, and such land use may not be realistic if Loop 323 is converted to an access-controlled freeway (such as the case in the substitute route scenarios). The results of these runs are included in Appendix A, and the relevant results are also discussed below.

Impact of Incorporating Time-of-Day Disaggregation

When looking only at single-strategy improvements (and thus ignoring combination strategies), allowance for different travel times and network loads across distinct times of day resulted in the largest VMT and VHT changes (network-wide and on Loop 323), versus the base model, as compared with the other model enhancements' impacts. In the severely congested case, the base model underestimates network VHT by 28.6% and overestimates network VMT by 8.5%, as compared with the scenario utilizing four time periods per day, which corresponds to a 2.3% underestimate in toll revenues on Loop 323. This result highlights the importance of disaggregating travel behavior across time periods, since a single 24-hour period model ignores the severe peak-hour congestion levels that reduce travel speeds and cause a corresponding increase in vehicle-hours traveled. Moreover, differences in other model outputs between the two- and four-time-of-day segmentations were noticeable, with the added periods resulting in greater changes in network and Loop 323 metrics (i.e., flows and Loop 323 toll revenues), particularly under the most congested scenario (Table 5's Time of Day 2 Scenario). For example, under severe congestion, the four-times-of-day scenario underestimates network VMT by 11.7%, whereas the two-times-of-day scenario underestimates network VMT by 24.1%, compared with the most sophisticated scenario modeled here (Combination 6). In addition to more accurate model outputs, incorporating such temporal disaggregation in the TDM also allows modelers, planners, and policymakers to directly model the impacts of variable tolling policies - like those whose rates and high-occupancy-vehicle (HOV) policies vary by time of day and/or with congestion, as is the case with most managed lanes (Perez et al. 2012b).

Impact of Incorporating a Mode-Choice Step

The addition of a mode-choice step was next in line, in terms of magnitude of impact on model results, versus the base specification. Under severe congestion, the base model overestimates network VHT by 10.8%, as compared with the scenario with a fixed-shares mode choice step. With auto travel dominating mode choices (capturing approximately 95% of person-trips in the test network), the MNL mode-choice model did not provide significantly better estimates than the fixed-mode-shares (as a function of trip distance) model. For example, under moderate congestion (Table 4), Loop 323 VHT and VMT outputs from the fixed-share model are actually closer to the estimates from the most sophisticated Scenario Combination 6, while the reverse is true under severe congestion (Table 5). However, in a network with greater shares of transit and non-motorized travel (as evident in Table 4's and Table 5's High Transit scenario, which predicted 25% transit and non-motorized trips), the differences are quite significant: the base model underestimates network VHT by 23.4%, as compared with the scenario with an MNL mode choice step (Table 5). The more behaviorally defensible MNL mode-choice model is also generally preferred in current TDM practice (URS 2011).

Impact of Incorporating Multi-class Assignment

When road tolls distinguish vehicle types, as they almost always do (e.g., LDVs pay much less than HDVs), simply distinguishing between these vehicle types (using at least two user classes) is quite important for tolling traffic and revenue (T&R) estimation. When comparing the Base and Base Alt 1 scenarios, Loop 323's estimated toll revenues rise by 2.1% and 1.8%, under moderate and severe congestion, as a direct result of adding two user classes. However, differences in model results were not estimated to be significant when the specifications incorporated multiple (user) classes within the LDV category when analyzed in a single 24-hour period. Differences in VMT and VHT were less than 2% when the LDV trips were classified by household income versus by household income and trip purpose (work versus non-work), relative to the base specification, even when the network was congested. However, combined with incorporation of time-of-day disaggregation (Scenarios Combination 2 and Combination 3) in the severely congested case, the models' metrics are comparable to those in the most sophisticated scenario modeled here (Combination 6), with all network and Loop 323 metrics within 7% of those of Combination 6. Scenario Combination 2 (which uses four times of day with four user classes) suggests that the base model underestimates network VHT by 19.8% and overestimates network VMT by 13.9% under severe congestion. While these differences may be exaggerated by the lack of a substitute route for Loop 323 in Tyler, scenarios with good substitute routes (on a network with tolled Loop 323 freeway lanes and non-tolled frontage lanes, as seen in Appendix A) still reflect that the Base model underestimates network VHT by 18.5% and overestimates network VMT by 9.1%, as compared with scenario Combination 2 under severe congestion.

Interestingly, the introduction of two HDT user classes in Scenario User Class 3 (segmented as for-hire versus private carriers) produced more significant model-output differences. The high income LDV user class had double the VOTT of the low income LDV user class, whereas the high VOTT HDV user class had triple the VOTT of the low VOTT HDV user class. These results suggest that multi-class assignment in a model recognizing user classes with relatively high VOTTs (as is the case of for-hire carriers, modeled here at \$60/hour – versus \$20/hour for the privately held HDVs and \$18/hour and under for all LDV trips), output differences are more significant, up to 6% in the severely congested condition. However, additional scenarios in which all LDV and HDV VOTTs were assumed to be extremely high (double the VOTTs originally assumed) or extremely low (half the VOTT originally assumed) did not yield significant differences in model outputs. Thus, these results appear to highlight the importance of *relative* differences in competing user classes' VOTTs for TDM outputs: absolute VOTT increases or decreases across user classes are less important than big relative differences within a single model run, at least in this situation with no true competing route. In addition, and as expected, a more congested setting meant that incorporation of such multi-class assignment (and reliance on more user classes) had a greater effect on the tolled corridor's VHT and VMT values and revenues. Incorporating eight user classes brought toll revenue estimates to within 11% of the estimate from the most sophisticated scenario (Combination 6) under moderately congested conditions, and within 3% under severely congested conditions.

Impact of Incorporating Outer Feedback Loop

In both the moderately and severely congested network cases, incorporating an outer feedback loop provided moderate model improvements, as suggested by changes of less than 5% in network and Loop 323 VHT and VMT values. Under congested conditions, an outer feedback loop helps ensure that models do not prematurely stop at an intermediate solution before reaching true convergence (as measured by the %RMSE differences across generalized travel costs for all OD pairs for a select time period: peak auto travel time for two time-of-day specifications and AM peak auto travel time for four time-of-day specifications). Other benefits of this outer feedback loop are behavioral defensibility and no added model assumptions (Slavin et al. 2012).

CONCLUSIONS, CAVEATS, AND RECOMMENDATIONS

As demonstrated on the Tyler network, a wide variety of behaviorally disaggregate model improvements can enhance the basic TDM specifications that are common in many smaller cities and regions, and some larger regions, in the U.S. and/or abroad. Under the scenarios tested here, model improvements that resulted in the greatest VHT and VMT changes on the tolled corridor and entire network are as follows (in order of impact, with the most important enhancements shown first):

- Recognizing multiple time periods in a day (to reflect variable travel times and to add flexibility for modeling time-variable tolls)
- Adding a mode-choice step (particularly in regions with higher transit and non-motorized trip shares)
- Disaggregating traveler classes by values of time (particularly when there are significant differences in VOTTs across user classes)
- Incorporating an outer feedback loop to reflect congestion levels and ensure consistency in travel cost assumptions

Combination 6 represents the most sophisticated and disaggregate model pursued in this study, by recognizing tolling, four times of day, seven user classes, an MNL mode-choice specification, a 0.0001 network convergence criterion, and an outer feedback loop (designed to meet a 1% RMSE target). Compared with Combination 6, the base model overestimates toll revenues along Loop 323 by 13% in the moderately congested scenario and 5.7% in the severely congested scenario. Such differences suggest important mis-prediction errors that can harm decision-making and budget allocations. With respect to the different combination scenarios (which rely on a set of model enhancements), adding both multi-class assignment and time-of-day disaggregation to a standard TDM (as done in the Combination 2 and 3 scenarios) seems to be very effective in mimicking results of the most sophisticated, behaviorally disaggregate model tested here, Combination 6 (particularly in Combination 2), which utilizes four times of day and four user classes and estimates severe-congestion toll revenues within 4%, as shown in Table 5. Given that most if not all commercially available TDM packages can readily accommodate such model specifications, it seems wise for most if not all regions to enable such modeling improvements in their TDM setups. When transit mode shares are significant in a community, the incorporation of a mode choice step, along with multi-class assignment and time-of-day-disaggregation (as modeled in Combinations 4 and 5), brings the toll revenue estimates to within 8% under moderate congestion and 7% under severe congestion, when compared with the most sophisticated model (Combination 6). The results presented here highlight the importance of having a behaviorally defensive TDM that will better forecast travel demands (and other outputs of interest, like toll revenues), particularly in communities with new transportation policies (such as tolls that vary by vehicle occupancy or time of day) and important alternative modes (such as transit, walking, cycling, carsharing, bike sharing, and carpooling).

While model outputs in this paper appear specific to the Tyler, Texas, context, the use of Tyler data sets simply allows one to demonstrate model specification effects across a set of realistic traffic analysis zones and network conditions. Model inputs are based primarily on national averages, and demand levels, network attributes, mode shares, and other behaviors were varied; so predicted outputs are not a future forecast for this particular region. However, the general magnitude of the effectiveness of specific TDM improvement strategies should be transferrable to other transportation networks, since contextual modifications (like higher transit shares, extremely low and high VOTTs, and addition of substitute network routes) did not impact the relative effectiveness of model improvement strategies.

Of course, each region has its own pressing transportation challenges and unique transportation culture. As discussed in the results, a region's specific transportation characteristics (e.g., existence of dynamically or occupancy-based tolled facilities, and high transit and/or non-motorized mode shares) also impact the rankings of these strategies, and model flexibility may override absolute output differences.

Moreover, it would be worthwhile testing different model specifications. For example, the trip distribution step used here follows a traditional gravity model calibrated to highly aggregated metrics (in this case, trip-length-based frequency distributions). In practice, singly constrained destination choice models based on MNL specifications are generally considered more behaviorally defensible for almost all trip purposes and can be applied in a disaggregate manner, relative to gravity models (Cambridge Systematics 2010). There are also limitations to modeling toll demand within a traditional trip-based model. Microsimulation via a journey-based modeling approach (associating multiple, connected trips to a unique decision maker) may be key for capturing individuals' valuations of time and trip-making heterogeneity (Parsons Brinkerhoff et al. 2013), and tour-based and activity-based models can better account for the dependence of related trip-making. Lastly, current TDMs are built upon household travel survey data, describing past trip patterns and travel alternatives so they can miss the rise of carsharing, bike-sharing, and other emerging options (Lawton 2014).

The relative performance of these competing model improvements also depends on the TDM's specific, intended application(s). For example, in applications focused on emissions estimation, rather than toll demand estimation, time-of-day disaggregation becomes more important, along with the presence of multiple user classes (for trucks versus auto travel), since emissions rates and route preferences can vary quite a lot with speeds – unless there truly is no real congestion (or speed variation) expected in these networks 20 years forward. Finally, increased complexity of a region's transportation system, via introduction of various congestion pricing schemes (e.g., static and dynamic tolling scenarios) and alternative modes of transit and para-transit (e.g., bus rapid transit, car and bike sharing), highlight a need for transportation planners in all regions to appreciate the type of flexibility and result variations that each of these TDM enhancements (to better reflect human behavior and heterogeneity) enables when evaluating various system changes, over time and space. In a 2004 survey of MPOs, 70% mentioned needed improvements to their modeling processes to better model road pricing, time-specific transportation policies, and non-motorized travel (Wachs et al. 2007). This work illuminates many of the options and their effects on a mid-size network.

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Endnotes

1. Convergence gap is defined as $Gap = \frac{\sum_{i \in I} \sum_{k \in K} f_k t_k - \sum_{i \in I} d_i t_{min,i}}{\sum_{i \in I} d_i t_{min,i}}$, where I is the set of all OD pairs, K_i is the set of all paths used by trips traveling between OD pair I, f_k is the number of trips taking path k, t_k is the travel time on path k, d_i is the current flow on link i, and $t_{min,i}$ is the travel time on the shortest (or minimum-cost) path between OD pair I (Morgan and Mayberry 2010).

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APPENDIX A

Table 6: Network and Tolled Route (with Substitute Route for Loop 323) Metrics with Moderate Congestion Across Select Scenarios

							Network Results				Loop 323 Results			
SCENARIO	**Toll**	**# Times of Day**	**# User Classes**	**Mode Choice**	**NA Conv.**	**Fdbk. Loop**	**VHT (hours)**	**% Change**	**VMT (10^6 miles)**	**% Change**	**VHT (hours)**	**% Change**	**VMT (miles)**	**% Change**
Base	N	1	1	-	0.001	N	158,346	-	4.732	-	8,569	-	468,283	-
Base Alt 1	N	1	2	-	0.0001	N	158,348	0.00%	4.732	0.00%	8,570	0.01%	468,352	0.01%
Base Alt 2	Y	1	2	-	0.0001	N	159,758	0.89%	4.732	0.01%	8,581	0.14%	468,053	-0.05%
Time of Day 1	Y	2	2	-	0.0001	N	161,214	1.81%	4.732	0.01%	8,578	0.11%	466,229	-0.44%
Time of Day 2	Y	4	2	-	0.0001	N	159,936	1.00%	4.731	-0.03%	8,540	-0.34%	466,363	-0.41%
User Class 1	Y	1	4	-	0.0001	N	156,683	-1.05%	4.686	-0.97%	8,486	-0.97%	463,281	-1.07%
User Class 2	Y	1	7	-	0.0001	N	159,757	0.89%	4.741	0.19%	8,598	0.34%	468,900	0.13%
Mode Choice 1	Y	1	2	Fixed Share	0.0001	N	150,071	-5.23%	4.601	-2.78%	8,360	-2.44%	457,120	-2.38%
Mode Choice 2	Y	1	2	MNL	0.0001	N	156,893	-0.92%	4.706	-0.54%	8,551	-0.21%	466,618	-0.36%
Feedback Loop	Y	1	2	-	0.0001	Y	160,454	1.33%	4.664	-1.43%	8,558	-0.13%	466,681	-0.34%
Comb. 1	Y	4	2	-	0.0001	N	159,936	1.00%	4.731	-0.03%	8,540	-0.34%	466,363	-0.41%
Comb. 2	Y	4	4	-	0.0001	N	138,223	-12.71%	4.296	-9.21%	7,834	-8.58%	429,510	-8.28%
Comb. 3	Y	4	7	-	0.0001	N	148,282	-6.36%	4.560	-3.64%	8,200	-4.30%	449,544	-4.00%
Comb. 4	Y	4	7	Fixed Share	0.0001	N	139,861	-11.67%	4.418	-6.64%	7,964	-7.06%	442,247	-5.56%
Comb. 5	Y	4	7	MNL	0.0001	N	136,433	-13.84%	4.350	-8.07%	7,950	-7.22%	437,614	-6.55%
Comb 6.	Y	4	7	MNL	0.00001	Y	136,816	-13.60%	4.259	-10.00%	7,970	-6.99%	436,316	-6.83%

Table 7: Network and Tolled Route (with Substitute Route for Loop 323) Metrics with Severe Congestion Across Select Scenarios

							Network Results				Loop 323 Results			
SCENARIO	Toll	# Times of Day	# User Classes	Mode Choice	NA Conv.	Fdbk. Loop	VHT (hours)	% Change	VMT (10^6 miles)	% Change	VHT (hours)	% Change	VMT (miles)	% Change
Base	N	1	1	-	0.001	N	456,335	-	7.160	-	13,209	-	675,490	-
Base Alt 1	N	1	2	-	0.0001	N	456,350	0.00%	7.159	0.00%	13,204	-0.04%	675,305	-0.03%
Base Alt 2	Y	1	2	-	0.0001	N	466,142	2.15%	7.162	0.03%	13,240	0.23%	673,122	-0.35%
Time of Day 1	Y	2	2	-	0.0001	N	474,918	4.07%	7.169	0.13%	13,346	1.04%	671,723	-0.56%
Time of Day 2	Y	4	2	-	0.0001	N	465,279	1.96%	7.170	0.15%	13,258	0.37%	679,604	0.61%
User Class 1	Y	1	4	-	0.0001	N	450,941	-1.18%	7.089	-0.98%	13,084	-0.95%	667,211	-1.23%
User Class 2	Y	1	7	-	0.0001	N	465,081	1.92%	7.174	0.20%	13,270	0.46%	674,427	-0.16%
Mode Choice 1	Y	1	2	Fixed Share	0.0001	N	415,702	-8.90%	6.958	-2.82%	12,851	-2.71%	658,948	-2.45%
Mode Choice 2	Y	1	2	MNL	0.0001	N	449,575	-1.48%	7.121	-0.54%	13,177	-0.24%	670,948	-0.67%
Feedback Loop	Y	1	2	-	0.0001	Y	464,640	1.82%	7.172	0.17%	13,330	0.92%	673,221	-0.34%
Comb. 1	Y	4	2	-	0.0001	N	465,279	1.96%	7.170	0.15%	13,258	0.37%	679,604	0.61%
Comb. 2	Y	4	4	-	0.0001	N	372,005	-18.48%	6.507	-9.11%	12,078	-8.56%	627,214	-7.15%
Comb. 3	Y	4	7	-	0.0001	N	405,812	-11.07%	6.906	-3.55%	12,657	-4.18%	656,390	-2.83%
Comb. 4	Y	4	7	Fixed Share	0.0001	N	359,383	-21.25%	6.743	-5.82%	12,264	-7.15%	639,935	-5.26%
Comb. 5	Y	4	7	MNL	0.0001	N	346,724	-24.02%	6.730	-6.00%	12,179	-7.80%	638,441	-5.48%
Comb. 6	Y	4	7	MNL	0.00001	Y	344,934	-24.41%	6.760	-5.58%	12,249	-7.27%	643,367	-4.76%

Severity of Pedestrian Crashes at Highway-Rail Grade Crossings

by Aemal Khattak and Li-Wei Tung

The objective of this research was to quantify the impacts of various factors on three different severity levels of pedestrian injuries sustained in crashes reported at highway-rail grade crossings. This research utilized the 2007-2010 crash and crossing inventory data. The three crash severity levels of pedestrians' injuries were: no injury, injury, and fatality.

Data analysis showed that pedestrian fatalities were associated with higher train speeds and with female pedestrians. Highway-rail grade crossings with a greater number of crossing lanes and those equipped with standard flashing light signals were associated with a lower likelihood of pedestrian fatalities.

INTRODUCTION

The objective of this research was to quantify the impacts of various factors on three different severity levels of pedestrian injuries sustained in crashes reported at highway-rail grade crossings (HRGCs). These severity levels were based on the intensity of pedestrians' injuries and included: no injury, injury, and fatality. HRGCs are conflict points between users of highways/streets and crossing trains. Since trains have the right of way at HRGCs, almost all crashes at these locations are the result of violations by highway/street users. The number of pedestrian crashes reported at HRGCs has increased by 55.4% over the 2001-2010 period. According to the Federal Railroad Administration (FRA), 2,017 crashes were reported at HRGCs in 2010 across the United States (FRA 2012a). Of these, 143 crashes involved pedestrians that resulted in 79 (55.2%) fatalities, 48 (33.6%) non-fatal injuries, and 16 (11.2%) no injuries.

Railroad companies report crashes at HRGCs on the FRA's Highway-Rail Grade Crossing Accident/Incident Report form (FRA F6180.57). As part of this form, narrative event descriptions are filed by involved railroad companies. Three such narratives from the 2010 HRGC crashes involving pedestrians highlight the three injury severity levels as well as show that crashes at HRGCs invariably result from encroachment of rail right-of-way by highway/street users:

- "An intoxicated pedestrian was struck by train while attempting to cross track at crossing. Pedestrian was hit by snow plow located on front of engine. After being struck pedestrian got back up and began to walk away from accident. He was detained by crew and checked out by EMS at the scene. No further medical attention needed" (incident number 000076300).
- "Train 798 moving north, 10 mph, across the 22nd street crossing in Fort Payne, AL when trespasser attempted to mount a moving rail car in the train and slipped and fell amputating his left foot" (incident number 039139).
- "Pedestrian was walking a dog eastbound through Coast Blvd crossing. Gates were down, lights and bells were working. Crew states man never looked up and continued through the crossing. Whistle was blowing continuously and train placed into emergency. Pedestrian was struck by front corner of locomotive and succumbed to his injuries one hour later" (incident number 04272010).

The organization of the remaining paper is as follows. After this introduction a brief review of pertinent literature on pedestrian injury severity at highway-rail crossings is given. The next section presents conceptualization of different variables affecting pedestrians' injury severity levels and data compilation. The ensuing section presents data analysis and results while conclusions and a brief discussion complete this paper.

LITERATURE REVIEW

A review of published literature uncovered publications dealing with pedestrian safety at HRGCs, although the possibility of less accessible reports held by railroad companies or government agencies exists. Lobb (2006) reported on the issue of train-pedestrian crashes and commented on the "remarkably" little research available on this topic. Lobb (2006) highlighted major types of railway crash research and suggested the use of behavioral and cognitive psychology to obtain insights into trespassing incidents.

Studies have shown that while crashes at HRGCs are relatively uncommon (compared with crashes on the rest of the highway system), such crashes are more likely to result in death or severe injuries (Goldberg et al. 1998, Evans 2003). Alcohol consumption on the part of pedestrians appears to play a role in train-pedestrian crashes; Pelletier (1997) reported 82% of trespasser fatalities in North Carolina tested positive for alcohol use while Cina et al. (1994) reported 80% of the fatalities in their study were intoxicated. It should be noted that these two studies were focused on trespassers not necessarily at HRGCs.

Silla and Luoma (2011) reported on the effects of fencing, landscaping, and use of message signs on reducing trespassing on rail tracks. Fencing was the most effective, reducing trespassing by 94.6% followed by landscaping, which reduced trespassing by 91.3%, while message signs reduced trespassing by 30.7%. The majority of illegal crossings were committed alone (i.e., not in the company of another person) and the violators were mostly adult males.

In another study, Silla and Luoma (2012) reported on the main characteristics of train-pedestrian fatalities on Finnish railroads. The 2005-2009 data showed that 311 pedestrians were killed in train-pedestrian collisions, including 264 (84.9%) suicides, 35 (11.3%) accidents, and 12 (3.9%) unclassified events. Male victims were the majority for each type of event. Most suicide victims were in the 20–29 year age group and, on average, younger than people who chose some other form of suicide. About half of all victims were intoxicated by alcohol, medicines, and/or drugs. Both suicides and accidents occurred most often at the end of the week but no specific peak for time of year was found. Crashes occurred most frequently during rush hours and in densely populated areas. The authors recommended a systems approach involving effective measures introduced by authorities responsible for urban planning, railways, education, and public health.

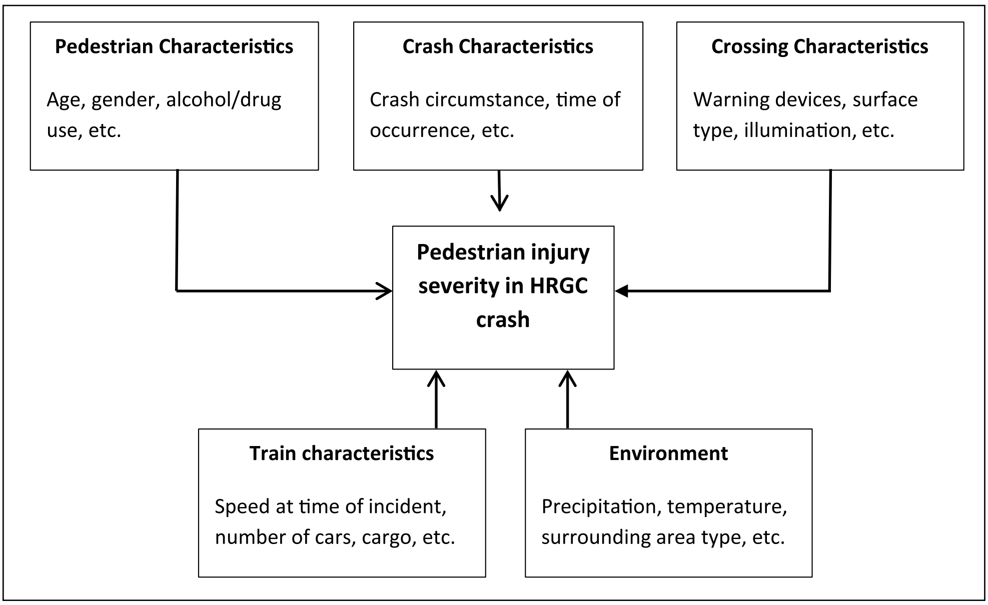
Transportation agencies responsible for public safety have produced guides for improving the safety of pedestrians at HRGCs. Transport Canada developed a pedestrian grade crossing safety guide (Transport Canada 2007) that provides different strategies on improving pedestrian safety at grade crossings. FRA also provided guidance on pedestrian safety crossings at or near passenger stations (FRA 2012b). Suggested safety-improving approaches included audible and visual warnings, infrastructure improvements, enforcement, and education of crossing users to improve pedestrian safety.

In summary, limited published literature is available on train-pedestrian crashes; of the available literature most is focused on trespassing pedestrians not necessarily at HRGCs. Prominent characteristics of train-pedestrian crashes include higher levels of injuries compared with other crashes, alcohol consumption by pedestrians, young adults, and male pedestrians. Some transportation agencies provide guidance on making HRGCs safer for pedestrians. However, this review of literature did not uncover publications dealing with severity levels of pedestrian injuries sustained in HRGC crashes. Knowledge of variables associated with different levels of pedestrians' injuries can potentially help with more informed decisions regarding safety improvements at HRGCs. This study attempts to quantify the impacts of different variables on severity levels of pedestrians' injuries sustained in HRGC crashes. The next section presents conceptualization of variables that may potentially impact injury severity levels of pedestrians and a description of the dataset compilation used for analysis presented herein.

CONCEPTUALIZATION AND DATA COMPILATION

A number of variables can potentially affect the severity of pedestrians' injuries. These were grouped in five categories: pedestrian characteristics, crash characteristics, crossing characteristics, train characteristics, and environment (Figure 1). Each category consists of multiple variables and ideally each variable should be analyzed for relevance to pedestrians' injury severity levels. However, available crash data collected using FRA form F6180.57 and crossing inventory data collected via FRA form F6180.71 limit the number of variables that may be investigated.

Figure 1: Conceptualization of Variables Affecting Pedestrians' Injury Severity



This research utilized the 2007-2010 HRGC crash data and the national highway-rail crossing inventory data. Both datasets were obtained from the FRA Office of Safety Analysis website: <http://safetydata.fra.dot.gov/officeofsafety/ default.aspx> (accessed June 18, 2012). Readers interested in details of data collection and measurement of different variables are referred to the FRA Guide for Preparing Accident/Incident Reports (FRA 2003) and the U.S. DOT Crossing Inventory Form Data File Structure and Field Input Specifications (FRA undated) or the more recent Guide for Preparing U.S. DOT Crossing Inventory Forms (FRA 2015) in lieu of the undated FRA document.

Crash data for 2007-2010 were combined (487 crashes) and then reduced to records pertaining to pedestrian crashes reported at public HRGCs (the crash database identifies pedestrians as a distinct type of highway user). However, these data included 47 crashes that were suicides or attempted suicides. These records were excluded from the data leaving 440 crashes involving pedestrians only. They were excluded because these crashes are the result of deliberate efforts on the part of the suicidal person and the underlying reasons are different than other (non-suicidal) crashes. Crash records contain limited grade crossing related information; more details are available in the national highway-rail crossing inventory data. Therefore, crash and highway-rail crossing inventory data files were merged together using the unique USDOT crossing identification number (available in both data files). The merging procedure produced 400 records of HRGC pedestrian crashes along with relevant HRGC details that were subsequently analyzed. Three pedestrian crash severity levels were obtained based on the intensity of their injuries: no injury (coded as 0 in the data), injury (coded as 1), and fatality (coded as 2). This variable was named "Severity" and it was the dependent variable in the analysis.

DATA ANALYSIS

Table 1 presents salient features of the final dataset as presentation of information on all variables in the dataset was not feasible. It contained many more fatal crashes than injury or no injury crashes, reflecting the ominous nature of HRGC crashes. About 76% of the crashes involved train speeds in excess of 26 miles per hour (mph) at the time of the incident. This speed is either estimated or obtained from the train recorder after an incident. About 95% of the crashes involved rail equipment (e.g., locomotives) striking pedestrians rather than the pedestrian striking rail equipment (e.g. a pedestrian running into or somehow pushed into a moving train).

Traversing highways consisted of two lanes at 64% of the rail crossings where crashes were reported; 65% of the involved pedestrians were male. Standard flashing light signals were installed at 72% of the crossings while the crossbuck sign (consisting of two wooden or metal slats in the shape of an X with Railroad Crossing printed) was present at 52% of the crossings. The incident crossings were located in different types of developments with 55% reported in commercial type areas. Concrete and asphalt were common types of crossing surfaces; relatively few crashes were reported occurring during cold (less than 32^{o}F) or hot (greater than 80^{o}F) temperatures, perhaps due to the presence of relatively few pedestrians during such temperatures. Analysis of this dataset was based on the ordered probit model, which is explained below. Readers familiar with this model may go to the subsection titled Modeling Results.

Table 1: Characteristics of HRGC Pedestrian Crash Data (n=400)

Variable	Description/categories	Frequency	Percent
Severity	Crash severity level		
	No injury	16	4.0
	Injury	142	35.5
	Fatality	242	60.5
Trnspd	Train speed at time of incident, mph		
	< 25 mph	96	24.0
	26-45 mph	155	38.8
	>45 mph	148	37.0
	Missing	1	0.3
Typacc	Crash circumstance		
	Rail equipment struck pedestrian	378	94.5
	Pedestrian struck rail equipment	22	5.5
Traficln	Number of traffic lanes at crossing		
	1 lane	5	1.3
	2 lanes	256	64.0
	3 lanes	21	5.3
	4 lanes	87	21.8
	> 4 lanes	31	7.6
Pedgen	Pedestrian gender		
	Female	73	18.3
	Male	258	64.5
	Unknown/Missing	69	17.3

Table 1 (continued)

Variable	Description/categories	Frequency	Percent
Gates	Crossing gates		
	Present	366	91.5
	Not present	34	8.5
Stdfls	Standard flashing light signals		
	Present	286	71.5
	Not present	114	28.5
Hwy_Sig	Highway signals		
	Present	23	5.8
	Not present	377	94.3
Xbux	Crossbuck sign		
	Present	192	48.0
	Not present	208	52.0
Develtyp	Type of area development		
	Open space	30	7.5
	Residential	90	22.5
	Commercial	220	55.0
	Industrial	48	12.0
	Institutional	12	3.0
Xsurface	Crossing surface type		
	Timber	72	18.0
	Asphalt	63	15.8
	Asphalt and flange	51	12.8
	Concrete	140	35.0
	Concrete and rubber	12	3.0
	Rubber	59	14.8
	Unconsolidated	3	0.8
Weather	Weather conditions		
	Clear	299	74.8
	Cloudy	78	19.5
	Rain	13	3.3
	Fog	5	1.3
	Snow	5	1.3
Temp	Temperature at time of incident (F)		
	0-32	36	9.0
	33-60	126	31.5
	61-80	178	44.5
	81-105	60	15.0

MODEL BACKGROUND

The dependent variable was injury severity level, which was ordinal in nature. Usual models to use for ordinal data are ordered probit/ordered logit and multinomial logit models. The analysis presented herein utilized the ordered probit model (the results from the ordered logit model are fairly similar). According to Long (1997), the ordered probit model can be derived from a measurement model in which a latent, unobservable, continuous variable y^* ranging from $-\infty$ to $+\infty$ is mapped to an observed ordinal variable, e.g., injury severity with three levels, denoted by y. Variable y* provides severity propensity and variable y is thought of as providing incomplete information about the underlying y* according to the measurement equation:

$$(1) \qquad y_i = m \text{ if } \tau_{m-1} \leq y_i^* < \tau_m$$

Where the τ's are threshold points between the intervals. The extreme categories, 1 and J, are defined by open-ended intervals with $\tau_o = -\infty$ and $\tau_J = \infty$. The observed y is related to y* according to the measurement model:

$$(2) \quad y_i = \begin{cases} 1 \Rightarrow \textit{No injury if} \quad \tau_o = -\infty \leq y_i^* < \tau_1 \\ 2 \Rightarrow \textit{Injury if} \quad \tau_1 \leq y_i^* < \tau_2 \\ 3 \Rightarrow \textit{Fatality if} \quad \tau_2 \leq y_i^* < \tau_3 = \infty \end{cases}$$

The ordered probit model has the structural form:

$$(3) \qquad y_i^* = \mathbf{x}_i \boldsymbol{\beta} + \varepsilon_i$$

Where:

$\mathbf{x}_i$ is a row vector (with 1 in the first column for the intercept),
β is a column vector of structural coefficients (with the first element being the intercept β_o), and
ε is an error term.

Maximum likelihood (ML) estimation is used to estimate the regression of y* on **x**. Its use requires assuming a distribution of the error term, ε. For the ordered probit model, ε is assumed distributed normal with mean 0 and variance 1. After specification of the error term, the probabilities of observing values of y given **x** can be computed. The probability of any observed outcome y = m given **x** is:

$$(4) \qquad \Pr(y_i = m \mid \mathbf{x}_i) = \Phi\left(\tau_m - \mathbf{x}_i \beta\right) - \Phi(\tau_{m-1} - \mathbf{x}_i \beta)$$

The marginal effects of variables **x** on the underlying crash severity propensity can be evaluated by taking the partial derivative of Equation 4 with respect to $\mathbf{x}_i$. The marginal effect is the slope of the curve relating $\mathbf{x}_i$ to $\Pr(y = m|\mathbf{x})$, holding all other variables constant and is usually computed at the mean values of all variables. For a dummy independent variable, the derivative while treating it as a continuous variable provides an approximation. The marginal effects are useful to obtain a sense of the direction of effects of independent variables on the interior categories of an ordered dependent variable (for detail see Washington et al. 2011). A measure of the model goodness of fit (ρ^2) can be calculated as:

$$(5) \quad \rho^2 = 1 - \left[\frac{\ln L_b}{\ln L_o}\right]$$

Where ln L_b is the log likelihood at convergence and L_0 is the restricted log likelihood. The ρ^2 measure is bound by zero and one. Values of ρ^2 closer to one indicate a better fit of the model. The estimated coefficients can be tested for statistical significance using the student's t-test. An absolute t-value of 1.64/1.96 shows statistical significance at the 90/95% confidence level). Alternatively, readers may utilize p-values for judging statistical significance.

MODELING RESULTS

During model estimation (using NLogit software Version 5, Econometric Software, Inc.) an attempt was made to include as many independent variables as possible in the model specification from among the available variables. Statistical significance of the independent variables was used to retain or exclude them from the model specification. Table 2 presents an ordered probit model with pedestrians' injury severity as the dependent variable and a set of nine independent variables. Positive estimated coefficients in the model imply increasing likelihood of fatalities and decreasing likelihood of no injuries, while marginal values provide information on how injury severity probabilities change with a unit change in the value of an independent variable beyond its mean, while all other variables are held at their mean values.

Train speed (Trnspd) at the time of incident from the train characteristics category (Figure 1) was included in the model specification with the expectation that higher train speeds will contribute to more severe injuries. The estimated coefficient for this variable was positive and statistically significant (95% confidence level), implying that higher speeds of trains increased the probability of pedestrian fatalities. The finding is plausible and as expected.

Table 2: Estimated Ordered Probit Model for Pedestrians' Crash Injury Severity Levels

Variable	Brief Description	Estimated Coefficient	t-statistic	p-value	Variable Mean	Marginal Values		
						No Injury	Injury	Fatality
Trnspd	Train speed in mph	0.025	6.969	0.000	40.774	-0.001	-0.008	0.009
Typacc	Indicator for rail equipment struck pedestrian	0.678	2.588	0.010	0.945	-0.058	-0.207	0.265
Female	Indicator for female pedestrians	0.584	3.119	0.002	0.183	-0.019	-0.184	0.203
Commr	Indicator for commercial type areas	0.333	2.434	0.015	0.549	-0.016	-0.110	0.126
Temp	Temperature in degree Fahrenheit	0.007	2.005	0.045	62.987	-0.0003	-0.0024	0.0027
Clear	Indicator for clear weather	-0.324	-2.045	0.041	0.747	0.013	0.106	-0.119
Traficln	Number of traffic lanes at crossing	-0.118	-2.212	0.027	2.759	0.006	0.039	-0.045
Stdfls	Standard flashing light signals at crossings	-0.275	-1.881	0.060	0.714	0.011	0.091	-0.102
Timber	Indicator for crossing surface of timber	0.262	1.488	0.137	0.178	-0.010	-0.086	0.096
Constant	Model constant	0.409	1.040	0.299	-	-	-	-
τ_1		1.758	12.807	0.000	-	-	-	-
	Model Summary Statistics		Note: Dependent variable: Severity (No injury, injury, and fatality)					
	Number of observations	399						
	ρ^2	0.145						
	$\chi 2$	92.510						
	p-value for $\chi 2$	0.000						

The marginal value for train speed showed that each 1-mph speed increase in train speed beyond its mean value of 40.774 mph increased the probability of a fatal crash by 0.009 (i.e., 0.9%), while the probabilities of no injury and injury categories decreased by 0.001 (0.1%) and .008 (0.8%), respectively. The marginal effects for any variable sum to zero, which follows from the requirement that the probabilities add to 1.

Crash circumstance (Typacc) from the crash characteristics category (Figure 1) was included in the model specification with the expectation that crashes involving pedestrians struck by rail equipment would be more severe. The statistically significant estimated coefficient indicated that fatal crashes were more likely when rail equipment struck pedestrians (as expected) rather than when pedestrians struck rail equipment. The marginal values show that the likelihood of fatality increased by 26.5% when pedestrians were struck by rail equipment compared with crashes in which pedestrians struck rail equipment. From the pedestrian characteristics category, pedestrians' gender was included in the model. Before model estimation, the expectation was that female pedestrians may be more severely injured; this expectation was based on research showing higher fatality risk for females compared with males of the same age in vehicular crashes (NHTSA 2013). The result showed that females were more likely to die in pedestrian crashes at HRGCs compared with others (males + unknown/missing values).

Three independent variables from the environment category were included in the model: commercial area type (Commr, which was part of Develtyp variable in Table 1), temperature at the time of crash (Temp), and clear weather conditions (Clear). Results showed that fatalities were more likely at HRGCs located in commercial type areas; this finding is plausible as pedestrians in commercial areas may be distracted by signs and billboards and may fail to take crash evasive maneuvers, resulting in more severe injuries. Higher temperatures at the time of crash were associated with pedestrian fatalities although the reason for this is not readily apparent.

Table 2 shows the marginal values for temperature to four decimal points because of the small values. The estimated coefficient for clear weather (compared with adverse weather) was negative, showing that fatalities were less likely (by 11.9%) than no injuries/injuries in clear weather compared with crashes in adverse weather.

Several variables from the crossing characteristics category were tried as independent variables in the model specification. Results showed negative estimated coefficients for a greater number of traffic lanes at crossings (Traficln) and presence of standard flashing light signals at crossings (Stdfls, statistically significant at 90% confidence level). The results implied reduced probability of pedestrian fatalities at HRGCs with a greater number of traffic lanes, perhaps due to the greater area for evasive maneuvers by pedestrians coupled with standard flashing light signals.

Different types of crossing surfaces were tried in the model because of the possibility that crossing surfaces may affect pedestrians' ability to cross safely. Only timber type surface (Timber) showed limited positive association with fatal crashes but it was not statistically significant. Many other independent variables (e.g., highway average annual daily traffic, total daily train traffic, presence of illumination at the crossing, etc.) were tried but none showed strong statistical evidence of association with pedestrians' injury severity levels.

CONCLUSION AND DISCUSSION

This research achieved its objective of quantifying impacts of various variables on three different severity levels of pedestrians' injuries sustained in HRGC crashes using a dataset that combined both crash and HRGC inventory data. Variables possibly affecting severity levels of pedestrians' injuries were first conceptualized and then identified using the assembled dataset and the ordered probit model. The conclusion is that diverse variables pertaining to characteristics of pedestrians, trains, crossings, environments, and crashes exist that are associated with higher or lower levels of pedestrians' injury severity. Amongst these, higher train speeds were associated with a higher likelihood of pedestrian fatalities. While slowing down train speeds at HRGCs (especially those with significant pedestrian traffic) may not enable trains to readily stop but it may afford pedestrians that extra moment or two to get out of harm's way. The probability of a female pedestrian fatality at HRGCs was higher; this information can be used in safety campaigns targeted toward female HRGC users.

HRGCs located in areas designated as commercial were found to be associated with pedestrian fatalities. New research is uncovering relationships between urban forms and traffic safety (e.g., Dumbaugha and Raeb 2009), and this finding lends support to a relationship between pedestrians' injury levels sustained in HRGC crashes and type of area. Clear weather was found to be associated with a lower likelihood of pedestrian fatality compared with adverse weather conditions. Education programs aimed at improving pedestrian safety at HRGCs should emphasize extra caution when using HRGCs in adverse weather conditions. Presence of standard flashing light signals was associated with lower probability of pedestrian fatality; and where not installed, transportation agencies may consider installing such signals.

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Hard Red Spring Wheat Marketing: Effects of Increased Shuttle Train Movements on Railroad Pricing in the Northern Plains

by Elvis Ndembe

Despite the widespread adoption of shuttle train grain elevators and their potential for reducing rates for grain transport, few studies have evaluated their impact on railroad pricing. The aim of this paper is to assess railroad pricing behavior as well as empirically examine the impact of shuttle train movement on hard red spring wheat transport from North Dakota over time. Ordinary least squares estimation of the pricing model has rate per ton-mile as a dependent variable and supply and demand determinants as regressors. Intermodal competition and shuttle trains were found to have played a significant role in rate reduction over time.

INTRODUCTION

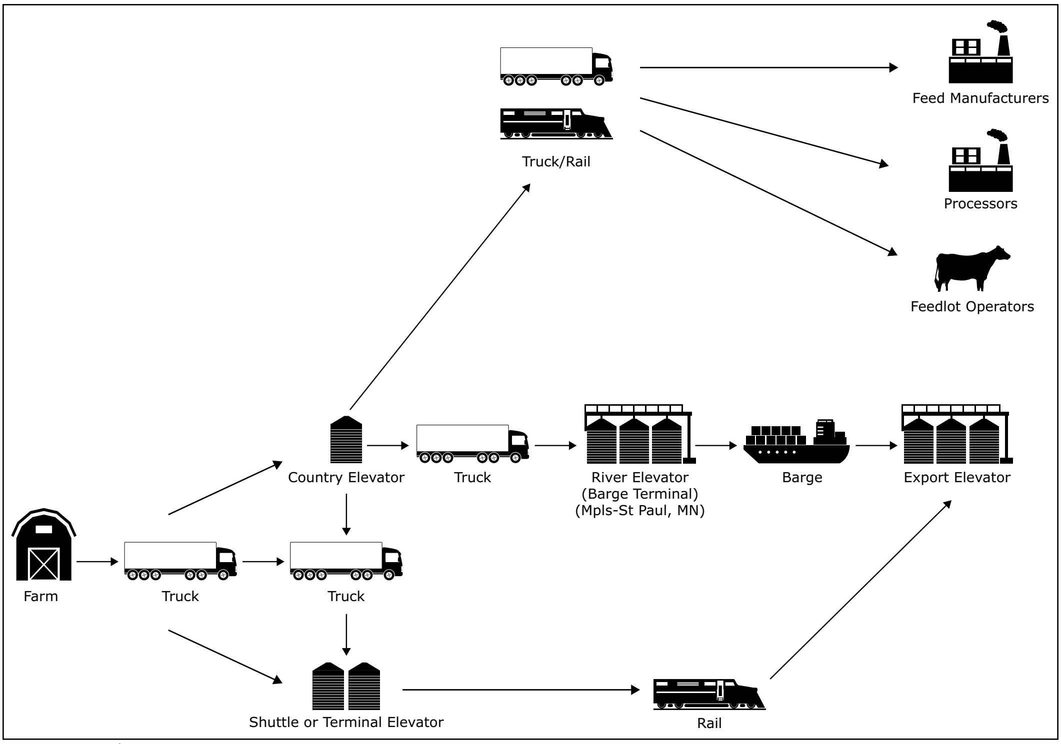
The widespread implementation and use of shuttle train grain elevators is affecting hard red spring wheat marketing in U.S. Northern Plains states like North Dakota where shippers are highly rail dependent. Shuttle trains are considered more efficient because of limited railcar switching requirements (movements often involve cycling between a single origin and destination). As such, they can potentially reduce rail carriers' cost with likely benefits transferred to shippers in the form of lower rates. U.S. Senate Committee on Commerce, Science, and Transportation, (2002) showed that the variable costs associated with shuttle movements were 47% and 15% lower than those for single-car (1 to 6 railcars) and unit-train (52 railcars) shipments, respectively.

Shuttle train rates were introduced by Burlington Northern (BN) (Burlington Northern Santa Fe [BNSF] since 1996) in the Northern Plains in the 1990s (NDDOT 2007). Prior to this innovation, unit-train services were considered the most efficient. An illustration of how grain is marketed in the United States is useful to understanding how railroad pricing affects hard red spring wheat producers in North Dakota.

Grain producers usually sell their commodities to local county elevators or grain sub-terminals that subsequently sell to terminals and export elevators. At the local or sub-terminal elevator, the producer is quoted the price at an export port (e.g., Portland Grain Exchange) less other costs, including transportation, loading, storage, and margin (Miljkovic 2001). Given that grain producers are responsible for transportation cost, in the short run, changes in rail rates could affect North Dakota hard red spring wheat producers in two distinct ways. Increases in transportation rates decrease producer profits, whereas potential reduction in rates stemming from efficient transportation increases profits. Such effects are likely to disproportionately impact agricultural shippers in North Dakota given that the state accounts for a large proportion of U.S. hard red spring wheat production and shippers in the state rely heavily on rail for grain shipments.

Some hard red spring wheat is shipped out of state by truck as well. Based on data from the North Dakota grain movement database, between 1999 and 2012, rail was responsible for 93.3% (62,296,905 tons) of all hard red spring wheat movements out of North Dakota while truck movements represented 6.7% (4,465,737.09 tons). This high reliance on rail suggests rail rates are likely one of the main determinants of prices received by producers. The market channel for North Dakota hard red spring wheat is shown in Figure 1.

Figure 1: North Dakota Hard Red Spring Wheat Marketing Channel



Source: Author

This study presents a railroad pricing model for hard red spring wheat shipments from North Dakota to all major domestic and export destinations. The pricing analysis is undertaken to determine if shuttle trains have had a significant impact on rail rates for the shipment of hard red spring wheat out of North Dakota, as well as to assess the comparative rate advantage associated with using shuttle trains relative to three other rail movement types: unit, multi-car, and single-car. The pricing model is similar to the dominant firm price leadership approach used by Koo et al. (1993) in their evaluation of railroad pricing in North Dakota. They argue that such a condition is likely because two railroads are responsible for all grain transportation out of state. The econometric procedure here is complemented with the inclusion of regional and service variables to capture likely differences in rail rates among regions and service types.

Several studies have dealt with the impact of shuttle trains on railroad pricing (Vachal and Button 2003) and grain movement (e.g., Vachal et al. 1999 and Sarmiento and Wilson 2005). Others have focused on their impact on truck movements and highway pavement damage (Babcock and Bunch 2003, Tolliver et al. 2006, and Bai et al. 2010). Vachal et al. (1999) assessed the potential of marketing hard red spring wheat in 100-plus car trains in North Dakota while Vachal and Button (2003) provided a market-based synopsis of the likely impact of shuttle rates on grain flow in North Dakota using different scenarios. Their overall conclusion was that shuttle elevators can play a role in grain procurement in the state by handling most of the grain produced. This paper differs from previous related studies because it explicitly assesses the impact of shuttle trains on railroad pricing. Apart from filling the lack of research in this area, an evaluation of this nature is important, given the value-added role railroads play in the grain supply chain by moving commodities for long distances from rural areas to consumption centers. This research also provides potential insight for public policy.

BACKGROUND

The Staggers Act of 1980 partially deregulated the railroad industry and gave it more control to price its services. Following deregulation, U.S. Class I railroads adopted various cost reduction strategies to enhance their efficiency and increase profitability (Babcock and Bunch 2003). Gallamore (1999) observed that the pricing flexibility provided by deregulation has led to several innovations that have benefitted shippers. In agricultural transportation, railroads have increased emphasis on elevators with large capacities that can load and unload longer trains. An initial innovation related to longer train operations was the introduction of unit train rates (52 railcar shipments) shortly following deregulation. Prior to unit trains, multiple-car rates (6 to 49 railcars) and single-car rates (1 to 5 railcars) were the norms of the industry (Wilson et al. 1988). Following the adoption of unit trains, BN introduced shuttle rates (110 or more railcars) in the 1990s.

Shippers wishing to benefit from economies of shipment size through lower rates offered by shuttle services had to invest in track sidings, inventory, and storage capacity and, in some cases, construct new facilities able to accommodate and load longer trains. Incentives provided by this form of shipment led to increased adoption and use of shuttle elevators and shuttle trains to transport grains. USDA (2013) observed that shuttle train shipments of grain and oilseeds in tons increased by close to 37% between 1994 and 2011. In 2010, shuttle trains were responsible for approximately 51% of all U.S grain and oilseed movements. While shuttle trains have witnessed a surge in use, all other service types have declined during the same time period. The effect of shuttle trains in North Dakota is reflected in the total tonnage of hard red spring wheat movements out of state. Shuttle train tonnage (representing 100 railcars and above) of all wheat movements increased from 9% in 1999 to 66% in 2012 based on waybill sample data from the Surface Transportation Board (STB).

The primary operational difference between shuttle and unit trains is side track capacity in terms of the number of railcars that can be loaded or assembled for loading. Side track capacity is measured in equivalent number of cars (NDDOT 2007). An elevator requires 6,600 feet of track space to hold 110 railcars (shuttle train) with the total track requirement exceeding 7,000 feet to accommodate dedicated locomotive power and spotting clearance (NDDOT 2007). Unit trains (typically 52 railcars) on the other hand, require half that amount of space. Additionally, The U.S. Senate Committee on Commerce, Science, and Transportation (2002) notes that unit trains typically have to be matched with one of a similar size or with several smaller multi-car blocks before a large grain train can be put together. Shuttle trains do not require putting a train together. Dedicated power, locomotives, and railcars involved in shuttle movements remain in a single block as they move from origin to destination, thus enhancing rail car utilization. Shuttles trains are a more dedicated service than unit train services.

The two Class I railroads responsible for all out-of-state grain movements in North Dakota have requirements that shippers must meet to participate in their shuttle programs. BNSF defines a shuttle train as one made up of 110 covered hopper cars, each with a capacity of 111 tons, and a shuttle elevator as one that has enough track capacity to accept 110 cars and load and unload them in 15 hours up to three times per month without clogging the main line (NDDOT 2007). On the other hand, SOO Line, the U.S subsidiary of Canadian Pacific Railroad (CP), refers to shuttle trains as "efficiency trains" and defines them as trains with 100 cars and efficiency elevators as those that can load 100 cars within a 24-hour period without disruption to the main line. They added that a 110-car train made up of 111-ton covered hopper cars will carry 400,000 bushels of wheat. The required volume and the time for loading and unloading make production and storage capacity an important aspect of the shuttle program (NDDOT 2007).

North Dakota led U.S. hard red spring wheat production within the analysis period based on data from the United States Department of Agriculture, National Agricultural Statistics Service (USDA NASS). As a percentage of U.S. production, North Dakota's production ranged from 33% in 1999 to 50% in 2009. In fact, on average between 1999 and 2012, North Dakota accounted for close to 44% of all U.S. hard red spring wheat production similarly based on USDA, NASS data. This high volume production corresponds to the state's role both in U.S. consumption and export demand as well as potential effects of railroad pricing on grain producers. Hard red spring wheat has the highest protein content of all other wheat types produced in the United States, and is preferred for making bread (North Dakota Wheat Commission 2015). Bread is an important dietary component around the world.

Shipper pricing complaints are prevalent in the railroad industry. In fact, railroad pricing complaints from captive shippers was one of the rationales behind the 1887 Interstate Commerce Act that established the Interstate Commerce Commission (ICC) and gave it the authority to regulate railroads. The ICC was replaced by the Surface Transportation Board (STB) in 1996. North Dakota is used extensively as a captive market in theory (Koo et al. 1993). Policymakers are often interested in equity issues and the wellbeing of shippers. Potential effects from shuttle train implementation can help inform policy makers about likely changes in railroad pricing and intermodal and intramodal competition in North Dakota over time.

The rest of this paper will proceed in the following manner. The next section will provide the theory of intermodal competition and model specification similar to that used by Koo et al. (1993). Data description, empirical results for the railroad pricing model, and study implications are highlighted in the final section.

THEORY OF INTERMODAL COMPETITION

Three principal modes are used to transport agricultural and other commodities in the United States to export and domestic destinations: rail, truck, and truck-barge. Shippers' mode choice decisions are often based on the availability of a mode and its cost relative to that of others. Transportation cost, in turn, is a function of distance between an origin and destination.

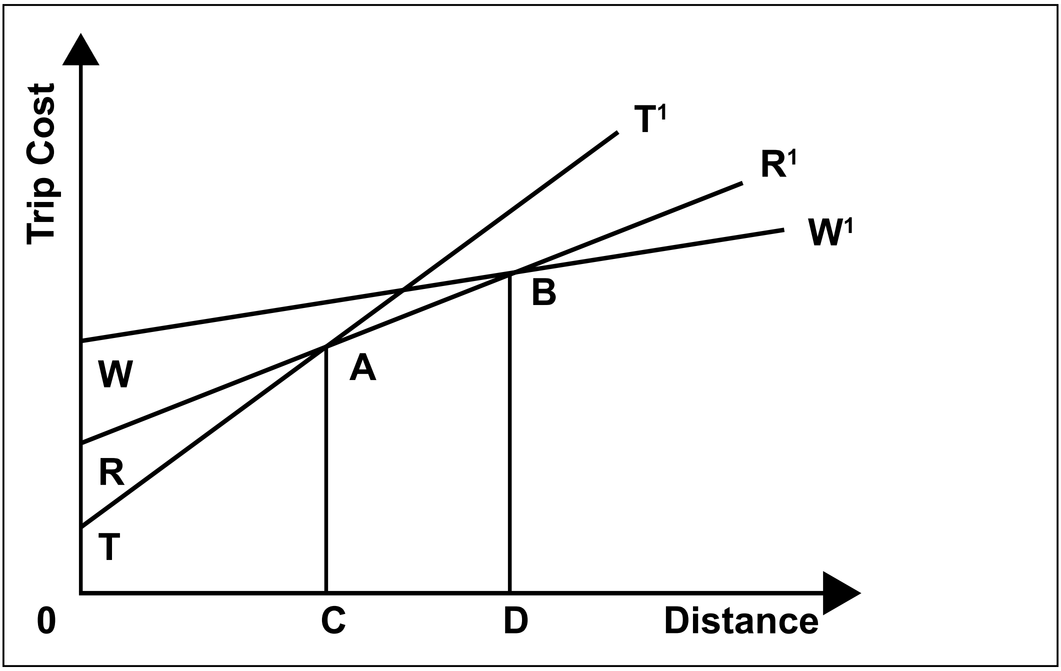
Koo et al. (1993) and the Congressional Research Service (CRS 2005) provide a hypothetical cost curve for the three main modes shown in Figure 3 to illustrate competition between different modes according to distance between an origin *i* and destination *j*. Their illustration shows that, generally, trucking has a relative advantage for shorter-distance traffic while rail and barge dominate longer-distance hauls [(Koo et al. (1993), Congressional Research Service (2005)].

Potential trucking dominance of the short haul stems from the fact that it has relatively small fixed and terminal costs that offset comparatively higher linehaul cost over short distances. Linehaul cost refers to those costs that vary with operations (e.g. fuel, labor, tire wear). The hypothetical cost curve of trucking is shown as *TT'*. The cost curve for barge traffic, depicted as *WW'*, suggests that water transportation has the lowest distance-related unit cost as well as higher terminal or fixed cost compared with other modes. Consequently, barge transportation has considerable advantages for long-distance trips relative to short-distances trips.

Barge operations are confined to U.S. waterways, including the Mississippi, Illinois, Ohio, Columbia, and Snake rivers. This benefits shippers in close proximity to these waterways. Given the lack of waterways in North Dakota, the only other mode comparable to barge serving shippers in the state is railroad transportation. The cost curve for railroad traffic lies between that for truck and barge transportation. Koo and Uhm (1984) noted that the shape of the railroad cost curve is a reflection of the "rate taper" concept, which they described as rates that increase at a decreasing rate with distance attributable to economies of long haul. They noted that railroad firms realize economies of haul as distance increases specifically because fixed terminal cost can be spread over greater mileage.

Attention was also placed on the fact that several other factors affect rail rates, including volume, commodity characteristics, and weather conditions. However, if rail rates were determined entirely by cost, then the transportation market will be segregated between the three modes according to shipment distances. In that case, trucking will have natural dominance for traffic in the figure's OC

Figure 2: Hypothetical Trip Cost Curve



Source: Koo et al. (1993) and Congressional Research Service (2005)

market; rail in the CD market and barge for distances beyond OD. Koo et al. (1993) concluded that competitive factors, from intermodal and intramodal competition where they exist, play an essential role in shaping rail rates by constraining railroads' pricing behavior. This stems from the fact that railroads have an incentive to compete with other modes by using pricing to penetrate markets with traffic weakly dominated by other modes. For example, MacDonald (1989) observed that multi-car rates enabled railroads to regain medium-distance traffic from trucks on grain shipments from Minnesota and the Dakotas to Duluth, MN/Superior, WI. Deregulation also increased the importance of intermodal and intramodal competition. Burton (1983) observed that railroads have become more responsive to intermodal and intramodal competition since passage of the Staggers Act. This study extends the railroad pricing model undertaken by Koo el al. (1993). Contrary to their study, which uses cross-section data in their annual estimation, this study utilizes a time series technique to evaluate potential changes over time between 1999 and 2012. Additionally, the influence of volume on rates is explicitly analyzed by comparing shuttle train rates to those of other services. Finally, the railroad designated Bureau of Economic Analysis regions (BEA) are included to take into account potential regional differences in rates.

MODEL AND EMPIRICAL SPECIFICATION

Prices for transportation of agricultural products are determined by demand and supply conditions similar to those obtainable in a competitive market system (Koo et al. 1993). They defined the demand for the transportation services of a railroad (Q_d) as a function of the price a rail carrier charges for its services ($R_2,R_3\ldots$), prices other rail carriers charge for their services, prices charged by other transportation modes ($T_1,T_2,\ldots$), and other factors influencing demand for transportation services (θ) as follows:

(1) $Q_d = f(R_1,R_2,R_3\ldots T_1,T_2,\theta)$

The supply of a rail carrier's freight transportation services is defined as a function of prices of all rail carriers' and other modes' freight transportation services ($R_1, R_2, R_3 \ldots T_1, T_2$) and related cost influences like distance (D) and shipment volume (V), and other related factors affecting the cost of transportation (Z) as:

(2) $Q_s = f(R_1, \ldots T_1, T_2, D, V, Z)$

By combining equation (1) and (2) assuming the existence of equilibrium, ($Q_d = Q_s$), price charged by railroad 1 for transportation services can be given as:

(3) $R_1 = f(R_2, R_3 \ldots T_1, T_2, D, V, Z, \theta)$

Considering other rail carriers' prices (R_2, R_3) as intramodal competition (R_{com}) and prices of other modes (T_1, T_2) as intermodal competition (INT_{com}) equation 4 can be rewritten as:

(4) $R_1 = f(R_{COM}, INT_{COM}, D, V, Z, \theta)$

Koo et al. (1993), and other related research studies including Bitzan et al. 2003 and Macdonald (1989), used market concentration in the form of the Herfindahl-Hirschman index to measure intramodal competition (rail-to-rail). However, in the context of North Dakota, Babcock et al. (2014) noted that intramodal competition is very limited in the state. Regional and local railroads often act as subsidiaries for both Class I railroads, hence do not compete directly with them (Babcock el al. 2014). For example, Dakota Missouri Valley and Western (DMVW), a local subsidiary of Canadian Pacific (CP), serves areas in the state that BNSF does as well, but not CP (Babcock et al. 2014). As such DMVW competes with BNSF for this traffic. Additionally, the Red River Valley and Western (RRVW), a subsidiary for BNSF in North Dakota, operates in areas of the state where CP has a strong presence (Babcock et al. 2014). In that case, RRVW competes with CP for traffic. In this way, regional and local affiliates compete on behalf of both Class I railroads (Babcock el al. 2014). This fact makes it difficult to assess rail-to-rail competition (R_{COM}). Since this paper is concerned with out-of-state movements undertaken by Class I railroads, intramodal competition was dropped. Equation 4 can be rewritten as:

(5) $R_1 = f(INT_{COM}, D, V, Z, \theta)$

Equation (5) serves as the basis for the empirical model used in this paper. Multivariate regression in the form of ordinary least squares (OLS) is used to evaluate the comparative rate effect associated with using shuttle trains relative to other rail services, including unit, multi-car, and single-car. To do this, other factors influencing rail demand (including number of cars available), intermodal competition, distance of shipment, weight per car, and seasonal variables, are used as independent variables while revenue per ton-mile is used as the single dependent variable. Seasonal quarter dummy variables will allow a potential test for seasonality of rates while the time trend will indicate if rates are changing over time with shuttle use. Regional dummy variables are included to measure relative rail rates among the four main Bureau of Economic Analysis (BEA) regions in North Dakota used by railroads for assigning rates. These include BEA110 (Grand Fork), BEA111 (Minot), BEA112 (Bismarck), and BEA113 (Fargo-Moorhead). The dependent variable and all other continuous variables are transformed into natural logarithm, which allows for the coefficients to be interpreted as elasticities. The general mathematical representation of the model is:

(6) $LnRRPTM = \beta_0 + \beta_1\ InSHRT + \beta_2\ InBDIST + \beta_3\ LnCARS + \beta_4\ LnLOAD + \beta_5\ Time + \beta_6\ TIMESQ + \beta_7 Q_1 + \beta_8 Q_2 + \beta_9 Q_3 + \beta_{10}\ SHUTTLE + \beta_{11}\ OBEA110 + \beta_{12}\ OBEA111 + \beta_{13}\ OBE113 + \varepsilon$

Where,

RRPTM	=	Real revenue per ton-mile (in 2010 prices)
SHRT	=	Length of haul in short-line miles
BDIST	=	Closest highway distance from barge loading facility weighted by total tons from BEA (Calculated from North Dakota Grain Movement Database)
CARS	=	Number of railcars in shipment
LOAD	=	Load factor representing weight per railcar
Time	=	Time trend, year of shipment
TIMESQ	=	Squared time trend
Q_1	=	Dummy variable representing first quarter
Q_2	=	Dummy variable representing second quarter
Q_3	=	Dummy variable representing third quarter
SHUTTLE	=	Dummy variable shuttle train shipment, include 100 cars or more
*OBEA*110	=	Dummy variable representing origin-BEA (110)
*OBEA*111	=	Dummy representing origin-BEA (111)
*OBE*113	=	Dummy variable representing origin-BEA (113)
ε	=	Normal effect error term

Expected signs = $\beta_1, \beta_3, \beta_4, \beta_5, \beta_{10}, < 0.$
$\beta_2, > 0.$
$\beta_6, \beta_7, \beta_8, \beta_9, \beta_{11}, \beta_{12}, \beta_{13} <> 0.$

From the specified model in equation (6), the natural log of length of haul in short-line miles is expected to have a negative effect on the natural log of real revenue per ton-mile. The literature on the influence of distance on transportation cost suggests that as distances increases, the rate per ton-mile of freight decreases. This is particularly the case with railroads because a significant part of rail shipment cost is constant regardless of the distance. MacDonald (1989) noted that cost components such as switching, classification, and loading of cars are not impacted by the distance of shipment. He added that some cost associated with movement between origins and destinations such as train speed does not increase at the same rate with mileage, consequently the rate per ton-mile decreases with distance.

Railroads previously used 100-ton covered hopper cars. However, because of innovations related to track composition, the weight limit and load per car has increased substantially. In the 1970s, a significant portion of rail branch lines were limited to gross car weights of 220,000 pounds, which permitted net loads of 70 to 80 tons (NDDOT 2007). Presently, Class I railroad main line tracks are able to support 286,000-pound cars, enabling freight loads of between 110 and 115 tons. Some railroads operate 315,000-pound cars with corresponding net loads of 125 tons in particular corridors. The increasing use of larger-capacity rail cars has led to increasing railroad revenue per car without a corresponding direct increase in cost to shippers (increase per car payload). These facts mean the natural log of rate per ton-miles should decrease at a decreasing rate with the increasing number of rail cars and load factor. The load factor measures the average weight per car. Because the shuttle dummy variable is a reflection of larger number of cars in a shipment, it is expected to have a sign similar to that for number of cars in shipment. Inclusion of the shuttle dummy will enable an assessment of its relative rate advantage over the other three principal rail services, including unit, multi-car, and single-car rail. The Soo Line shuttle train definition (100 cars and more) is used here to properly reflect the two railroads responsible for grain movements out of North Dakota. Using the BNSF definition of 110 or more cars will exclude likely Soo Line movements.

The U.S. Class I railroad industry moved from a cost-based structure in the regulatory era to market-oriented differential pricing in the deregulatory environment, which makes intermodal competition an important factor (Bitzan et al. 2003). Despite their observations that shippers in regions with less intermodal service might have benefited least from deregulation, MacDonald (1989) noted that deregulation might have more impact in such areas. As observed previously, the number of shuttle shipments of wheat from North Dakota increased substantially between 1999 and 2012. Shuttle trains are associated with lower cost; therefore, their increasing use potentially means shippers are paying lower rates over time compared with other services. The time trend is consequently expected to have an inverse relationship with the log of revenue ton-miles.

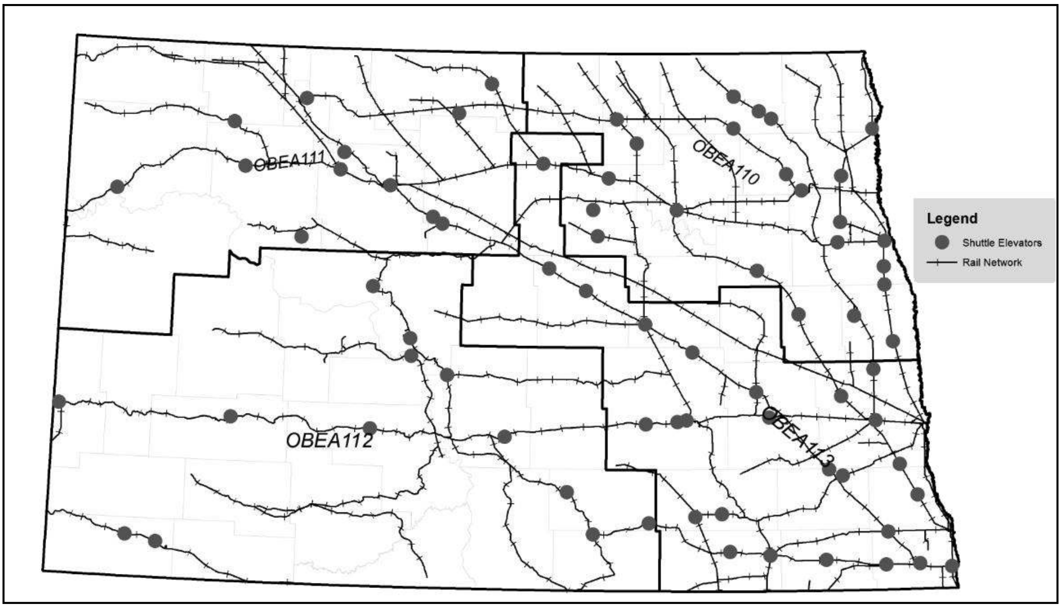
Intermodal competition is measured by the weighted highway distance to the closest barge-loading facility. The closest barge-loading facilities are located in Minneapolis-St Paul, MN. Intermodal competition can potentially reduce the pricing power of rail carriers (Koo et al. 1993). This is likely the case because barges can compete with rail for long-haul transportation of bulk commodities. Consequently, the viability of intermodal competition reflected in truck-barge combinations declines as the distance from barge terminal increases. As such, rates are expected to be positively related to BDIST.

To account for possible changes in rates between seasons, three seasonal dummy variables are included, with the fourth quarter of the year serving as the base period. Quarterly rather than monthly dummy variables are used for the analysis to better reflect various seasons (e.g., planting, harvesting, and off seasons). Hard red spring wheat is often planted from April to early June with harvest taking place between August and September. As such, the demand for rail transportation of hard red spring wheat is likely to increase in late September and peak in the fourth quarter (October, November, and December). Fourth quarter rates are expected to be relatively higher than those in the first three quarters of the year.

The rest of the variables are those with indeterminate relationships with the natural log of revenue ton-miles (relationship could be either negative or positive). The squared time trend was included to allow a changing time trend over time. The regional BEAs were included to account for potential spatial variability in rail rates stemming from geographic competition related to location of shuttle elevators and crop production. For example, there is a perceived notion among shippers in western North Dakota that they pay higher rates for shipping hard red spring wheat, particularly to the Pacific Northwest, compared with shippers in the eastern region. The U.S. Senate Committee on Commerce, Science, and Transportation, (2002) noted that one of the issues behind the spread of this belief is the fact that shuttle services (likely lower rates) have not been widely available to shippers in all areas.

Based on data from the North Dakota grain movement database, in 1999, there were 330 licensed grain elevators within the state. This number declined to 199 in 2012. This reduction is a reflection of increasing consolidation witnessed in the rail and grain elevators industries. An average of 53 licensed grain elevators scattered across the state had shuttle capabilities in 2012. The four BEA areas comprising the study area, rail network, and location of shuttle elevators are shown in Figure 3.

Figure 3: Study Area, Rail Network, and Shuttle Elevator Locations



Source: Author

DATA AND DATA DESCRIPTION

Data used to estimate the model in this paper are from the rail public use waybill data and the North Dakota Grain Movement database between 1999 and 2012. The waybill sample contains railroad shipment data from a stratified sample. Railroads are mandated to submit this information to the Surface Transportation Board (STB) for regulatory purposes. Contrary to the master waybill file, which contains detailed information (e.g., contract rates), the public use file is masked to preserve such confidential information. For this reason, some, including Wolfe and Linde (1997), have argued that the waybill might not be an accurate reflection of railroad rates. This point is particularly concerning in the case of this paper because shuttle movements are not under the jurisdiction of the STB (contract rates). Given confidentiality issues, which make it impossible for most researchers to gain access to the master file, most transportation studies are based on the public waybill sample (Fuller et al.1983, Kwon et al. 1994).

The grain movement database contains grain movement information reported by country elevators to the North Dakota Public Service Commission (NDPSC) with the most recent being for 2012. All movements are classified by elevator number, month, year, commodity, mode, and destination of movements. The mode includes truck and four rail services defined as: single-car (1-25 cars), multi-car (26 -50 cars), unit train (50-100 cars), and shuttle (100 or more cars) shipments. Grains destinations include those within the state and six aggregated destinations. These include Duluth, MN, Minneapolis, MN, other Minnesota (other cities in Minnesota), Gulf (e.g., New Orleans, LA; Galveston, TX), Pacific Northwest (e.g., Portland, OR; Seattle-Tacoma, WA) and other (all other U.S. destinations). The closest distance to barge loading facility is constructed using the grain movement database while all other variables are obtained or calculated from the waybill dataset. Descriptive statistics for variables used in the regression analysis are shown in Table 1.

Table 1: Means for Continuous Variables Used in Regression

Year	RRPTM*	SHRT	BDIST	CARS	LOAD
1999	0.05080	779.3	412.3	16	99.9
2000	0.04430	865.5	414.6	24	100.2
2001	0.04591	881.7	419.9	29	100.9
2002	0.04545	843.3	411.7	34	101.3
2003	0.04410	819.6	408.2	35	101.2
2004	0.04797	908.6	402.8	40	101.2
2005	0.08426	916.6	391.3	37	100.3
2006	0.05009	949.1	378.9	39	102.0
2007	0.03593	970.1	374.0	41	103.0
2008	0.03934	1027.6	376.5	38	102.3
2009	0.04581	913.6	367.5	34	103.5
2010	0.04871	929.7	377.1	34	102.7
2011	0.05179	916.3	377.7	33	102.9
2012	0.05258	941.3	366.5	39	103.6

*Revenue ton-miles adjusted by GDP price deflator with 2010 base year
Source: Surface Transportation Board Public Use Waybill Sample.

The BEA unit area of analyses used in the public waybill sample encompasses several counties. The waybill sample splits North Dakota into four BEA regions (BEAs 110, 111, 112, and 113 describing the Grand Forks, Minot, Bismarck, and Fargo-Moorhead regions, respectively). Rather than use the centroid of the four BEAs as the origins to estimate distances to the closest barge loading facility, weighted average distances were calculated using elevators in each BEA as the origin. The zip codes for shipping grain elevator locations were used to estimate the highway distance from hard red spring wheat grain reporting elevators to one of the barge-loading facilities in the Minneapolis-St Paul area using PCMILER®. This distance was multiplied by the total shipments from that elevator for all elevators in the BEA. This is weighted by the total tons moved from that BEA to the barge destination by truck. The weighted average distance is calculated as:

$$(7)\quad BDIST_{bbl} = \frac{\sum_{1}^{e}[(TTons_{emin} * HD_{emin})]}{\sum(TTons_{bmin})}$$

Where,

$BDIST_{bbl}$ = Weighted average highway distance from BEA, *b,* to barge facility, *bl*
$TTons_{emin}$ = Truck movements in tons from elevator, *e,* to MPLS-St Paul
HD_{emin} = Highway distance elevator, *e,* to MPLS-St Paul
$TTons_{bmin}$ = Total truck movements in tons from BEA, *b,* to MPLS-St Paul

EMPIRICAL RESULTS

The model specified in equation 6 is estimated using ordinary least squares with 1999 to 2012 data following the theoretical model and justification by Koo et al. (1993). To account for potential bias in selection of shuttle elevators, the shuttle dummy variable was instrumented using a binomial logit regression and the predicted values used to replace the shuttle dummy variable in equation 6. Econometric diagnostic tests are conducted to ensure the validity of the estimated parameters. The

Durbin Watson (DW) test for autocorrelation (DW = 1.73) suggest the absence of serial correlation at the 5% level of significance. Estimation results are presented in Table 2.

Table 2: Regression Estimates

Variable	Parameter Estimates
Intercept	3.7985* (0.0001)
Short-Line Miles	-0.4916* (0.0001)
Distance from Barge Facility	0.0866* (0.0090)
Number of Rail Cars	-0.0424* (0.0001)
Load Factor	-0.8794* (0.0001)
Time	-0.0337* (0.0001)
Time Squared	0.0036* (0.0001)
First Quarter Dummy	-0.0174** (0.0379)
Second Quarter Dummy	-0.0162*** (0.0598)
Third Quarter Dummy	-0.0163** (0.0484)
Shuttle-Train Dummy (100 or more cars)	-0.0700* (0.0001)
OBEA110	-0.0406* (0.0002)
OBEA111	0.1441* (0.0001)
OBEA112	0.0309 (0.1128)

Adjusted $R^2 = 0.709$
Observations used = 6160
P-values in parentheses
* Significance at the 1% level
** Significance at the 5% level
*** Significance at the 10% level

The adjusted R-squared of 0.709 indicates that variables included in the model explain at least 71% of the variation in revenue per ton-mile. All explanatory variables have their expected signs with most of the variables significant at the 1% level. The distance variable (length of haul) has a negative sign and is significant at the 1% level. Therefore, as length of haul increases, rate per ton-mile decreases. The observed decrease in rates with distances is attributed to the spreading of fixed and terminal costs over longer distances. Parameter estimates on the other movement characteristics, including number of rail cars and load factor, all have their expected signs. The negative sign on the number of rail cars indicates that rate per ton-mile decreases as the number of cars in the shipment increases. This is significant at the 1% level. Similarly, the load factor, which is a reflection of the weight per car, has a negative sign and is significant at the 1% level. This shows that rail rates decline with increasing weight per car. For example, shippers are often charged for total capacity so if $3,000 is charged per car, then a shipper that loads 110 tons in a car pays $27.2 per ton, whereas another shipper that loads 100 tons pays $30 per ton. This way, the load factor is a reflection of rail car capacity utilization. The latter shipper pays for unused car capacity.

As expected, the highway distance from a barge-loading facility representing intermodal competition from truck-barge combination is positive and significant at the 1% level. This suggests that a 1% increase in distance from loading barge facilities will increase rates by approximately 0.087%. This also highlights the likelihood that railroad pricing behavior in shipping hard red spring wheat from the state is affected by intermodal competition from truck-barge combination.

As expected, the time trend is negative and significant at the 1% level. The negative sign on the time trend suggests that rate per ton-mile for shipping hard red spring wheat has decreased from year to year. However, the squared time trend variable, which measures the change in the time trend over time, suggests that the change in rate reductions over time may be increasing. Three seasonal dummy variables are another delineation of the influence of time on rail rates. The three dummy variables, including first, second, and third quarters, measure rates in comparison with the fourth quarter. All three quarterly estimates are negative. Both the first and the third quarter are significant at 5%, whereas the second is strictly significant at the 10% level. These results suggest that rates for all three quarters are lower than those for the fourth quarter. These results are intuitive given that the hard red spring wheat harvest usually occurs in late September. More grain is likely available following harvest in the fourth quarter of the year potentially satisfying shuttle service capacity requirements (e.g., a shuttle train requires 400,000 bushels of wheat to load).

Two of the three dummy variables accounting for relative rail rates stemming from potential spatial differences from geographic locations are significant at the 1% level. These three regions are compared to the Fargo-Moorhead region BEA113. These regional definitions are established by railroads for the purpose of rate determination. Results suggest that shippers in the Grand Forks region (BEA110) pay lower rates compared with those in BEA113. Shippers in the Minot region (BEA111), on the other hand, pay more than those in the Fargo-Moorhead area. No difference in rates exists between the Fargo-Moorhead region (BEA113) and the Bismarck region (BEA112).

Rail carriers publish rail rates based on the number of cars in a train. From these published rates, four main movement types can be delineated: single-car, multi-car, unit train, and shuttle train services. Shuttle trains, described herein as those with 100 or more rail cars, are viewed as the most efficient owing to their characteristics (e.g., less decoupling and quick turnaround at destination). A single dummy variable was introduced to assess if shuttle trains have a relative rate advantage over the other three rail service types for shipping hard red spring wheat out of North Dakota. The dummy variable for shuttle trains is significant at the 1% level. As expected, the sign of the parameter estimate is negative. This suggests that shuttle trains have a rate advantage over other rail services. A 1% increase in shuttle service used is associated with a 0.070% decrease in rail rates. In fact, it shows that this form of shipment has potentially played a role in reducing rates for shipping hard red spring wheat out of North Dakota over time.

IMPLICATION AND CONCLUSIONS

This paper assessed railroad pricing behavior in North Dakota. Specifically, the primary aim was to examine the effect of shipping hard red spring wheat using shuttle trains to all out-of-state destinations using an econometric technique with time series data between 1999 and 2012. The use of shuttle trains required the construction and upgrading of elevators to increase grain capacity and rail track sidings to accommodate 100 or more rail cars. The loading of a shuttle train requires about 400,000 bushels of wheat, making production an important determinant. In undertaking this evaluation, several other factors influencing rail rates and costs were included in the model.

As expected, cost factors, including distance, number of cars, and load, play an important role in reducing rates. Competitive factors, including intermodal competition, in this case by truck-barge combination, place downward pressure on rail rates. Rates were also observed to vary by month, which alluded to seasonality. The time trend pointed to a general decrease in rail rates from year to year. However, the regional dummy variables tend to indicate that rates vary for the four rail designated areas. It seems that rail rate concerns of hard red spring wheat shippers in the west with regard to paying higher rates are legitimate. Shuttle trains were found to play an important role in reducing rates to shippers. However, it is likely that not all regions have benefitted equally from shuttle rates due to the spatial distribution of elevators that can handle shuttle trains. Overall, results show that shuttle trains have influenced rate reductions. The trend in shuttle adoption and its increasing role, portrayed by the total tons moved relative to other modes and rail services, supports this finding.

These findings have widespread implications. One of the main rationales behind deregulation of the railroad industry was to increase operational efficiency. Deregulation gave the industry flexibility to innovate. Use of shuttle trains is one of the innovations that have enabled carriers to reduce costs. Some of these cost reductions are passed to shippers in the form of lower rates. North Dakota has often been used as an example of a captive transportation market for rail because it is located a significant distance from water transportation. It has been shown here that, despite the relatively longer distances from the closest barge facility, intermodal competition in the form of truck-barge combination has an influence on rail rates. Other research has noted the impact of shuttle elevators on local road degradation and increasing repair costs. Alternatively, findings here indicate that shuttle elevators can significantly reduce rail rates for North Dakota hard red spring wheat shippers. Whether the benefits to shippers outweigh related impacts to local communities is a question for further analysis. Accrued benefits to shippers from using shuttle trains are more important in regions like North Dakota because if benefits from this innovation are widespread, then shippers might not be as captive as previously thought.

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Book Review

Budd, Lucy, and Ison, Stephen, eds. Low Cost Carriers: Emergence, Expansion and Evolution. Burlington, VT: Ashgate/Lund Humphries Publishing Co., 2014. ISBN: 978-1-4094-6903-2

Low Cost Carriers: Emergence, Expansion and Evolution

by Curtis M. Grimm

The effects of airline deregulation across the globe are closely intertwined with the incidence of low cost carrier entry. Across most countries, freeing up legacy carriers to compete has had only modest effects without the catalyst of low-cost carrier entry. The entry of low cost carriers seems to "stir the competitive pot."

A recent edited volume has done an excellent job of bringing together a collection of published papers on the topic of low-cost carriers. The volume is organized into six parts. Part I covers deregulation and liberalization and includes information on deregulation in the United States, Europe and Asia. Part II is on business models and operating characteristics and provides detail on entry and profits of low-cost carriers. Part III, The Airline-Airport Relationship, provides a perspective from airports regarding the advantages and implications of low-cost carriers. Part IV addresses network characteristics, discussing the geography of the United States as it relates to the role of low-cost carriers as well as low-cost carrier networks within the EU and their impacts on competition. Part V, Pricing and Competition, includes details on the price strategies of low-cost carriers along with the response and strategies of legacy and full service competitors. The final section, Part VI, is Impacts and Implications for the Future. This consists of four relatively recent articles that illustrate the topic is not only of historical importance but remains of interest into the future. The following questions are raised: Can the low-cost model be transferred to long-haul operations? What about the "carrier within carrier" approach, where legacy carriers develop low-cost affiliates within their corporate umbrella? Will legacy carriers respond effectively to low-cost competition? Have they? Are there limits to growth of such carriers?

Impressive in the collection is the range of disciplines and journals covered. Transportation is a multidisciplinary field, with most work developed within a disciplinary silo. This volume is a welcome exception, with coverage across economics, geography, operations, and management. There are fascinating and important questions involving both public policy and business policy or strategy, with strong coverage of both.

Not being overwhelmed with technical details, the papers are accessible to a wide audience.

I will end with my own experience regarding airline deregulation and the important role of low-cost carrier entry. In 1991 on sabbatical in Canberra, Australia, I led a team at the Bureau of Transport and Communications Economics to study the impacts of Australian airline deregulation in its first year. Key to the impacts was the entry of Compass, a low cost carrier providing vigorous price competition in major markets. Two legacy carriers met the competition, and our report issued in December 1991 found strong economic benefits with lower fares and greater flight frequencies. However, the bankruptcy of Compass late in December, at peak seasonal travel time, provided a short-term bump in the road and widespread displeasure from "stuck" travelers regarding airline deregulation. It was a good time to return from sabbatical!

Curtis M. Grimm *is professor and Charles A. Taff chair of economics and strategy at the Robert H. Smith School of Business, University of Maryland. Grimm served as Logistics, Business and Public Policy department chair from 1995-2003. He received his Ph.D. in economics from the University of California-Berkeley, with primary focus on industrial organization. Grimm has conducted extensive research in both supply chain and strategic management. His research has focused on the interface of business and public policy with strategic management, with a particular emphasis on competition, competition policy, deregulation, and microeconomic reform both in the U.S. and overseas. This research has resulted in four books and more than 80 published articles.*

Transportation Research Forum

Statement of Purpose

The Transportation Research Forum is an independent organization of transportation professionals. Its purpose is to provide an impartial meeting ground for carriers, shippers, government officials, consultants, university researchers, suppliers, and others seeking an exchange of information and ideas related to both passenger and freight transportation. The Forum provides pertinent and timely information to those who conduct research and those who use and benefit from research.

The exchange of information and ideas is accomplished through international, national, and local TRF meetings and by publication of professional papers related to numerous transportation topics.

The TRF encompasses all modes of transport and the entire range of disciplines relevant to transportation, including:

Economics	Urban Transportation and Planning
Marketing and Pricing	Government Policy
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Organization and Planning	Environment and Energy
Technology and Engineering	Intermodal Transportation
Transportation and Supply Chain Management	

History and Organization

A small group of transportation researchers in New York started the Transportation Research Forum in March 1958. Monthly luncheon meetings were established at that time and still continue. The first organizing meeting of the American Transportation Research Forum was held in St. Louis, Missouri, in December 1960. The New York Transportation Research Forum sponsored the meeting and became the founding chapter of the ATRF. The Lake Erie, Washington D.C., and Chicago chapters were organized soon after and were later joined by chapters in other cities around the United States. TRF currently has about 300 members.

With the expansion of the organization in Canada, the name was shortened to Transportation Research Forum. The Canadian Transportation Forum now has approximately 300 members.

TRF organizations have also been established in Australia and Israel. In addition, an International Chapter was organized for TRF members interested particularly in international transportation and transportation in countries other than the United States and Canada.

Interest in specific transportation-related areas has recently encouraged some members of TRF to form other special interest chapters, which do not have geographical boundaries – Agricultural and Rural Transportation, High-Speed Ground Transportation, and Aviation. TRF members may belong to as many geographical and special interest chapters as they wish.

A student membership category is provided for undergraduate and graduate students who are interested in the field of transportation. Student members receive the same publications and services as other TRF members.

Annual Meetings

In addition to monthly meetings of the local chapters, national meetings have been held every year since TRF's first meeting in 1960. Annual meetings generally last three days with 25 to 35 sessions. They are held in various locations in the United States and Canada, usually in the spring. The Canadian TRF also holds an annual meeting, usually in the spring.

Each year at its annual meeting the TRF presents an award for the best graduate student paper. Recognition is also given by TRF annually to an individual for Distinguished Transportation Research and to the best paper in agriculture and rural transportation.

Annual TRF meetings generally include the following features:

- Members are addressed by prominent speakers from government, industry, and academia.
- Speakers typically summarize (not read) their papers, then discuss the principal points with the members.
- Members are encouraged to participate actively in any session; sufficient time is allotted for discussion of each paper.
- Some sessions are organized as debates or panel discussions.

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