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On the cover: Freeway work zone congestion inflicts costs on drivers in the form of increased travel time and fuel costs. Qin, Chen, and Noyce suggest that real-time information on work zone conditions provided to drivers can reduce these costs. In their paper, “Real-time Traveler Information Performance Measures for Work Zone Congestion Management” they develop an advanced traveler information System (ATIS) to promote utilization of alternative routes and improve local road network performance. (Photo credit: AAA Foundation for Traffic Safety).
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A Message from the JTRF
Co-General Editors

This issue covers a wide variety of topics. They are

- Pricing in retail gasoline markets
- Application and comparison of regression and Markov chain methods in bridge condition prediction and system benefit optimization
- Transportation impacts of increased ethanol production
- Public transit training
- Public-private partnerships in transportation
- Estimation of railroad capacity using parametric methods
- Real-time traveler information performance for work zone congestion management.

Russell et al. study price-cost margins of retail gasoline stations in Oregon by testing for price leadership in the retail gasoline market using a vector autoregression (VAR) model. They use proprietary gasoline price data collected by a multi-branded retail gasoline firm on firms it considered its competitors in 25 markets, and secondary data on spot prices from the U.S. Energy Administration. The difference between gasoline retail price in the proprietary data and the price reported by the U.S. Energy Administration including taxes and delivery fees is the measure of price-cost margin they use. Russell et al. find sticky downward trends in gasoline prices, price leadership in 12 of the 25 markets studied, no brand of gasoline as the consistent price leader, and that each market has a margin leader with different characteristics. In further analysis of the determinants of price-cost margins by regression they find that firms that sell gasoline perceived as lower quality have lower price-cost margins. They also found weak support for lower margins for gasoline stations in cities, higher margins for coastal gasoline stations and those by interstates, and price leadership based on efforts to stabilize prices.

Yi Jiang compares regression and Markov chain methods of predicting bridge condition. In predicting bridge condition he notes that traditional methods use regression models whose dependent variables are ratings of bridge condition and the independent variables are age and traffic volume. He notes that Markov chain models are stochastic and assume that the future state of a variable is independent of its current state but dependent on its state and transition probabilities. Consequently, Jiang defined 10 states of a bridge over time using bridge condition ratings and multiplied them by transition probabilities to predict the future condition of that bridge. These 10 states were also used in the regression equation he estimated. Further, he used an integer programming optimization technique to produce optimal strategies to select bridges for rehabilitation. His optimization produced different benefit values and led to the selection of candidate bridges for rehabilitation that differed depending upon whether the selection was based on actual bridge condition rating, regression of the ratings, or the Markov Chain technique. He found that compared with the Markov Chain analysis the predictions of benefits from the regression approach deviated from actual benefits by a large amount. This led Jiang to conclude that the Markov Chain analysis yields more accurate results than regression.

Quite different from these studies is that by Babcock on the impacts of ethanol production in Kansas on the transportation of corn and sorghum, and its effects on road conditions near ethanol plants. He used direct interviews, questionnaires, and secondary sources to obtain his data. His analysis revealed that as a result of increased ethanol production there have been decreased shipments of corn from country elevators to feedlots while shipments of corn to ethanol plants have increased as have shipments of sorghum. According to Babcock, these increased shipments have resulted in
road deterioration near ethanol plants in six counties but not in two counties and areas where the plants are near state highways. He also found split opinions among county representatives regarding how trucks from the ethanol plants have affected annual bridge and road maintenance expenditures.

Shaheen et al. analyze public transit training to increase ridership among older adults using data from a training program in the Rossmoor Senior Adult Community in Walnut Creek, California. The program teaches residents about public transit options and how to access information on public transit with a focus on encouraging behavioral changes and increasing transit use among older adults. Shaheen et al. evaluate the effectiveness of the Rossmoor program using a before-after study of six training sessions and a survey of previous program participants. Their results show that after the training 85.7% of the participants said they intended using transit frequently, and there were positive shifts in participants’ comfort levels in using transit. The part of the study which focused on prior program participants showed a 14.8% increased use of public transit, no change in the use of the Rossmoor bus transit program, a 27.9% increase in the County Connection bus service, no indication of barriers to public transit use, and a 19.1% increase in participants’ confidence in finding information on public transit after the program.

Pagano’s paper analyzes public-private partnership (PPP) programs in transportation with the purpose of developing a rationale for them, and using the rationale to evaluate several of these programs. He distinguishes the following PPP programs: build-operate, where a private company designs and builds a new public facility; build-operate-transfer, where a private company finances, builds, and operates a public facility for some years and transfers the facility to the public sector; and Brownfield Concessions, in which a public facility is leased to a private company for a long term. He also distinguishes competitive tendering, in which a public sector contracts with a private company to operate and maintain a specified service; asset sales, in which the private sector finances, operates, and maintains a facility with the public sector playing a role or no role in the facility; and vouchers, where users of a public facility receive vouchers which they can use to purchase the service from private providers. Finally, he distinguishes deregulation, in which private companies are allowed to compete with a former monopoly; and “publicization,” where the private sector becomes involved in what was previously a public sector operation. He evaluates and ranks each program in terms of allocative and cost inefficiency, and from this evaluation Pagano finds that the Brownfield Concession is problematic but can be modified with shorter contract periods and upfront fee payments by the private entity to achieve social goals and lower cost. He also finds that the design-build, competitive contracting, asset sales, vouchers, and deregulation have potentials to lead to allocative efficiency.

Mitra et al. extend the work of Prokopy and Rubin (1975) by developing a computer algorithm to measure railroad section capacity to inform planning and managerial decisions. According to them, this algorithm can be used to identify bottlenecks in railroad networks. They also use regression to develop relationships between railroad capacity and related factors (e.g., infrastructure parameters such as spacing and distribution of siding, traffic parameters including speed limit and distribution, and operational parameters including planned and unplanned maintenance) that affect capacity. Further, they used simulation to develop relationships between train delay and trains dispatched, and applied their results to estimate the capacities of railroad subsections in North Dakota as well as track utilization in terms of the ratio of observed trains per day and practical capacity.

The last paper is by Qin et al., and covers real time traveler information performance measures for work zone congestion management. The authors evaluated an advanced traveler information system (ATIS) developed by a Minnesota based consulting firm to guide travelers in selecting alternative routes in congested work zones and tested it on a four-lane divided road in Wisconsin. Their findings suggest that the amount of traffic exiting from the highway in one direction decreased with the presence of the ATIS because it displayed short delay time, and increased in the other direction because it displayed higher delay time. They suggest that the time displayed by ATIS may encourage traffic to stay on a freeway instead of taking an alternative route, and delays less than 15 minutes
should not be displayed because they encourage drivers to remain on freeways instead of taking alternative routes. Tests of the statistical impact of the presence of the ATIS showed it significantly affected the distribution of exiting traffic regardless of delay time. Further, traffic volume and the proportion of exiting traffic when there are no lane closures affected traffic diversion, and the ATIS effectively controlled maximum queue length.

Michael W. Babcock
Co-General Editor

Kofi Obeng
Co-General Editor
Public Transit Training: A Mechanism to Increase Ridership Among Older Adults

by Susan Shaheen, Denise Allen, and Judy Liu

In Summer 2007, researchers evaluated the Rossmoor Senior Adult Community transit training through a “before-and-after” training survey. Surveys also were administered to participants who had taken the training over the past two years to identify any long-term changes (longitudinal). Results of the before-and-after survey revealed a positive shift in participant comfort levels with public transit and in finding transit information. More than 85% planned to take public transit more frequently. Longitudinal survey results revealed a significant decrease in private auto use after training. Both survey results suggest that training may have an impact on transit attitudes and a longer-term impact on travel behavior.

INTRODUCTION

As the number of older adults living in the United States (U.S.) continues to rise, providing adequate transportation services for an increasing number of older travelers presents several challenges (Shaheen and Rodier 2007; Burkhardt, Cradock, Nelson, and Mitchell 2002). There are currently an estimated 35 million senior citizens living in the U.S., and this population is expected to more than double by the year 2030, comprising 20% of the U.S. population (Meyer 2000; Himes 2002). These travelers include the Baby Boomer cohort, some 76 million strong (Himes 2002). Not only will the Baby Boomers contribute to a substantial rise in the number of elderly travelers, but due to numerous medical advances, they will be among the healthiest and longest-living individuals in America. This large change in the demographic landscape of America will lead to great implications for all aspects of life, not the least of which will be transportation.

Automobiles are integral to the lives of older Americans and the aging Baby Boomer population. Elderly Americans rely on their personal auto for a majority of their trips, more than any other age group (Pucher and Renne 2003). Despite improvements in medicine, physical and cognitive changes continue to accompany the aging of older adults and may compromise their ability to drive, particularly after the age of 75 (Shaheen and Rodier 2007; Lyman, Ferguson, Braver, and Williams 2002). Driving cessation reduces the mobility of older adults, particularly if there are no other modes of transportation that are easily accessible (Bailey 2004). This lack of connection with the outside world only leads to greater psychological distress and lower life satisfaction (Lyman et al. 2002; Collia, Sharp, and Giesbrecht 2003).

Exacerbating the transportation problem are the phenomenon of aging-in-place and the movement of Baby Boomers into the suburbs. Aging-in-place is the situation where an individual chooses to stay and grow older in the same home that they lived and worked in during their younger years. The suburbanization of the elderly population removes them from easy access to public transit options, making driving more preferable and convenient. Giving up their driver’s licenses would mean more than a cessation of driving and would radically change their lifestyles, likely reducing their travel outside of the home (Rosenbloom 2003). The aging of the Baby Boomers and the subsequent growth in the older American population is expected to strain current transportation resources in the U.S. (Rosenbloom 2003). A growing older adult population with increased longevity also means there will be a greater number of individuals relying on public transportation for a longer time period. To enable older adults to maintain healthy, active, and involved lifestyles, development of adequate transportation alternatives is needed (Harrison and Ragland 2003).
Public Transit Training

Despite the need for alternative transportation among older adults, public transit is grossly underused among this population (Pucher and Renne 2003; Rosenbloom 2003). Many older adults cannot access transit because there is a lack of available services in their neighborhoods and communities (Shaheen and Rodier 2007; Holmes, Sarkar, Emami, and Shaules 2002). However, research indicates that older adults would not use public transit even if services were available to them (Shaheen and Rodier 2007; Holmes et al. 2002). In addition, many older travelers are unfamiliar with public transit and may experience a number of potential barriers that prevent them from accessing it, including physical and cognitive challenges and an overall lack of information on routes and services (Ritter, Straight, and Evans 2002; Burkhardt 2002; Burkhardt, McGavock, Nelson, and Mitchell 2002). Research suggests that older travelers may require additional information and instruction on how to access public transit, including “mobility planning and training programs” (Shaheen and Rodier 2007; Burkhardt et al. 2002).

This paper evaluates the effectiveness of an in-person, transit training program offered at the Rossmoor Senior Adult Community in Walnut Creek, California. This ongoing transit training class teaches residents about local transit options and how to access information resources. The training also includes a bus tour of the route lines of two major buses available to the community: the Rossmoor and County Connection buses. The class draws upon social cognitive theory and its emphasis on self-efficacy—or the idea that an individual’s perceptions of their own capabilities influence their actions and life events—to encourage older travelers to learn about public transit use and to promote desired behaviors in seniors (Bandura 1994). In Summer 2007, researchers implemented surveys with participants prior to and following the transit training session to assess changes in perceptions and intended transit use (before-and-after survey). In addition, a questionnaire was administered to residents who had taken the transit training course over the past two years to identify any longer-term changes in their public transit use and attitudes (longitudinal survey).

This paper consists of four main sections. First, the authors begin with a review of the literature on aging trends and mobility, as well as self-efficacy and social cognitive theories relevant to the transit training. A methodological discussion follows, including survey design, response rate, and study limitations. Next, the authors present the study results. In the last section, a summary of key findings and conclusions are provided.

LITERATURE REVIEW

This literature review is focused on current and future trends associated with the growing senior population in the U.S. The authors also describe social cognitive and self-efficacy theories relevant to this transit training study. It includes six sections: 1) growth trends, 2) older drivers, 3) driving cessation, 4) public transportation barriers, 5) the aging-in-place phenomenon, and 6) self-efficacy and social cognitive theory.

Growth Trends

According to the U.S. Census Bureau (2000), individuals aged 65 and older numbered 35 million and made up 12% of the U.S. population (Meyer 2000; Himes 2002). This number is expected to double by 2030 as members of the Baby Boomer cohort—approximately 76 million born from 1946 to 1964—join the ranks of those aged 65 and older (Himes 2002). In 2000, life expectancy increased by approximately four years for men and women 65 and older (based upon 1950 projections) (Himes 2002; U.S. Census Bureau 2000). Individuals aged 85 and older have become the fastest growing population segment (Himes 2002). Furthermore, the gender gap is increasing (i.e., there are many more older women than older men) (Himes 2002). These changes in the U.S. demographic landscape will lead to notable impacts on all aspects of life, including transportation.
Older Drivers and Driving Cessation

Automobiles are integral to the lives of older Americans and the aging Baby Boomers. The National Household Travel Survey (NHTS) indicates that seniors rely on their personal auto for 89.1% of their trips—more than any other age group (Pucher and Renne 2003). The number of older U.S. drivers is likely to increase as Americans continue to age and live longer. Hu et al. (2000) predict that by 2025, drivers between the ages of 65 and 69 will increase by 7% among men and 28% among women, while drivers 85 and older will increase by 22.3% for men and 113% for women (Hu, Jones, Reuschem, Schmoyer, and Truett 2000).

Despite improvements in medicine, physical and cognitive changes continue to accompany aging in older adults and may compromise driving ability. Physical limitations, such as decreased strength and flexibility, make safe driving challenging (Shaheen and Niemeier 2001). Other health issues, including vision and hearing deterioration and declining cognitive and perceptual functions, also make older drivers a potential threat to road safety. Ultimately, these health problems often lead to driving cessation.

Driving cessation has additional implications for the lives and well being of older Americans besides decreased mobility. In their study of driving cessation impacts, Harrison and Ragland (2003) found that cessation adversely affects the quality of life of seniors, leading to feelings of lost independence and increased feelings of isolation and depression (Harrison and Ragland 2003). Driving cessation reduces mobility, particularly if there are no easily accessible alternative transportation modes. According to Foley et al. (2002), men between the ages of 70 and 74 will rely on alternative transportation an average of seven years after driving cessation, and women in the same age range for 10 years (Foley, Heimovitz, Guralnik, and Brock 2002). However, despite the need for alternative transportation modes, older adults grossly underuse available public transit—making up only 1.3% of all trips in 2001 (Pucher and Renne 2003; Rosenbloom 2003).

Public Transportation Barriers

There are a number of potential barriers that prevent older adults from using public transportation. In several research studies, participants mentioned the following concerns regarding public transit (Shaheen and Rodier 2007; Ritter et al. 2002; Burkhardt 2002; Burkhardt et al. 2002):

- Lack of door-to-door services
- Infrequent schedules
- Lack of direct routes and stops at certain key destinations
- Reliability of public transit services
- Transfers
- Safety on buses, walking to bus stops, and at bus shelters
- Physical concerns (e.g., climbing stairs, walking to bus stops, carrying large bags on board, etc.)
- Financial concerns about public transportation costs

Additionally, the tendency to perceive dependence on others as an inconvenience may serve as a potential barrier, as many seniors are consequently highly resistant to assistance (Burkhardt 1999). Furthermore, Dumbaugh (2008) posits the intrinsic barriers of the built environment as another barrier, emphasizing the impacts of community planning and design on public transportation, as well as a community’s ability to provide transportation services for older adults (Dumbaugh 2008).

According to the National Household Travel Survey, only about half of all Americans have access to public transportation (Bailey 2004; U.S. DOT 2004). This leaves many, particularly those in rural areas, with no viable alternatives to the private auto. And even where public transit is available, most seniors still prefer to drive. According to a study by Burkhardt et al. (2002), some of the qualities that make driving more appealing for younger people are the same as those that discourage older Americans from using public transit (Burkhardt et al. 2002).
Public Transit Training

“Senior-friendly” transit options that provide more direct routes are located in safe areas and employ drivers that can provide assistance to older travelers are needed to create better public transit options (Kerschner and Aizenberg 2004).

Aging-in-Place Phenomenon

Exacerbating the transportation problem is the aging-in-place phenomenon and movement of the Baby Boomers into the suburbs. This phenomenon has contributed to the “graying” of the suburbs where 56% of the elderly live (Rosenbloom 2003; DeSalles 2002).

The need for transportation alternatives is even more critical in light of the growing Baby Boomer population who will likely continue to live in the suburbs. A recent analysis of 102 metropolitan areas across the U.S. indicated that the suburbs are getting older, and individuals 35 years and older continue to move there at a higher rate than cities (Frey 2003). In 2000, 70% of those 35 and older lived in the suburbs (Frey 2003). Given this trend, institutions all over the U.S. are anticipating the strain this will cause on existing public transportation and are developing new services to prepare for the aging Baby Boomers.

Self-Efficacy and Social Cognitive Theory

Bandura’s (1997) social cognitive theory is an extension of social learning theory and stresses the important influence of cognitive processes on human behaviors and motivations (Bandura 1997). According to social cognitive theory, human functioning results from the interaction among behavior, the environment, and personal factors—a relationship Bandura refers to as “triadic reciprocity” (Bandura 1986; Pajares 2002). Personal factors include what Bandura calls a “self system” that allows individuals to reflect on and regulate their actions and thoughts and to therefore change their environment (Pajares 2003). According to this view, an individual’s perception of his or her own ability can be a better indication of future behaviors and motivations (Bandura 1997; Pajares 2002). This measure of self-efficacy is central to Bandura’s social cognitive theory.

Self-efficacy is the idea that an individual’s perceptions of their own capabilities influence their actions and life events (Bandura 1994). A strong sense of self-efficacy, or faith in one’s own abilities, leads to a more active and involved life in which difficult situations are not avoided but are seen as challenges to be overcome. This manner of approaching life reduces stress, lowers the risk of depression, and leads to a greater commitment to goal setting. On the other hand, those with a weak sense of self-efficacy may limit their potential and avoid situations in which failure may be a high possibility.

One way in which to build self-efficacy is through social modeling. Social modeling centers on the idea that when an individual witnesses peers perceived to be similar to himself succeed in a task, he is more likely to believe in his own ability to complete the task as well. The alternative may also be true—if his peers fail, the individual may expect to have the same result and may be discouraged from trying the task (Bandura 1994). Social models also provide a forum in which individuals may learn from those peers that possess capabilities that they themselves aspire to, and as such, they may acquire new knowledge or capabilities that increase their own self-efficacy (Bandura 1994).

It is especially important for older adults to maintain higher levels of self-efficacy. Old age often leads to physical disabilities that force seniors to reassess their capabilities. Rather than viewing this negatively, a more optimistic point of view would be to use the intellect and experiences gained over the years to make up for physical disabilities. Hough et al. (2008) found that women with higher self-efficacy tended to be more active than those with lower self-efficacy (Hough, Cao, and Handy 2008; Hough 2007). These women were more likely to participate in outside activities and travel more for diverse reasons (Hough et al. 2008). Furthermore, Grembowski et al. (1993) have found that self-efficacy is positively correlated to better mental and physical health in the elderly (Grembowski et al. 1993). Those with higher self-efficacy for health behaviors were more likely to partake in healthy
beverages, such as seeking preventive care, and were healthier individuals. Finally, Shaheen (1999) found that individuals were more accepting of a transportation innovation after participating in a behavioral modeling study (i.e., watching a video that demonstrated individuals using a new service and successfully trying the innovation in a trial clinic) (Shaheen 1999). The transit training class at Rossmoor draws on social cognitive and self-efficacy theory to encourage older adults to learn about public transportation use.

**METHODOLOGICAL APPROACH**

The Rossmoor Senior Adult Community, located in Contra Costa County in Walnut Creek, California, has been offering a transit training program to residents since 2005. In 2008, the community had a population of 9,305 residents with 6,678 residential units on 2,200 acres of land. Most residents have access to a personal vehicle and also can take the Rossmoor bus within Rossmoor and to connect to the County Connection bus system, which takes travelers to outside locations, including downtown Walnut Creek and the local Bay Area Rapid Transit (BART) District station.

Research is needed to address the increasing mobility needs and perceived public transit barriers of older adults. In this paper, researchers evaluated the effectiveness of the Rossmoor Senior Adult Community transit training class. The research methodology consisted of two main components. First, researchers implemented questionnaires “before-and-after” six transit training sessions held in Summer 2007 to assess changes in public transit attitudes and usage on the same day of the class (before-and-after survey). In the second part, researchers conducted a survey with individuals who had previously taken the transit training to identify any longer-term changes in transit attitudes or use (“longitudinal survey”).

Both surveys collected basic demographic data: age, gender, health, and income. The two study populations (before-and-after survey participants and longitudinal survey participants) had very similar p-values for the four demographic variables, ranging from 0.1 - 0.7. However, application of the Mann-Whitney U test (a non-parametric statistical test comparing two independent populations) to income data yielded a p-value of 0.05, indicating some significant differences between the two population’s income levels. This is likely explained by the notably higher incomes of longitudinal study participants than the before-and-after survey population. Over 80% of participants from both groups were age 75 and older. Also, more than 80% were female. Over 85% reported having good, very good, or excellent health. Annual incomes of both study populations varied from below $10,000 to more than $110,000. All participants graduated from high school, and most had at least some college or possessed higher degrees. Overall, participants were predominantly Caucasian.

Recruitment for the before-and-after and longitudinal surveys was conducted through flyers and advertisements in the local Rossmoor newspaper. Interested residents called the Rossmoor transportation office to enroll in the transit training study. To encourage study participation, respondents were entered into a $50 gift card raffle.

**Before-and-After Survey**

The before-and-after survey was conducted in conjunction with six training sessions, held June through August 2007. Two sessions were conducted on a single training day of each month. Each questionnaire took approximately 15 minutes to complete. A total of 42 residents participated in this study. Prior to each training session, respondents completed a “before” questionnaire to assess their: 1) experience with different transportation modes, 2) current travel behavior, 3) public transit attitudes, 4) barriers to transit use, and 5) training program expectations. Next, they participated in one of the six, two-hour training sessions, led by the transportation coordinator at Rossmoor. Immediately following each session, researchers administered the “after” questionnaire, which focused on potential changes in transit attitudes, knowledge gained through the training, and intended changes in travel behavior. The “after” survey also provided participants with the opportunity to
evaluate the training program and to suggest improvements. The before-and-after questionnaire is in the Appendix.

**Longitudinal Survey**

In the second study part, researchers administered a 15-minute questionnaire to prior training participants (individuals who had taken the class between six months to two years earlier) on August 15, 2007. A total of 61 participants completed the longitudinal survey. It included questions about travel behaviors prior to and after the training and perceived transit barriers, as well as an opportunity to comment on the training. The complete longitudinal survey is available from the authors on request.

**Study Limitations**

This study relied on the self-reported answers of participants. Due to privacy considerations, all participant surveys were anonymous, therefore making it impossible to verify if given information was correct. Furthermore, answers were based on respondent memories, and in the longitudinal survey, this was a long time—between six months to two years earlier. Poor memory or a misunderstanding of the questions could have led to false answers. In addition, many participants took part in different training sessions, which may have led to slightly different experiences.

Survey results may not be applicable to all older adult populations, since respondents are not representative of the diversity across the U.S. (e.g., the majority of them were Caucasian). Furthermore, the study was conducted in an area where there is an established public transportation system within the community. In contrast, many seniors in the U.S. are unable to easily access transit, and therefore they may respond differently than the participants of this study. Finally, respondents were educated with at least a high school diploma, and many were still able to drive. They all lived within the older adult community of Rossmoor. Despite these limitations, this study provides many insights into the potential of transit training in encouraging older adults to use public transit, an issue that all regions of the U.S. will likely face in the future.

**RESEARCH RESULTS**

A primary motivation of this study was to examine stated and actual behavioral changes following the Rossmoor transit training. The before-and-after and longitudinal surveys provided researchers with two methods for examining training impacts: immediate (intended response) and longitudinal (change over time). In this section, key findings from both study components are presented, including: 1) intended and actual travel behavioral changes, 2) public transit barriers, 3) public transit information resources, and 4) public transit training feedback.

**Intended and Actual Behavioral Changes**

**Before-and-After Participants.** Prior to training, the private automobile was the primary transportation mode for most participants (78.6%), followed by public transit (9.5%). Some reported equal use of both modes (2.4%). A majority of participants (69.1%) had not used the Rossmoor bus, while even more (76.1%) had never taken the County Connection bus prior to training. Some (9.5%) had even stopped driving but had not yet started using public transit. Immediately following the training, 85.7% of participants stated they intended to take transit more frequently in the future. The mode split of both study populations (before-and-after and longitudinal) prior to instruction was very similar; no statistical difference was found in their private auto use. The Two Sample Proportions test, however, showed that there was a difference in their public transit use ($p=0.0061$).
This is likely due to the greater proportion of before-and-after participants that used public transit as their primary mode prior to training.

**Public Transit Comfort Level Changes.** Respondents were asked a series of questions about their comfort level with taking the Rossmoor and County Connection buses prior to training. Comfort level refers to how comfortable participants felt traveling to various destinations via public transportation. Participants were given the choices: “Very Comfortable,” “Comfortable,” “Somewhat Comfortable,” and “Not Comfortable At All” to assess their own comfort levels. Results demonstrate that the course had a significant effect on public transit comfort perceptions. The McNemar test for paired proportions (a non-parametric statistical test comparing two correlated proportions) demonstrated p-values less than 0.01 for the Rossmoor and County Connection bus comfort questions.

Table 1 reflects a positive shift in participant comfort levels for the Rossmoor and County Connection buses. For instance, dramatic increases were demonstrated for trips to the Walnut Creek BART station and downtown Walnut Creek via County Connection. There was a 52.4 and 57.2 percentage point increase for trips to BART and downtown Walnut Creek, respectively.

**Table 1: Comfort Level Taking Rossmoor Bus and County Connection Bus Before-and-After Transit Training (N=42)**

<table>
<thead>
<tr>
<th>I Feel Comfortable Taking the Rossmoor Bus to:</th>
<th>Before</th>
<th>After</th>
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<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>Not Applicable</td>
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<td>2.4</td>
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<tr>
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<tr>
<td>I Do Not Know of the Rossmoor Bus</td>
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<td>33.3</td>
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<tr>
<td>Safeway Shopping Center</td>
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<th>Before</th>
<th>After</th>
</tr>
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<td></td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>%</td>
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<tr>
<td>Not applicable. I do not visit any of these</td>
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<tr>
<td>Downtown Walnut Creek BART Station</td>
<td>12</td>
<td>28.6</td>
</tr>
<tr>
<td>Downtown Walnut Creek</td>
<td>14</td>
<td>33.3</td>
</tr>
<tr>
<td>I do not know this transit provider.</td>
<td>17</td>
<td>40.5</td>
</tr>
</tbody>
</table>

*aMcNemar test for paired proportions*

**Longitudinal Participants.** Table 2 shows the primary transportation mode split of longitudinal participants before and following the training class. Although the private auto remained the primary mode for a majority of respondents after the training (67.2%), there was a significant decrease in private auto use (19.7 percentage points, with p-value equal to 0.001). In addition, there was a significant increase in public transit use (14.8 percentage points; p=0.006) after training. Increases in the number of participants reporting equal use of both modes (3.3 percentage points) were not significant.
Table 2: Primary Transportation Mode Split of Longitudinal Survey Participants (N=61)

<table>
<thead>
<tr>
<th>Modes</th>
<th>Before Training</th>
<th>After Training</th>
<th>Percent Difference</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private Auto</td>
<td>86.9%</td>
<td>67.2%</td>
<td>-19.7</td>
<td>0.001</td>
</tr>
<tr>
<td>Transit</td>
<td>1.6%</td>
<td>16.4%</td>
<td>14.8</td>
<td>0.006</td>
</tr>
<tr>
<td>Equal Use</td>
<td>11.5%</td>
<td>14.8%</td>
<td>3.3</td>
<td>0.75</td>
</tr>
<tr>
<td>Other</td>
<td>0.0%</td>
<td>1.6%</td>
<td>1.6</td>
<td>--</td>
</tr>
</tbody>
</table>

*aMcNemar test for paired proportions

Post-training results showed no change in Rossmoor bus ridership (p=1). However, County Connection bus usage increased significantly (27.9 percentage points; p=0.002). Significant increases were also demonstrated in County Connection bus ridership to Downtown Walnut Creek (p=0.002) and medical appointments (p=0.041). Ridership to the BART station increased slightly but not significantly (p=0.238). Table 3 summarizes these results.

Table 3: Rossmoor and County Connection Bus Ridership (N=61)

<table>
<thead>
<tr>
<th>Ridership</th>
<th>Before Training</th>
<th>After Training</th>
<th>Percent Difference</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rossmoor</td>
<td>59.0%</td>
<td>59.0%</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>County Connection</td>
<td>37.7%</td>
<td>65.6%</td>
<td>27.9</td>
<td>0.002</td>
</tr>
<tr>
<td>County Connection to…</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downtown Walnut Creek</td>
<td>9.8%</td>
<td>31.1%</td>
<td>21.3</td>
<td>0.002</td>
</tr>
<tr>
<td>Downtown Walnut Creek BART</td>
<td>27.9%</td>
<td>37.7%</td>
<td>9.8</td>
<td>0.238</td>
</tr>
<tr>
<td>Medical Appointments</td>
<td>14.8%</td>
<td>31.1%</td>
<td>16.3</td>
<td>0.041</td>
</tr>
</tbody>
</table>

*aMcNemar test for paired proportions

Public Transit Barriers

Both the before-and-after and longitudinal survey participants were asked to respond to statements regarding barriers that may have prevented public transit use. Not surprisingly, responses across both survey groups differ somewhat from the literature. The majority did not perceive many of the cited barriers. Most were neutral, disagreed, or strongly disagreed with statements that public transit was unsafe, expensive, inaccessible, and unfriendly across both populations. Most also disagreed with statements indicating difficulties entering the bus, reading bus schedules, purchasing tickets, and finding public transit information. This is likely due to the availability of a dedicated community bus service and the unique city-suburban environment in which study participants live.

Public Transit Information Resources

Respondents who took part in the before-and-after study were asked questions about their confidence levels in locating public transit information (e.g., schedules, routes) prior to and immediately following training. As shown in Table 4, there was a significant increase in participant confidence with finding public transit information after training among the before-and-after population (p=0.001). The number of those who felt very confident showed a 19.1 percentage point increase.
Table 4: Public Transit Information Resources: Changes in Before-and-After Survey Respondent Confidence and Longitudinal Survey Participant Use

<table>
<thead>
<tr>
<th>Before-and-After Changes in Confidence Level (N=42)</th>
<th>Not Confident/ Somewhat Confident</th>
<th>Confident</th>
<th>Very Confident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>66.7%</td>
<td>30.9%</td>
<td>2.4%</td>
</tr>
<tr>
<td>After</td>
<td>33.3%</td>
<td>45.2%</td>
<td>21.5%</td>
</tr>
<tr>
<td>Overall $p^a$ value</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Longitudinal Changes in Use (N=61)</th>
<th>No Use</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>49.2%</td>
<td>50.8%</td>
</tr>
<tr>
<td>After</td>
<td>19.7%</td>
<td>80.3%</td>
</tr>
<tr>
<td>Overall $p^b$ value</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
</tbody>
</table>

$^a$Wilcoxon Signed Rank Test
$^b$McNemar test for paired proportions

Longitudinal survey respondents were also asked questions about their public transit information use prior to and after training (longer term). As shown in Table 4, there is a significant increase in transit resource use after training. Prior to training, 50.8% used public transit resources. After instruction, 80.3% used this information—revealing a 29.5 percentage point increase ($p<0.0001$).

Public Transit Training Feedback

Prior to transit training, participants were asked what motivated them to take the class and what they hoped to gain from it. Most respondents (85.7%) enrolled in it to plan for their future. Other reasons included the environment (e.g., air pollution), medical conditions, family member encouragement, and financial reasons (e.g., gasoline costs). Similarly, most longitudinal survey respondents (68.9%) enrolled in the course for the same reasons.

Ninety-three percent of before-and-after respondents found the training to be helpful or very helpful, and all but one reported that their expectations had been met. More than 70% of longitudinal participants recommended the class to friends. All participants found the informational handouts distributed during the training, bus tour, and knowledgeable instructor particularly helpful. Possible improvements include: expanding the training to include evening trips, indicating destinations of interest along the bus route, and providing more information on other public transit options (e.g., BART instruction).

CONCLUSIONS

In Summer 2007, researchers implemented surveys prior to and following the transit training sessions to evaluate the effectiveness of the Rossmoor class by assessing changes in perceptions and intended/actual behaviors following it. In addition, surveys were administered to residents who had taken the transit training course over the past two years to identify any longer-term changes in public transit use.

The transit class teaches participants about local public transportation options, information resources, and how to plan future trips. It also includes a bus tour of two major bus routes available to the community. The training draws upon social cognitive theory to encourage older travelers to
Learn about public transit use. The following is a summary of key findings from the before-and-after survey:

- A majority of respondents (85.7%) stated that they planned to take public transit more frequently in the future
- A positive shift occurred in participant comfort levels taking the Rossmoor and County Connection buses to key destinations within the community (all p-values <0.004)
- Participant confidence with finding public transit information (e.g., schedules, routes) increased after training (p=0.001)

While the before-and-after survey relied on the reported intentions of participants to take public transit, the longitudinal survey allowed researchers to examine behavioral change following the training. Below is a summary of key findings from the longitudinal survey:

- After training, there was a significant decrease in private auto use as the primary transportation mode (p=0.001)
- Public transit use increased significantly (p=0.006)
- Rossmoor bus ridership showed no change (p=1), while ridership on the County Connection bus increased significantly (p=0.02)
- Use of public transit information resources increased significantly after training (p<0.0001)

Longitudinal survey findings are supported by feedback from the Rossmoor transit operator. Rossmoor bus ridership has increased slightly since August 2007. Furthermore, the Rossmoor Transportation Office has noticed a substantial increase in public transit schedule and route inquiries, as well as training requests. Consequently, the Rossmoor transit operator has expanded the training program to include additional instructors and sessions (Gretchen Hansen, unpublished data, July 2008).

Study limitations reflect the innate restrictions of the training (e.g., self-selection bias), self-reported behaviors, and the lack of diversity in the sample population (e.g., primarily Caucasian participants). Thus, the survey results may not be applicable to all older adult populations. Despite these limitations, this study provides many insights into the potential of transit training in encouraging older adults to seek public transit information and increase their familiarity and comfort with public transportation.

Researchers recommend enhancing the transit training by implementing several improvements: 1) developing a follow-up class one month after the initial training, as older adults may need repeated sessions to strengthen their memories and understanding; 2) adding training on evening routes and other public transit options (i.e., BART and Muni); and 3) providing uniformity across all sessions to ensure participants are provided with the same information and handouts. Other suggested improvements include: 1) media campaigns encouraging seniors to plan ahead; 2) area- or provider-specific websites that supply riders with reliable, up-to-date information about available transportation options (U.S. GAO 2004); 3) streamlining connectivity between public transit providers to improve transfers and accessibility for older adults; and 4) offering more direct and evening routes.

Opportunities for further research include re-surveying the before-and-after participants to assess behavioral change and modal shifts over time. Additional research could include post-training focus groups where class feedback, travel behaviors, mode choice, and public transit barriers are probed in greater detail. In addition, researchers could conduct similar studies in both urban and rural areas, which may offer greater understanding of the transportation needs of older adults. Finally, research could be expanded to examine more diverse populations (e.g., different ethnic groups and income levels).
References


Public Transit Training


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BEFORE—QUESTIONNAIRE
Survey No. ________.

Please complete this survey prior to taking part in the transit training course. This survey is anonymous—please do not write your name on any of these pages.

Thank you for contributing to our research.

In the first section, we would like to learn about your transportation patterns:
1. Please indicate the modes of transportation you use one or more times per week. Please check all that apply.
   - County Connection bus
   - Rossmoor bus
   - BART
   - Personal auto
   - Carpool
   - Bike
   - Walk
   - Other (Please specify):__________
2. Have you ever used any of the following modes of transportation? Please check all that apply.
   - County Connection bus
   - Personal auto
   - Rossmoor bus
   - Carpool
   - Muni
   - Bike
   - Walk
   - Other (Please specify):_______
3. Prior to moving to Rossmoor, have you ever lived or worked in a community in which you typically used transit one or more times per week?
   - Yes
   - No
4. Do you drive?
   - Yes
   - No
5. How many people in your household drive (including yourself)?_______
6. How many autos are available to your household for tripmaking?_______
7. Is your private auto your primary mode of transportation?
   - Yes
   - No
8. Is transit your primary mode of transportation?
   - Yes
   - No
9. To which destinations, if any, do you travel one or more times per week? Please check all that apply.
   - Work commute
   - Doctor’s visit
   - Visiting relatives and friends
   - Other (Please specify):__________
   - Running errands
   - Shopping
   - Leisure travel
10. What transportation modes do you use when traveling to these frequent destinations? Please check all that apply.
   - □ County Connection bus
   - □ Rossmoor bus
   - □ Muni
   - □ BART
   - □ Personal auto
   - □ Carpool
   - □ Bike
   - □ Walk
   - □ Other (Please specify): ____________

11. How does the cost of gasoline influence your travel? Please check all that apply.
   - □ I make fewer driving trips.
   - □ I drive to destinations that are closer to my home.
   - □ I carpool.
   - □ I combine two or more driving trips into one.
   - □ I substitute driving trips with transit.
   - □ Other (Please specify): ____________
   - □ The cost of gasoline does not influence my travel.

The next section will help us understand what transportation modes you prefer.

1. Which of the following destinations do you feel comfortable driving to by yourself? Please check all that apply.
   - □ Downtown Walnut Creek
   - □ Downtown Walnut Creek BART Station
   - □ Medical appointments (John Muir Medical Center or Kaiser)
   - □ Not applicable. I do not visit any of these destinations.

2. Which of the following destinations do you feel comfortable taking a Rossmoor bus to by yourself? Please check all that apply.
   - □ Safeway shopping center
   - □ Downtown Walnut Creek
   - □ Not applicable. I do not visit any of these destinations.
   - □ I do not know about this transit provider.

3. Which of the following destinations do you feel comfortable taking a County Connection bus to by yourself? Please check all that apply.
   - □ Downtown Walnut Creek
   - □ Downtown Walnut Creek BART Station
   - □ Medical appointments (John Muir Medical Center or Kaiser)
   - □ Not applicable. I do not visit any of these destinations.
   - □ I do not know about this transit provider.

4. Which of the following destinations do you currently travel to on County Connection buses? Please check all that apply.
   - □ Downtown Walnut Creek
   - □ Downtown Walnut Creek BART Station
   - □ Medical appointments (John Muir Medical Center or Kaiser)
   - □ Not applicable. I never travel to these destinations.

5. How confident do you feel about finding transit information when you need it? Please check one of the response options below.
   - Not confident at all
   - Somewhat confident
   - Confident
   - Very confident
6. How would you describe your overall familiarity with transit? Please check one of the response options below.

- [ ] Unfamiliar
- [ ] Somewhat familiar
- [ ] Familiar
- [ ] Very Familiar

7. What would increase your comfort level with taking transit? Please check all that apply.

- [ ] Announcement of next vehicle arrival
- [ ] Better connections between different transit options
- [ ] More frequent schedules (shorter waits)
- [ ] More direct routes
- [ ] Later schedules (e.g., evening and night services)
- [ ] Better safety measures (e.g., visible security, better lighting)
- [ ] More available seating
- [ ] Easy-to-read schedules
- [ ] Easier parking at transit stations/bus terminals
- [ ] Other (Please specify): ______________________________

The following questions will provide us with a better understanding of how you find transit information.

1. When using transit, what are the resources you use to find transit information? Please check all that apply.

- [ ] Not applicable. I don’t use transit.
- [ ] Paper schedule from the bus station
- [ ] Rossmoor bus transportation information line
- [ ] Internet
- [ ] Brochures
- [ ] Ask a family member or friend
- [ ] Transit training class
- [ ] 511 transit & traffic information phone line or website
- [ ] Other (Please specify): _____________

2. Are you familiar with the following sources of transit information? Please check all that apply.

- [ ] County Connection (CCCTA) website
- [ ] BART website
- [ ] 511.org website
- [ ] 511 transit & traffic information phone line
- [ ] Rossmoor bus transportation info line

3. Have you participated in the Rossmoor transit training class previously?

- [ ] Yes
- [ ] No

If yes, how many times have you participated in the transit training class? _____
This section will help us identify potential barriers to transit use.

What prevents you from using transit or from using transit more often? (Please respond by checking one of the following response options: I strongly disagree, I disagree, I am neutral, I agree, I strongly agree.)

1. It is difficult to read the bus or train schedules.
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree

2. Transit stations are not easily accessible (bus shelters, BART station, etc.).
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree

3. Transit does not provide door-to-door service.
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree

4. I am not comfortable making transit transfers.
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree

5. Transit service is unfriendly.
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree

6. Transit is too expensive.
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree

7. Transit is unsafe.
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree

8. I am uncomfortable going to unfamiliar areas using transit.
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree

9. Friends or family have advised against transit use.
   - Strongly Disagree
   - Disagree
   - Neutral
   - Agree
   - Strongly Agree

10. It is difficult stepping on or off the bus or train.
    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree

11. It is challenging to purchase tickets or pay the fare.
    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree

12. I do not know where to find information about how to take transit.
    - Strongly Disagree
    - Disagree
    - Neutral
    - Agree
    - Strongly Agree
The following questions will help us to understand why you decided to enroll in the Rossmoor transit training.

1. Why did you enroll in the transit training program? Please check all that apply.
   - □ I am attending for environmental reasons.
   - □ I am attending for financial reasons.
   - □ A family member encouraged me to attend.
   - □ I am attending with a friend.
   - □ A family member has a medical condition that impacts their ability to drive.
   - □ I have a medical condition that impacts my ability to drive.
   - □ I am planning for the future.
   - □ Other (Please specify): ____________________________

2. What do you hope to get out of the transit training program? Please check all that apply.
   - □ I want to feel more confident when taking transit.
   - □ I want to take transit to my frequent destinations.
   - □ A family member wants to take transit to their frequent destinations.
   - □ I want to replace some driving trips with transit.
   - □ I want to replace all driving trips with transit.
   - □ Other (Please specify): ____________________________

3. Do you plan on taking transit more often after completing the transit training program?
   - □ Yes    □ No

Transit Barriers: An Evaluation of the Rossmoor Transit Training Program

AFTER—QUESTIONNAIRE
Survey No. __________.

Please complete this survey after taking part in the transit training course at Rossmoor. This survey is anonymous—please do not write your name on any of these pages. Thank you for contributing to our research.

1. Now that you have taken part in the transit training class, do you think that you will take transit more frequently?
   - □ Yes    □ No
   Please describe why or why not: ____________________________

2. Which transit options, if any, would you consider taking more frequently. Please check all that apply.
   - □ County Connection bus □ Rossmoor bus
   - □ BART    □ Other (Please specify): ____________________________
   - □ I do not plan to take transit more frequently.
3. Which of the following destinations do you **now** feel comfortable taking the **Rossmoor bus** to by yourself? Please check all that apply.
   - Safeway shopping center
   - Downtown Walnut Creek
   - Other (Please specify): _________________________________________
   - Not applicable. I do not visit these destinations.
   - I do not know this transit provider.

4. Which of the following destinations do you **now** feel comfortable taking the **County Connection bus** to by yourself? Please check all that apply.
   - Downtown Walnut Creek
   - Downtown Walnut Creek BART Station
   - Medical appointments (John Muir Medical Center or Kaiser)
   - Other (Please specify): _________________________________________
   - Not applicable. I do not visit any of these destinations.

5. Which of the following destinations would you **now** consider taking a **County Connection bus** to instead of **driving**? Please check all that apply.
   - Downtown Walnut Creek
   - Downtown Walnut Creek BART Station
   - Medical appointments (John Muir Medical Center or Kaiser)
   - Other (Please specify): _________________________________________
   - Not applicable. I never travel to this destination.

6. What sources of transit information are best suited for your personal transit use in the future? Please check all that apply.
   - Paper schedule from the bus station
   - Rossmoor bus transportation information line
   - Internet
   - Brochures
   - Ask a family member or friend
   - Travel training class
   - 511.org website
   - 511 transit & traffic information phone line
   - Other (Please specify): _________________________________________
   - Not applicable. I do not plan to use transit in the future.

7. In the future, what sources of transit information would you use when planning transit travel? Please check all that apply.
   - County Connection (CCCTA) website
   - BART website
   - 511.org website
   - 511 transit & traffic information phone line
   - Rossmoor bus transportation info line
   - Not applicable. I do not plan to use transit in the future.
8. How confident do you feel about finding transit information in the future? Please check one of the response options below.
   Not confident at all    Somewhat confident    Confident    Very confident
   □                      □                      □                     □

9. How comfortable do you feel informing others about using transit? Please check one of the response options below.
   Not comfortable at all    Somewhat comfortable    Comfortable    Very comfortable
   □                      □                      □                     □

10. After taking transit training, I now know how to take transit. Please check one of the response options below.
    Strongly Disagree    Disagree    Neutral    Agree    Strongly Agree
    □                      □                      □                     □                     □

The following questions will help us get a better understanding of how to improve the Rossmoor transit training program.

1. How helpful did you find the transit training class? Please check one of the response options below.
    Not Helpful    Somewhat Helpful    Helpful    Very Helpful
    □                      □                      □                     □

2. Did you get what you need out of the class?
   □ Yes    □ No
   Why or why not?_____________________________________________________
   _________________________________________________________________
   _________________________________________________________________

3. What did you find most helpful about the transit training class? Please check all that apply.
   □ I now know where to find transit information.
   □ The training included my frequent destinations.
   □ The training included the types of transit I plan to use in the future.
   □ The training was specific to Rossmoor residents.
   □ The instructor was able to answer my transit questions.
   □ Other (Please specify):_________________________________________
   _______________________________________________________________
   _______________________________________________________________

4. What did you find least helpful about the transit training class? Please check all that apply.
   □ I am unclear on where to find transit information.
   □ The training did not include my frequent destinations.
   □ The training did not include the types of transit I plan to use in the future.
   □ The instructor was unable to answer my transit questions.
   □ Other (Please specify):_________________________________________
   _______________________________________________________________
5. How do you suggest we improve the transit training class? Please check all that apply.
   □ Expand the training to include BART trips
   □ Expand the training to include evening trips
   □ Other (Please specify): ______________________________________
   ______________________________________________________________
   ______________________________________________________________
   □ Not applicable. I am satisfied with the transit training.

6. Do you have any final comments or suggestions to share regarding the transit training class?
   Please provide your thoughts in the space below.
   ______________________________________________________________
   ______________________________________________________________
   ______________________________________________________________
   ______________________________________________________________
   ______________________________________________________________
   ______________________________________________________________
   ______________________________________________________________

The last section asks for basic demographic data.

1. Are you...  □ female  □ male?

2. What is your age?
   □ 55 to 64  □ 65-74  □ 75-84  □ 85 or older

3. Which of the following best describes your current health status? Please check one of the response options below.
   Poor  Fair  Good  Very Good  Excellent
   □  □  □  □  □

4. I have health problems that impact my ability to drive. Please check one of the response options below.
   Strongly Disagree  Disagree  Neutral  Agree  Strongly Agree
   □  □  □  □  □

5. I have health problems that impact my ability to access transit. Please check one of the response options below.
   Strongly Disagree  Disagree  Neutral  Agree  Strongly Agree
   □  □  □  □  □

6. What is your current marital status?
   □ Single  □ Married  □ Separated  □ Divorced  □ Widowed

7. What is the last level of education that you completed?
   □ Grade school  □ Bachelor’s degree
   □ Some high school  □ Some graduate school
   □ Graduated high school  □ Master’s degree
   □ Associate’s degree  □ Ph.D. or higher
   □ Some college  □ Other (Please specify): ___________________
8. How long have you lived in Rossmoor? ____________

9. What is your ethnicity? (Please choose one)
   - □ White/Caucasian
   - □ Black/African American
   - □ Native American
   - □ Asian
   - □ Hispanic
   - □ Pacific Islander
   - □ Other (Please specify): ____________
   - □ Decline to answer

10. What was your household’s 2006, pre-tax income?
    - □ Under $10K
    - □ $10K - $19.9K
    - □ $20K - $49.9K
    - □ $50K - $79.9K
    - □ $80K - $109.9K
    - □ More than $110K
    - □ Decline to respond

11. Do you use a…
    - □ Cellular phone
    - □ Personal Digital Assistant (PDA)
    - □ E-mail
    - □ Internet
Transportation Impacts of Increased Ethanol Production: A Kansas Case Study

by Michael W. Babcock

The rapid expansion of the biofuel industry has driven the Kansas agricultural market into a new era. Nationally, fuel alcohol production has increased from 1,630 million gallons in 2000 to 9,239 million gallons in 2008, a 467% increase. This national trend has occurred in Kansas as well. As of December 2009 there are 10 operational ethanol plants in Kansas with a combined annual production capacity of 438 million gallons.

The growth of ethanol production in Kansas has affected the Kansas corn and sorghum markets in unknown ways. Historically, the principal market destination of Kansas corn was Kansas, Oklahoma, and Texas livestock feedlots with motor carriers accounting for all these shipments. The purpose of this research is to measure the transportation impact of Kansas ethanol production on the transportation of Kansas corn and sorghum. The specific objectives are: Objective A – Investigate the transportation impact of Kansas ethanol production on Kansas transportation from the point of view of the Kansas ethanol production industry, the grain elevator industry, and the Kansas railroad industry. Objective B – Investigate the impact of incremental truck traffic on road conditions in the vicinity of ethanol plants.

Anticipated results include the inbound and outbound shipments to and from Kansas ethanol plants by mode and origin/destination. This information is likely to indicate that Kansas ethanol production has altered the traditional corn and sorghum logistics system.

INTRODUCTION

The rapid expansion of the U.S. biofuel industry has driven the Kansas agricultural transportation market into a new era. Nationally, fuel alcohol production rose from 1,630 million gallons in 2000 to 9,239 million in 2008, a 467% increase (Renewable Fuels Association 2008). The number of ethanol production plants increased from 54 in January 2000 to 170 in January 2008, a 215% increase.

Many factors have contributed to the growth of the U.S. ethanol industry. Energy security and energy independence from unstable foreign countries has increased U.S. ethanol output. Global warming caused in part by combustion of fossil fuels, has encouraged consumption of ethanol. Rural economic development related to corn and ethanol production has contributed to biofuel expansion. Federal energy policies have also played a role. The Energy Policy Act of 2005 includes the Renewable Fuel Standard Program (RFS), which mandates the minimum amount of renewable fuels to be blended into gasoline. The RFS doubles the use of ethanol by 2012. The Energy Independence and Security Act of 2007 further expands the RFS by requiring that 36 billion gallons of renewable fuels be blended into gasoline and diesel by 2022. The record high prices of oil in the first half of 2008 contributed to ethanol production growth. However, the substantial decline in oil prices, which began in the Fall of 2008, has contributed to a slowdown in ethanol demand.

These national trends have occurred in Kansas as well. At the end of 2009, there were 10 operational ethanol plants in Kansas with a combined annual capacity of 438 million gallons (Kansas Corn Commission, Kansas Corn Growers Association, and Kansas Grain Sorghum Producers Association 2009). Of the 438 million gallons of capacity, 81% became operational between 2004 and 2008 (Kansas Corn Commission, Kansas Corn Growers Association, and Kansas Grain Sorghum Producers Association 2009).

The growth of ethanol production in Kansas has affected the Kansas corn and sorghum markets in unknown ways with resulting implications for Kansas agricultural transportation. Traditionally
Ethanol Production

(late 1970s to 2000), Kansas corn was delivered by motor carrier at harvest to the nearest country grain elevators. Prior to the expansion of ethanol production in Kansas, the primary destination corn markets of Kansas country elevators were Kansas, Oklahoma, and Texas livestock feedlots with motor carriers accounting for all of these shipments (Kansas State Board of Agriculture 1980; Kansas Department of Agriculture 2002). In Kansas, most of these corn shipments went to the western one-third of the state, which accounts for 77% of the feedlots in Kansas (Kansas State Board of Agriculture 1980; Kansas Department of Agriculture 2002). Some corn was shipped from country elevators by truck to alcohol plants in Kansas and Nebraska. About 15-20% of the Kansas corn was shipped from country elevators by truck to large terminal elevators in Hutchinson, Wichita, Salina, Topeka, and Kansas City, Kansas and then subsequently shipped by railroad to Texas Gulf of Mexico ports for export or to livestock feed locations in other states (Kansas State Board of Agriculture 1980; Kansas Department of Agriculture 2002).

While a large number of studies have been written on the economics of ethanol, very few studies have examined the impacts of increased ethanol production on regional agricultural transportation markets. The main objective and motivation of this paper is to contribute to this small but growing literature and in the process to indicate a useful methodology that can be used by researchers in other states. The specific objectives of the paper are:

- Investigate the transportation impact of Kansas ethanol production from the point of view of the Kansas ethanol production industry, the grain elevator industry, and the railroads serving Kansas.
- Investigate the impact of incremental truck traffic on state and county road conditions in the vicinity of Kansas ethanol plants.

U.S. AND KANSAS ETHANOL PRODUCTION AND CONSUMPTION

As of the end of 2009, there were 10 ethanol plants operating in Kansas (Table 1). Most of the plants are located in the western half of Kansas with East Kansas Agri-Energy being the lone exception. The plants vary widely in production capacity with Arkalan Energy, LLC, the largest (110 million gallons per year) and NESIKA Energy, LLC, the smallest (10 million gallons annually). The total production capacity of the Kansas ethanol plants is 438 million gallons per year, and they collectively use 156.2 million bushels of grain annually. Four of the plants are served by the Union Pacific Railroad and one by the Burlington Northern Santa Fe (BNSF) Railway. The Kansas and Oklahoma Railroad serves two plants and the Kyle Railroad, one. Two plants are not located on a railroad, but one of those will be served by the Kyle Railroad by the end of 2010.

The U.S. demand for ethanol is concentrated in high population density states where most of the people and vehicles are located. Table 2 contains the top dozen ethanol consumption states, which account for 65.3% of the total U.S. ethanol consumption. The top two states are California (14.49%) and Texas (9.46%), which together consume 24% of the U.S. total. Illinois accounts for 6% and a group of Midwestern states (Ohio, Michigan, and Minnesota) collectively account for 12% of total consumption. Five eastern states (New Jersey, New York, Massachusetts, Virginia, and Maryland) together account for 20.5% of total U.S. ethanol consumption.

Most of the U.S. ethanol production is concentrated in less than 10 Midwestern states (Tables 3 and 4). Table 3 displays the annual production capacity of the top eight states, which collectively account for 81.8% of the total U.S. ethanol production capacity. Iowa is the leading ethanol production capacity state, accounting for 27.7% of the national total. Illinois has 11.9% of the U.S. total, so these two states together account for more than one-third of national capacity.

Table 4 contains the number of operating ethanol plants in the top nine states, which collectively account for 81.2% of the U.S. total. Iowa is the leading state with 21.5% of the U.S. plants. Other leading ethanol producing states are Nebraska (13.1%), Minnesota (11.5%), South Dakota (7.9%), and Illinois (7.3%).

30
## Table 1: Kansas Ethanol Plants (Production Capacity in Millions of Gallons Per Year)

<table>
<thead>
<tr>
<th>Production Plant</th>
<th>Location</th>
<th>Production Capacity</th>
<th>Starting Date</th>
<th>Bushels of Grain Used</th>
<th>Originating Railroad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abenoga Bioenergy Corp</td>
<td>Colwich</td>
<td>25</td>
<td>1982</td>
<td>8.9 million</td>
<td>Kansas &amp; Oklahoma</td>
</tr>
<tr>
<td>Arkalon Energy, LLC</td>
<td>Hayne (near Liberal)</td>
<td>110</td>
<td>2007</td>
<td>39 million</td>
<td>Union Pacific</td>
</tr>
<tr>
<td>Bonanza Energy, LLC</td>
<td>Garden City</td>
<td>55</td>
<td>2007</td>
<td>19.6 million</td>
<td>Burlington Northern Santa Fe</td>
</tr>
<tr>
<td>East Kansas Agri-Energy</td>
<td>Garnett</td>
<td>40</td>
<td>2005</td>
<td>12.5 million</td>
<td>Union Pacific</td>
</tr>
<tr>
<td>Kansas Ethanol, LLC</td>
<td>Lyons</td>
<td>55</td>
<td>2008</td>
<td>19.6 million</td>
<td>Kansas &amp; Oklahoma</td>
</tr>
<tr>
<td>Prairie Horizon Agri-Energy</td>
<td>Phillipsburg</td>
<td>40</td>
<td>2006</td>
<td>14.3 million</td>
<td>Kyle Railroad</td>
</tr>
<tr>
<td>Reeve Agri Energy</td>
<td>Garden City (near Oakley)</td>
<td>13</td>
<td>1982</td>
<td>5.4 million</td>
<td>None</td>
</tr>
<tr>
<td>Western Plains Energy</td>
<td>Campus</td>
<td>45</td>
<td>2004</td>
<td>16.1 million</td>
<td>Union Pacific</td>
</tr>
<tr>
<td>White Energy</td>
<td>Russell</td>
<td>45</td>
<td>2001</td>
<td>17.2 million</td>
<td>Union Pacific</td>
</tr>
<tr>
<td>NESIKA Energy, LLC</td>
<td>Scandia</td>
<td>10</td>
<td>2008</td>
<td>3.6 million</td>
<td>None</td>
</tr>
<tr>
<td>Total Capacity and Grain Used</td>
<td></td>
<td>438</td>
<td></td>
<td>156.2 million</td>
<td></td>
</tr>
</tbody>
</table>


## Table 2: Top Dozen Ethanol Consumption States, 2007

<table>
<thead>
<tr>
<th>Rank</th>
<th>State</th>
<th>Thousands of Gallons</th>
<th>Percent of Total U.S. Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>California</td>
<td>978,516</td>
<td>14.49</td>
</tr>
<tr>
<td>2</td>
<td>Texas</td>
<td>638,526</td>
<td>9.46</td>
</tr>
<tr>
<td>3</td>
<td>Illinois</td>
<td>405,258</td>
<td>6.00</td>
</tr>
<tr>
<td>4</td>
<td>New Jersey</td>
<td>387,114</td>
<td>5.73</td>
</tr>
<tr>
<td>5</td>
<td>New York</td>
<td>341,244</td>
<td>4.65</td>
</tr>
<tr>
<td>6</td>
<td>Ohio</td>
<td>305,382</td>
<td>4.52</td>
</tr>
<tr>
<td>7</td>
<td>Michigan</td>
<td>270,564</td>
<td>4.01</td>
</tr>
<tr>
<td>8</td>
<td>Massachusetts</td>
<td>253,218</td>
<td>3.75</td>
</tr>
<tr>
<td>9</td>
<td>Minnesota</td>
<td>236,418</td>
<td>3.50</td>
</tr>
<tr>
<td>10</td>
<td>Virginia</td>
<td>224,700</td>
<td>3.33</td>
</tr>
<tr>
<td>11</td>
<td>Maryland</td>
<td>204,498</td>
<td>3.03</td>
</tr>
<tr>
<td>12</td>
<td>Arizona</td>
<td>192,564</td>
<td>2.86</td>
</tr>
</tbody>
</table>

Table 3: Annual Production Capacity, March 2009 (Millions of Gallons Per Year)

<table>
<thead>
<tr>
<th>State</th>
<th>Capacity</th>
<th>Percent of U.S. Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa</td>
<td>2,866</td>
<td>27.67%</td>
</tr>
<tr>
<td>Illinois</td>
<td>1,233</td>
<td>11.90%</td>
</tr>
<tr>
<td>Nebraska</td>
<td>1,001</td>
<td>9.66%</td>
</tr>
<tr>
<td>South Dakota</td>
<td>906</td>
<td>8.75%</td>
</tr>
<tr>
<td>Minnesota</td>
<td>837.6</td>
<td>8.09%</td>
</tr>
<tr>
<td>Indiana</td>
<td>697</td>
<td>6.72%</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>498</td>
<td>4.81%</td>
</tr>
<tr>
<td>Kansas</td>
<td>438</td>
<td>4.23%</td>
</tr>
<tr>
<td>Total Top 8 States</td>
<td>8,476.6</td>
<td>81.83%</td>
</tr>
</tbody>
</table>

U.S. Total Capacity 10,358.0


Table 4: Major Ethanol Production States, 2009

<table>
<thead>
<tr>
<th>State</th>
<th>Number of Operating Plants</th>
<th>Percent of U.S. Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iowa</td>
<td>41</td>
<td>21.5%</td>
</tr>
<tr>
<td>Nebraska</td>
<td>25</td>
<td>13.1%</td>
</tr>
<tr>
<td>Minnesota</td>
<td>22</td>
<td>11.5%</td>
</tr>
<tr>
<td>South Dakota</td>
<td>15</td>
<td>7.9%</td>
</tr>
<tr>
<td>Illinois</td>
<td>14</td>
<td>7.3%</td>
</tr>
<tr>
<td>Indiana</td>
<td>12</td>
<td>6.3%</td>
</tr>
<tr>
<td>Kansas</td>
<td>10</td>
<td>5.2%</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>9</td>
<td>4.7%</td>
</tr>
<tr>
<td>Ohio</td>
<td>7</td>
<td>3.7%</td>
</tr>
<tr>
<td>Total</td>
<td>155</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>191</td>
<td></td>
</tr>
<tr>
<td>% Top 9 States</td>
<td></td>
<td>81.2%</td>
</tr>
</tbody>
</table>


LITERATURE REVIEW

To date, relatively few studies have investigated the transportation implications of increased ethanol production. One of these studies (Yu and Hart 2008) analyzed transportation flow patterns of crops and biofuels in Iowa. The authors accomplish this goal by surveying grain marketers, grain handlers, corn/ethanol processors, and biodiesel producers concerning their grain, biofuels, and biofuels co-product transport flows in the 2006-2007 marketing year. They found that corn shipments to livestock feeding locations have declined due to increased ethanol production, although livestock feeding...
is still the primary end user of Iowa corn. According to their surveys the biggest transportation infrastructure problems were unimproved gravel roads, while the biggest marketing problem was transportation costs.

Denicoff (2007) examines the changes in corn-based ethanol transportation requirements and grain transportation caused by growth in the ethanol industry. This was accomplished by analyzing surveys conducted by USDA personnel. Denicoff found that corn is being used less as livestock feed or export and more for ethanol production. The author found that in 2005, 60% of the ethanol was shipped by rail, 30% by trucks, and 10% by barge. She said that railroads were affected by increased ethanol production through a decrease in grain shipments and an increase in ethanol tonnage. Barge shipments decreased due to a decrease in corn exports.

Wu and Markham (2008) suggest strategies to ensure ethanol growth in Minnesota is not limited by logistical problems. The authors accomplish this by evaluating Minnesota Department of Agriculture surveys of ethanol plant managers. Some of the issues that concerned ethanol plant managers included the following:

- Railroad turnaround time
- Poor condition of rail track
- Lack of funds to improve rail track
- Costly and unreliable transportation
- Transportation capacity for transporting ethanol and DDG (dried distillers grain)
- Railroad reluctance to accept public funding

Wu and Markham’s strategy for addressing these issues consist of an educational program to acquaint stakeholders with potential logistics problems and the negative consequences if nothing is done about them. They also identify public-private partnerships as the key to adequate investment in railroad infrastructure. The authors note policy support can aid railroads serving Minnesota in finding investment funds.

Khachatryan et al. (2009) explore the economic feasibility of cellulosic ethanol production in Washington State by presenting the availability, transportation, and collection costs of crop residue. The authors use farm gate costs, transportation costs, physical availability of feedstock, and geographical distribution of feedstock to obtain crop residue supply curves. From analyzing these curves the authors conclude that transportation costs have a considerable influence on the delivered cost of feedstock. However, the magnitude of this influence depends on the capacities of the processing plants and the haul distance to them. The authors perform a sensitivity analysis and find that small capacity processing plants, relative to plants with large capacity, have delivered feedstock costs that are less sensitive to higher diesel fuel prices.

Thompson and Meyer (2009) simulate consumer demand for ethanol together with ethanol transportation costs with respect to benchmark oil and ethanol prices. The authors find a nonlinear relationship between benchmark prices and ethanol transportation costs. The relationship depends on how widely ethanol is used within a state and how close ethanol prices are to the price of corresponding types of energy. For states with widespread use of ethanol, the authors found that the amount of ethanol shipped to that state is insensitive to fuel prices, but an increase in transportation prices will increase transportation expenditures. In contrast, Thompson and Meyer (2009) found that states where ethanol is less widely used as a fuel additive have a more price sensitive (elastic) demand for ethanol. The sensitivity increases if fuels with different levels of additives are priced the same in local markets. The authors note that the difference in energy values between ethanol and the fuel it is replacing will cause an increase in each state’s transportation costs since a larger volume of gasoline with an ethanol additive will be required to generate the same energy output as gasoline with a MTBE additive.
METHODOLOGY AND DATA

Objective A was accomplished through personal interviews with managers of Kansas ethanol production plants, managers of Kansas grain companies, and personnel of the railroads serving Kansas ethanol plants. (Questionnaire in the Appendix. Questionnaires for other respondents available on request.) In addition to the interviews, managers of ethanol plants were asked to complete a detailed questionnaire containing the following sections:

a. Production and Capacity
b. Inbound Transportation
c. Outbound Transportation
d. Carrier Choice Decision Factors
e. Kansas Transportation Infrastructure Quality
f. The Future

Seven of the 10 representatives of the ethanol plants answered all the questions on the questionnaire and the other three partially completed it.

The Kansas grain elevator industry supplies the corn and sorghum to the ethanol production plants. The author (and research assistants) interviewed 21 managers of Kansas grain companies that collectively account for 227 elevators and 200 million bushels of storage capacity. The managers also completed a questionnaire with the following sections:

a. Grain Receipts
b. Outbound Transportation
c. Carrier Choice Selection Factors
d. Summary (how have your markets for corn and sorghum changed as a result of increased ethanol production in Kansas?)

Representatives of the ethanol firms identified their grain suppliers, which resulted in the 21 grain company sample. Representatives of all 21 grain companies answered all the questions on the questionnaire.

Personnel of the railroads serving Kansas ethanol plants were interviewed by members of the research team. These railroads included the Union Pacific and the Burlington Northern Santa Fe, and two short line railroads – the Kansas and Oklahoma and the Kyle Railroad. Representatives of three of the four railroads answered all the questions on the questionnaire and the other one partially completed it. The questionnaire covers the following topics:

a. General Questions
b. Corn Shipments to Kansas Ethanol Plants
c. Outbound Ethanol Shipments from Kansas
d. Outbound DDG (dry distillers grain) Shipments from Kansas Ethanol Plants
e. Summary (expected ethanol car loadings in the next five years)

Objective B was accomplished by interviewing the county engineer or county road supervisor of counties that have ethanol plants. The county representatives also completed a questionnaire containing the following areas.

a. Current Condition of the County Roads
b. Revenue and Expenses
c. Impact of Ethanol Plant on County Roads

Representatives of all eight counties that have ethanol plants completed the questionnaire.

Secondary data sources include Kansas Ethanol Production (http://www.ksgrains.com/ethanol), the source for location, production capacity, and bushels of grain used in Kansas ethanol plants. State consumption of ethanol was obtained from Energy Information System, State Energy Data System (www.cia.doc.gov/emeu/states). State production capacity and number of ethanol plants was from Renewable Fuels Association (http://www.ethanolrfa.org).
TRANSPORTATION OF KANSAS ETHANOL PLANTS

The growth of ethanol production in Kansas has provided an additional market for Kansas corn and sorghum, and the transportation impacts of this new market are the subject of this section of the paper.

Inbound Transportation

The Kansas ethanol plants processed 156.2 million bushels of corn and sorghum in 2008, which was 22.3% of the combined Kansas production of corn and sorghum. Since the great majority of the inbound grain shipments are short distance hauls, motor carriers dominate the inbound shipments, accounting for 91% of the total. Nearly all the inbound motor carrier shipments (97.5%) were delivered in five axle semi-tractor trailer trucks. In a typical five day business week, the 10 Kansas ethanol plants unloaded 3,358 truckloads, or 672 per day. Since each truck hauls about 893 bushels, about 600,000 bushels are processed each day. The great majority of the shipments (82%) originate at grain elevators, with the other 18% delivered by farmers.

Most corn and sorghum shipments originate in the local area of the ethanol plants, with 91% originating within 100 miles of the plant. The remaining 9% are rail shipments predominantly from Iowa. Since the Kansas ethanol plants rely on the local area for corn and sorghum supply, the great majority (87%) of the truck shipments originate in Kansas.

Outbound Transportation

The outbound transportation of Kansas ethanol plants includes shipments of ethanol and co-products (DDG and WDG). Shipments occur by both rail and truck; however, rail is the dominant mode for outbound shipment of ethanol, accounting for 60% of the volume of shipments. Five plants shipped ethanol by rail to population centers in California, and four plants shipped ethanol to Texas by rail. Other rail shipment destinations include population centers in Illinois, New Mexico, Arizona, New York, and Washington. In general, rail was the preferred mode for long distance ethanol shipments.

Population centers in the states bordering Kansas were the principal destination markets for truck shipments of ethanol. Four Kansas plants shipped ethanol by truck to Colorado (primarily Denver) while six plants had truck shipments to Oklahoma (primarily Oklahoma City). Five ethanol plants shipped by truck to a wide variety of Kansas locations, including refineries, fuel blending locations, and retail outlets. Three plants had shipments to Texas population centers, including Dallas-Fort Worth, Houston, and Amarillo. In general, motor carrier was the preferred mode for relatively short distance ethanol shipments.

Most of the transportation of DDG (dry distillers grain) and WDG (west distillers grain) is handled by motor carrier. DDG and WDG are high protein livestock feed ingredients, and are both shipped relatively short distances by truck to livestock feeding locations. Kansas feedlots (mainly cattle and hogs) were named by all 10 ethanol plants as a primary market for DDG and WDG.

IMPACT OF ETHANOL PRODUCTION ON KANSAS GRAIN COMPANY TRANSPORTATION

This section of the paper documents how the Kansas grain industry’s markets for corn and sorghum have changed as a result of Kansas ethanol production, and what have been the associated transportation impacts. To do this, a sample was selected of 21 Kansas grain companies that operate 227 grain elevators with a total storage capacity of 200 million bushels. These companies collectively had 2007 corn receipts of 106.2 million bushels and 83.5 million bushels of sorghum (also referred to as milo). The corn receipts amount to 20.9% of total Kansas 2007 corn production. The corresponding percentage for sorghum was 39.9%.
Ethanol Production

Outbound Shipments to Kansas Ethanol Plants

The 21 Kansas grain companies delivered 22.5 million bushels of corn to Kansas ethanol plants in 2007, all of which were delivered by motor carriers. Thus, 21.2% of the total corn receipts of the sample grain companies were delivered to Kansas ethanol plants \[\frac{22.5}{106.2} \times 100 = 21.2\%\]. There were no corn shipments from the 21 companies to ethanol plants outside the state of Kansas.

In 2007, the sample grain companies shipped 22.1 million bushels of sorghum to Kansas ethanol plants, all of which were delivered by motor carrier. Thus, the Kansas grain companies shipped 26.5% of their total sorghum receipts to the 10 Kansas ethanol plants \[\frac{22.1}{83.5} \times 100 = 26.5\%\].

It is interesting to note that the total percentage of Kansas corn plus sorghum production absorbed by Kansas ethanol plants in the 2007-2008 period (22.1%) is nearly identical to the corresponding percentage of the sample grain companies (23.5%). Also, the 44.6 million bushels of corn plus sorghum represents 28.6% of the 156.2 million bushels of corn and sorghum absorbed by Kansas ethanol plants.

Outbound Shipments to Other (Non-Ethanol) Markets

In 2007, the 21 Kansas grain companies shipped 77.6 million bushels of corn to markets other than Kansas ethanol plants. Nearly all (76.4 million bushels) of these corn shipments were by motor carriers, with only 1.2 million bushels shipped by rail. Most of the truck corn shipments were to Kansas livestock feedlots and feed mills. Much smaller truck shipments went to Kansas terminal elevator locations (primarily Kansas City and Topeka), Kansas pet food manufacturing plants, and poultry feeding locations in Arkansas and Missouri.

Only 4 of the 21 sample grain companies shipped corn by rail to non-ethanol plant locations. Rail shipment destinations included livestock feeding locations in California, Arizona, New Mexico, Oklahoma, and Texas. Other rail corn shipments were to Texas Gulf of Mexico export ports, Wichita and Hutchinson, Kansas, terminal elevators, and poultry feeding locations in Arkansas and Missouri.

The 21 grain companies shipped 56.8 million bushels of sorghum to non-ethanol plant locations. Unlike corn, a large percentage of outbound sorghum shipments were by rail. The rail shipments were classified in two categories: rail and truck rail. The rail category is shipments from one of the country elevators of the grain company sample. The truck-rail category involves a short haul truck movement from a country elevator location to a shuttle (train loader) train location, from which the sorghum is subsequently shipped by rail to final destination. Of the 56.8 million bushels of sorghum shipped by the 21 grain companies, 30 million (53%) bushels were shipped by truck, 3.8 million (7%) by rail, and 22.9 million (40%) by truck rail. Thus, the total sorghum shipments by rail and truck were about equal (53% vs. 47%).

The principal destination markets for the truck shipments of sorghum were Kansas livestock feed yards and feed mills. Much smaller shipments went to Oklahoma feedlots, Kansas pet food companies, Hutchinson, Kansas terminal elevators, and poultry feeding locations in Arkansas and Missouri.

Texas Gulf of Mexico export ports were the only sorghum destination market for rail shipments from the country elevator locations of the sample grain companies. Nine of the 21 grain companies had truck-rail sorghum shipments to Kansas shuttle train locations with subsequent rail shipment to Gulf ports for export.

Grain Company Shipments by Crop, Market Destination, and Mode of Transportation

The results of the previous discussion are summarized in Tables 5 and 6. The data in Table 5 indicate that 21.2% of the corn receipts of the 21 companies went to Kansas ethanol plants and 73.1% was shipped to non-ethanol plant locations, together accounting for 94.3% of the total corn receipts of
the sample grain companies. The remaining 5.7% of the corn receipts were likely used by farmers to feed their livestock.

Table 5 data reveal 26.5% of the 21 grain company sorghum receipts were shipped to Kansas ethanol plants, with 68% going to non-ethanol plant locations.

Table 5: 2007 Shipments of Sample Grain Companies by Crop and Market Destination

<table>
<thead>
<tr>
<th>Market Destination</th>
<th>Corn Bushels (Millions)</th>
<th>Percent of Total Receipts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol Plants</td>
<td>22.5</td>
<td>21.2%</td>
</tr>
<tr>
<td>Non-Ethanol Plant Locations</td>
<td>77.6</td>
<td>73.1%</td>
</tr>
<tr>
<td>Total</td>
<td>100.1</td>
<td>94.3%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Market Destination</th>
<th>Sorghum Bushels (Millions)</th>
<th>Percent of Total Receipts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol Plants</td>
<td>22.1</td>
<td>26.5%</td>
</tr>
<tr>
<td>Non-Ethanol Plant Locations</td>
<td>56.8</td>
<td>68.0%</td>
</tr>
<tr>
<td>Total</td>
<td>78.9</td>
<td>94.5%</td>
</tr>
</tbody>
</table>

Table 6 data indicate that motor carriers shipped 100% of the corn going to Kansas ethanol plants and nearly all of the corn shipments to non-ethanol plant locations. Motor carriers accounted for all the sorghum shipments to Kansas ethanol plants, but only 53% of the sorghum shipments to non-ethanol plant locations.

In general, the emergence of ethanol plants as a new market for Kansas corn and sorghum hasn’t changed the mode of transportation since all shipments to ethanol plants are by truck, as were the shipments to livestock feedlots before the emergence of ethanol as an additional market. However, the market destinations have changed significantly with a higher percentage of the corn and sorghum shipped to ethanol plants and a corresponding reduction in the percentage shipped to non-ethanol plant markets.

Table 6: 2007 Shipments of Sample Grain Companies by Crop, Market Destination, and Mode of Transport

<table>
<thead>
<tr>
<th>Market Destination</th>
<th>Truck (millions of bushels)</th>
<th>Rail (millions of bushels)</th>
<th>Truck (percent of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol Plants</td>
<td>22.5</td>
<td>0.0</td>
<td>100.0%</td>
</tr>
<tr>
<td>Non-Ethanol Plant Locations</td>
<td>76.4</td>
<td>1.2</td>
<td>98.5%</td>
</tr>
<tr>
<td>Total</td>
<td>98.9</td>
<td>1.2</td>
<td>98.8%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Market Destination</th>
<th>Truck (millions of bushels)</th>
<th>Rail* (millions of bushels)</th>
<th>Truck (percent of total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol Plants</td>
<td>22.1</td>
<td>0.0</td>
<td>100.0%</td>
</tr>
<tr>
<td>Non-Ethanol Plant Locations</td>
<td>30</td>
<td>26.8</td>
<td>52.8%</td>
</tr>
<tr>
<td>Total</td>
<td>52.1</td>
<td>26.8</td>
<td>66.0%</td>
</tr>
</tbody>
</table>

*Includes Rail Only and Truck-Rail
Destinations and Transport Modes of Non-Ethanol Plant Markets Before and After Expansion of Ethanol Production

From the late 1970s up to year 2000, when the number of ethanol plants in Kansas began to increase, the primary destination corn markets of Kansas grain companies were Kansas, Oklahoma, and Texas livestock feedlots with motor carriers accounting for all of these shipments (Kansas State Board of Agriculture 1980; Kansas Department of Agriculture 2002). Small amounts of corn were shipped from Kansas grain elevators by truck to alcohol plants in Kansas and Nebraska. About 15-20% of Kansas corn was shipped by truck from country elevators to large terminal grain elevators and then subsequently shipped by railroad to Texas Gulf of Mexico ports for export or to livestock feed locations in other states (Kansas State Board of Agriculture 1980; Kansas Department of Agriculture 2002). Small amounts of corn were shipped by truck from southeast Kansas to poultry feeding locations in Missouri and Arkansas.

After ethanol production increased in Kansas, the non-ethanol plant destination markets and associated transport modes for Kansas corn remained essentially the same. As before, in 2007, the primary market for non-ethanol plant corn was livestock feedlots (mostly in Kansas) with nearly all the shipments (98.5%) moving by truck. Truck shipments of corn to Kansas terminal elevators and shuttle train loading stations remained about the same magnitude as the pre-2000 period. Relatively small amounts of corn were shipped by truck from southeast Kansas to poultry feeding locations in Missouri and Arkansas. As was the case prior to 2000, a relatively small amount of Kansas corn was shipped by rail in 2007 to livestock feeding locations in other states and to Texas Gulf ports for export.

The primary market destinations of sorghum in the period before the expansion of ethanol production in Kansas were livestock feed lots and Texas Gulf ports. Motor carriers accounted for nearly all the shipments of sorghum to livestock feedlots, while railroads handled all the sorghum shipments to the Texas Gulf ports for export (Kansas State Board of Agriculture 1980; Kansas Department of Agriculture 2002). Some rail shipments went directly to Mexico. The modal split varied from year to year depending on market conditions with railroads obtaining 40-60% of the total shipments (Kansas State Board of Agriculture 1980; Kansas Department of Agriculture 2002).

The market destinations and modal split for sorghum shipped to non-ethanol plant destinations in 2007 was essentially the same as in the pre-2000 period. Motor carriers accounted for all the shipments to feedlots, while the sole destination for rail shipments was Texas Gulf ports. Motor carriers accounted for 53% of the total sorghum shipments to non-ethanol plant markets with railroads handling 47%.

Total transportation of corn has likely increased given the increase in Kansas corn production. Average annual Kansas production of corn in the 1990-2003 period was 314.5 million bushels (U.S.D.A. (NASS) and Kansas Department of Agriculture, various years). In the 2004-2009 period, when most of the Kansas ethanol plants began operations, average annual corn production was 472.6 million bushels, a 50% increase (U.S.D.A. (NASS) and Kansas Department of Agriculture, various years). Average annual Kansas sorghum production in the 1990-2003 period was 215.9 million bushels, falling to 201.5 million bushels in the 2004-2009 period, a 6.7% decrease (U.S.D.A. [NASS]; Kansas Department of Agriculture, various years). It isn’t possible to document the trend in modal split in the post-2000 period since no statewide studies of Kansas grain movements have been conducted since 2000.

KANSAS ETHANOL PLANTS AND RAILROAD TRANSPORTATION

Rail transportation is important to Kansas ethanol plants. In some cases corn was delivered to these firms by rail and railroads supply outbound transportation of ethanol and distillers grain. The Kansas ethanol plants are served by two Class I railroads, which are Union Pacific (1,566 mainline track miles in Kansas) and Burlington Northern Santa Fe (1,237 mainline miles). Four Kansas ethanol
plants are served by the Union Pacific. The Burlington Northern Santa Fe serves one. Some Kansas ethanol plants are served by short line railroads. The Kansas and Oklahoma Railroad has 840 track miles in Kansas and serves two ethanol plants. The other short line serving a Kansas ethanol plant is the Kyle Railroad, which has 425 track miles in Kansas.

**Railroad Corn Shipments to Ethanol Plants**

In 2008, Class I railroads delivered 2,470 carloads of corn to Kansas ethanol plants. The typical shipment size was a 100-car unit train. Iowa was the origination state for 96% of the corn shipments with Minnesota accounting for the other 4%. One of the short lines delivered 14 carloads of sorghum to a Kansas ethanol plant.

**Railroad Shipments of Ethanol and Distillers Grain**

Railroads play a much larger role in the outbound shipments from Kansas ethanol plants than the inbound shipments of feedstock. In 2008, the two Class I railroads shipped a combined total of 8,200 cars of ethanol from Kansas ethanol plants. The two short line railroads shipped a combined total of 1,028 cars of ethanol which they subsequently interlined to one of the Class I railroads for shipment to the final destination. Thus, the 1,028 cars are part (12.5%) of the 8,200 cars shipped by Class I railroads.

Table 7 displays data on 2008 Class I railroad shipments from Kansas ethanol plants by destination market. The West region (California, Oregon, and Washington) and the South region (Texas, Oklahoma, and Louisiana) accounted for the largest percentage of ethanol shipments with 30.8% and 29.5%, respectively. The East of the Mississippi River region and the state of Arizona accounted for 19.1% and 16.1% of the total ethanol rail shipments from Kansas.

Railroad shipments of distillers grain are relatively minor since most of it is shipped by truck to Kansas feedlots. In 2008, 450 cars of DDG (dried distillers grain) were shipped from Kansas ethanol plants by Class I railroads. The primary destination was California.

**IMPACTS OF ETHANOL PLANT-RELATED TRUCK TRAFFIC ON COUNTY ROADS**

As noted previously, the 10 Kansas ethanol plants receive nearly all of their corn and sorghum by motor carrier. In a single business day they collectively unload about 670 trucks or 67 per plant. A similar number of trucks are involved in outbound movements of ethanol and distillers grain. Nearly all these trucks are five axle, 80,000 pound GVW (gross vehicle weight) semis. The purpose of this part of the paper is to assess the impact of this truck traffic on county roads in the eight Kansas counties that have ethanol plants.

**Current Condition of County Roads**

Collectively, the eight counties are responsible for 6,882 miles of county roads and 1,805 bridges. Of the 6,882 miles, only 34 are concrete, 1,551 are asphalt (22.5% of the total), and the majority (5,297 miles or 77%) are unpaved (gravel or dirt). The county engineer or road supervisor of each of the eight counties were asked to rate the current condition of their county roads, and the results are summarized in Table 8. For the 34 miles of concrete road, 8.9% were rated Poor, but nearly 56% were rated Good or Very Good. For the asphalt roads, 10.9% were rated Very Poor or Poor and 61.5% were rated Good or Very Good. The county representatives said only 3.7% of the county’s unpaved roads were Poor or Very Poor, while 48% were rated Good or Very Good.
Table 7: 2008 Class I Railroad Ethanol Shipments from Kansas by Destination Market

<table>
<thead>
<tr>
<th>Market Destination</th>
<th>Percent of Shipments</th>
</tr>
</thead>
<tbody>
<tr>
<td>West (California, Oregon, Washington)</td>
<td>30.8%</td>
</tr>
<tr>
<td>South (Texas, Oklahoma, Louisiana)</td>
<td>29.5%</td>
</tr>
<tr>
<td>East of the Mississippi River</td>
<td>19.1%</td>
</tr>
<tr>
<td>Arizona</td>
<td>16.1%</td>
</tr>
<tr>
<td>Midwest (Illinois, Missouri, Wisconsin)</td>
<td>3.2%</td>
</tr>
<tr>
<td>Mountain (Colorado, Nevada, Utah)</td>
<td>1.3%</td>
</tr>
</tbody>
</table>

Sedgwick County accounts for 37% of the 1,551 miles of asphalt road in the eight county sample. Sedgwick County representatives rated all 575 miles of their asphalt roads as being in Very Good condition. Sedgwick County is the most urbanized county in the state with a large tax base and dedicated funding sources. When Sedgwick County is removed from the eight county sample, a different picture of asphalt road conditions emerges in the other seven counties. The percentage of asphalt roads rated Very Poor or Poor increases from 10.9% to 17.2%, while the percentage rated as Good or Very Good falls from 61.5% to 38.9%.

Overall, the current condition of the roads in the eight counties is reasonably good for all road surface types with very few miles in the Very Poor and Poor categories.

Change in County Road Conditions

The county engineers/road supervisors were asked if truck traffic entering or leaving the ethanol plant has had an impact on the condition of the county roads. Six of the eight county representatives responded in the affirmative, while the other two respondents said they were not sure if there had been an impact.

Modifications to county roads generated by ethanol plant-related truck traffic include rebuilt roads, construction of turn lanes and widened turn radius, accelerated chip-seal maintenance rotation that includes asphalt overlay on roads that access the ethanol plant, and blading of roads to smooth out ruts. Representatives of counties with ethanol plants located on state highways said their county road condition had not been affected very much by truck traffic in and out of the plant.

Table 8: Ratings of the Current Condition of County Roads

<table>
<thead>
<tr>
<th>Road Surface Type</th>
<th>Very Poor % (miles)</th>
<th>Poor % (miles)</th>
<th>Fair % (miles)</th>
<th>Good % (miles)</th>
<th>Very Good % (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>-</td>
<td>8.9 (3)</td>
<td>35.3 (12)</td>
<td>38.2 (13)</td>
<td>17.6 (6)</td>
</tr>
<tr>
<td>Asphalt</td>
<td>2.3 (35)</td>
<td>8.6 (133)</td>
<td>27.6 (428)</td>
<td>21.7 (336)</td>
<td>39.8 (619)</td>
</tr>
<tr>
<td>Unpaved</td>
<td>-</td>
<td>3.7 (196)</td>
<td>48.3 (2,555)</td>
<td>45.7 (2,423)</td>
<td>2.3 (123)</td>
</tr>
</tbody>
</table>

Ratings of the Current Condition of Asphalt County Roads (Exc. Sedgwick County)

<table>
<thead>
<tr>
<th>Very Poor % (miles)</th>
<th>Poor % (miles)</th>
<th>Fair % (miles)</th>
<th>Good % (miles)</th>
<th>Very Good % (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.6 (35)</td>
<td>13.6 (133)</td>
<td>43.9 (428)</td>
<td>34.4 (336)</td>
<td>4.5 (44)</td>
</tr>
</tbody>
</table>

The county representatives were asked if ethanol plant-related truck traffic had affected the county’s annual expenditure for road and bridge maintenance. The respondents were divided on this question with three replying that maintenance expenditure had been affected, while three said there
had been no impact, with the other two representatives not sure if an impact had occurred. One of the respondents that said there had been no impact modified this response by stating that although total maintenance expenditure was unaffected, the county was redirecting maintenance resources to ethanol plant-related maintenance.

Although the majority of the eight county representatives revealed that ethanol plant-related truck traffic had affected the condition of the county’s roads, seven of the eight respondents said that the incremental truck traffic had not impaired the ability of the county to maintain an adequate level of service on the county’s roads. However, several respondents indicated that the ethanol plant had opened recently, and that it was too soon to tell what the longer run impact would be on the condition of the county’s roads.

CONCLUSION

In 2008, Kansas ethanol plants processed 156.2 million bushels of corn and sorghum, 22.3% of the combined Kansas production of corn and sorghum. Since the inbound grain transport movements are relatively short hauls, trucks dominate these shipments, accounting for 91% of the total inbound feedstock (corn and sorghum), with railroads accounting for the remaining 9%. Most of the corn shipments to Kansas ethanol plants originated in the local area of the ethanol plant, with 91% of the shipments originating within 100 miles of the plant. The remaining 9% are rail shipments originating primarily in Iowa.

The outbound transportation of Kansas ethanol plants includes shipments of ethanol and co-products DDG and WDG. Shipments of ethanol occur by rail and truck; however, rail is the dominant mode, accounting for 60% of the volume of shipments. In 2008, two Class I railroads shipped a combined total of 8,200 cars of ethanol from Kansas ethanol plants. The West region (California, Oregon, and Washington) and the South region (Texas, Oregon, and Louisiana) accounted for the largest percentage of ethanol shipments with 30.8% and 29.5%, respectively. The East of the Mississippi River region and the state of Arizona accounted for 19.1% and 16.1% of the total ethanol rail shipments from Kansas. Relatively minor amounts were shipped to the Midwest region (Illinois, Missouri, and Wisconsin) and the Mountain region (Colorado, Nevada, and Utah). In general, rail was the preferred mode for long distance ethanol shipments.

Population centers in the states bordering Kansas were the principal destination markets for truck shipments of ethanol. These include Denver, Colorado; Oklahoma City, Oklahoma; and Dallas-Fort Worth, Houston, and Amarillo, Texas. Kansas refineries, fuel blending locations, and retail outlets also received ethanol by truck. In general, motor carrier was the preferred mode for relatively short distance ethanol shipments.

Most of the transportation of DDG and WDG is handled by motor carrier since these co-products are shipped relatively short distances to livestock feeding locations, primarily Kansas feedlots for cattle and hogs.

The growth of Kansas ethanol production has affected the traditional markets for Kansas corn and sorghum. In the corn market, the percentage of shipments from country grain elevators to feedlots has declined and the percentage shipped to ethanol plants has increased. However, as before, nearly all of these shipments are by motor carrier, and feedlots remain the largest single market for Kansas corn. The impact in the sorghum market has been an increase in the percentage of truck shipments from country grain elevators to Kansas ethanol plants, and a decrease in the percentage of rail shipments to distant livestock feeding locations and Texas Gulf ports. The percentage of truck shipments of sorghum to feed mills and feed yards has also declined. Ethanol plants have increased the demand for Kansas corn and sorghum, resulting in higher bid prices for both grains.

It is difficult to identify recommendations for Kansas transportation policy given the uncertainties that exist in the ethanol market. At this time the critical determinants of the demand and supply of ethanol are unknown. Will the demand for Kansas ethanol emerge from the current downturn and increase in the future? Will corn supply in Kansas increase enough to supply the ethanol market as
well as the other non-ethanol corn markets? The answers to these and other questions will be partly
determined by national agricultural and energy policy. Another source of uncertainty is that half of
the Kansas ethanol plants have been in operation for less than four years. Thus, the long run impact
of Kansas ethanol plants on Kansas transportation is unknown at this time. Motor carriers and
railroads are both involved in the transportation of corn and sorghum to Kansas ethanol plants and
the transportation of ethanol and distillers grain from these plants. Therefore, it seems prudent for
Kansas to maintain its current transportation programs of maintaining a high quality state highway
system, state aid to county roads, and aid programs for Class II and III railroads.

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Michael W. Babcock is a professor of economics at Kansas State University (KSU). In his 38 year career at KSU, he has published 75 articles in professional journals, along with numerous monographs and technical reports, and his research has been cited in more than 75 books, the transportation press, and professional journals. He has presented 90 papers at professional meetings, and he was principal investigator or co-investigator on 33 federal and state government research grants worth a total of more than $2.3 million. Babcock is recognized as a leading national and international authority in three research areas, including short line railroad transportation, agricultural transportation, and impact of public policy on transportation market shares.

He has received numerous national awards for his transportation research. He has been recognized five times by the Transportation Research Forum for outstanding research in transportation economics. In addition, Babcock has received the Edgar S. Bagley Award four times from the KSU Department of Economics for outstanding achievement in transportation economics research. In 1999 he was awarded the ISBR Senior Faculty Award for Research Excellence in the Social and Behavioral Sciences from KSU. Babcock has served as an advisor to former Kansas Governor Bill Graves on transportation policy, and contributed testimony to congressional hearings on transportation issues.

APPENDIX: KANSAS ETHANOL PRODUCTION PLANTS

Company Name _________________________

PART A: PRODUCTION AND CAPACITY

1. What year and month did your plant begin operations? ___________

2. What is the annual capacity of the plant to produce ethanol?
   Designed Capacity (millions of gallons) ____________
   Actual Capacity (millions of gallons) ____________

3. What is the annual capacity of the plant to produce dried distillers grain (DDG)?
   Designed Capacity (tons) ____________
   Actual Capacity (tons) ____________

4. What was the annual ethanol production of your plant for the previous three years? If not available for calendar years, please specify your fiscal year.
   2006 million gallons ___________________________
   2007 million gallons ___________________________
   2008 (to date) million gallons ___________________________

5. What was the annual DDG production of your plant for the previous three years? If not available for calendar years, please specify your fiscal year.
   2006 tons ___________________________
   2007 tons ___________________________
   2008 (to date) tons ___________________________
6. What was the annual amount of corn (and sorghum if applicable) processed at your plant in the past three years? If not available for calendar years, please specify your fiscal year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Corn (bushels)</th>
<th>Sorghum (bushels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>2006</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>2007</td>
<td></td>
</tr>
<tr>
<td>2008 (to date)</td>
<td>2008 (to date)</td>
<td>2008 (to date)</td>
</tr>
</tbody>
</table>

7. What percent of the plant’s total revenue is derived from sales of ethanol and DDG in the past three years (2006-2008)?

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td></td>
</tr>
<tr>
<td>DDG</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>

PART B: INBOUND TRANSPORTATION

8. In the past 12 months, what percent of your total corn (and sorghum if applicable) were delivered to your plant in the following types of trucking equipment? Sum of percents must add to 100.

<table>
<thead>
<tr>
<th>Type of Truck</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single axle truck</td>
<td></td>
</tr>
<tr>
<td>Tandem axle truck</td>
<td></td>
</tr>
<tr>
<td>Semi-tractor trailer</td>
<td></td>
</tr>
<tr>
<td>Other (please specify)</td>
<td></td>
</tr>
</tbody>
</table>

9. In a typical business week, how many trucks of each of the types listed below deliver grain to your plant?

<table>
<thead>
<tr>
<th>Type of Truck</th>
<th>Number of Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single axle truck</td>
<td></td>
</tr>
<tr>
<td>Tandem axle truck</td>
<td></td>
</tr>
<tr>
<td>Semi-tractor trailer</td>
<td></td>
</tr>
<tr>
<td>Other (please specify)</td>
<td></td>
</tr>
</tbody>
</table>

10. Please provide your inbound corn (and sorghum if applicable) receipts by truck and railroad (if applicable) for the 2006-2008 period.

<table>
<thead>
<tr>
<th>Year</th>
<th>Inbound Corn Bushels</th>
<th>Inbound Sorghum Bushels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Truck</td>
<td>Rail</td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008 (to date)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11. In the past 12 months what percent of your total inbound corn (and sorghum if applicable) receipts originate in the following miles from your plant? Percents must add to 100.

Percent
(a) 1 to 10 miles from plant
(b) 11 to 30 miles from plant
(c) 31 to 50 miles from plant
(d) 51 to 100 miles from plant
(e) over 100 miles from plant

12. In the past 12 months what percent of your corn (and sorghum if applicable) originated in the following states? Percents must add to 100.

Percent
(a) Kansas
(b) Nebraska
(c) Missouri
(d) Iowa
(e) Other (please specify)

13. In the last 12 months, what percent of your corn or milo receipts have been obtained from farmers (farmer-owned trucks) and country elevators? Percents must add to 100.

From
Farmers
Country Elevators
Other (please specify)

<table>
<thead>
<tr>
<th>From</th>
<th>Percent of Total Corn Receipts</th>
<th>Percent of Total Milo Receipts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country Elevators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (please specify)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PART C: OUTBOUND TRANSPORTATION

14. Please list the most important destinations (markets) for your outbound ethanol shipments during the last 12 months. Also estimate the percent shipped by rail and truck to each destination market. Percents should add to 100 for each market.

**Outbound Ethanol**

**Current Markets (previous 12 months)**

<table>
<thead>
<tr>
<th>Market Name (City, State)</th>
<th>Percent Shipped by Truck</th>
<th>Percent Shipped by Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
15. Please list the most important destinations (markets) for your outbound DDG shipments during the last 12 months. Also estimate the percent shipped by rail and truck to each destination market. Percents should add to 100 for each market. Please include any exports to foreign markets.

<table>
<thead>
<tr>
<th>Market Name (City, State)</th>
<th>Percent Shipped by Truck</th>
<th>Percent Shipped by Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ______________________</td>
<td>________________________</td>
<td>________________________</td>
</tr>
<tr>
<td>2. ______________________</td>
<td>________________________</td>
<td>________________________</td>
</tr>
<tr>
<td>3. ______________________</td>
<td>________________________</td>
<td>________________________</td>
</tr>
<tr>
<td>4. ______________________</td>
<td>________________________</td>
<td>________________________</td>
</tr>
<tr>
<td>5. ______________________</td>
<td>________________________</td>
<td>________________________</td>
</tr>
<tr>
<td>6. ______________________</td>
<td>________________________</td>
<td>________________________</td>
</tr>
<tr>
<td>7. ______________________</td>
<td>________________________</td>
<td>________________________</td>
</tr>
</tbody>
</table>

PART D: CARRIER CHOICE QUESTIONS

16. Is your plant’s location on a railroad?
   Yes __
   No  __

If answer is No, skip to Part E.

17. What type of railroad is your plant located on?
   (a) Class I __
   (b) Class II or III __

If answer is (b), skip to question 19.

18. What is the primary reason the plant is located on a Class I railroad? Pick the primary reason from among the group listed below and put a 1 next to it, then put a 2 next to the second most important reason and 3 next to the third most important factor.
   (a) transportation cost ___
   (b) equipment availability ___
   (c) ability to ship to many markets ___
   (d) reliable transit time ___
   (e) fast transit time ___
   (f) shipment tracing capability ___
   (g) amount of weekly service ___
   (h) other, please specify ___

19. What is the primary reason the plant is located on a Class II or Class III railroad? Select the primary reason from the group listed below and put a 1 next to it, put a 2 next to the second most important reason, and a 3 next to the third most important factor:
   (a) reliable transit times _____
   (b) fast transit times ______
   (c) transportation cost ______
   (d) equipment availability _____
   (e) amount of weekly service ____
   (f) ability to ship to many markets____
   (g) other, please specify ______
PART E: KANSAS TRANSPORTATION INFRASTRUCTURE

20. How would you rate Kansas transportation infrastructure? Circle one answer per row:

<table>
<thead>
<tr>
<th></th>
<th>Poor</th>
<th>Average</th>
<th>Excellent</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Rail lines</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>(b) Roads</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>1. Interstate highways</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2. Primary State highways</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3. Paved county roads</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4. Unimproved county roads</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

21. What are the most important transportation issues for your company? Are there any constraints or problems in the logistics system for either ethanol or DDGs?

PART F: THE FUTURE

22. What changes do you see occurring in your transportation requirements in the next five years? Check all of the following that apply.

(a) an increase in ethanol shipments
(b) a decrease in ethanol shipments
(c) an increase in DDG shipments
(d) a decrease in DDG shipments
(e) a change in the sources of corn supply
(f) a change in principal transportation mode
(g) a change in ethanol markets
(h) a change in DDG markets

23. In your opinion what is the future of ethanol production in Kansas?
Ethanol Production
Real-time Traveler Information Performance Measures for Work Zone Congestion Management

by Xiao Qin, Yali Chen, and David A. Noyce

To mitigate the work zone impacts on freeways, an advanced traveler information system (ATIS) was designed to promote the utilization of alternative routes and improve local road network performance. The system evaluation was performed during a bridge reconstruction project on the four-lane divided I-39/90 near the interchange with WIS59 at Edgerton, Wisconsin.

Field comparisons between ATIS presence and absence discovered different diversion patterns in northbound and southbound directions associated with traffic delay. Drivers remained on the freeway when the displayed delay was less than 15 minutes while more drivers chose to leave the freeway with displayed delay greater than or equal to 15 minutes. A linear regression analysis was further conducted to investigate the impact of several factors, such as displayed delay time, freeway volume, exiting volume during the normal days (without a work zone), and the number of days after system implementation, on driver’s diversion behavior. The results showed that freeway volume, ramp exiting volume during normal days, and delay time were significant variables in causing a high diversion rate.

In addition, it was demonstrated that ATIS performed effectively in increasing the work zone operational capacity. Furthermore, the reduced operating speed associated with the advance speed warning (part of the system) suggested that drivers reacted to the warning messages responding to the real-time speed collected through detectors. This comprehensive evaluation enriched the knowledge of driver behavior and reaffirmed the effectiveness of ITS applications in congestion mitigation.

INTRODUCTION

Work zones are becoming more visible on all highway types because of the need to preserve and upgrade the transportation infrastructure. More construction is expected after the $787 billion stimulus package was signed into law. However, reduction in operating speed and the number of lanes is inevitable due to typical work zone activities. The likelihood of crashes may increase because performing construction activities on existing roads creates conflicts between work and traffic flow. In addition, work zones present an unusual traveling condition that often violates drivers’ expectancy. Unaware of the real-time traffic conditions in or near work zones, drivers often experience unnecessary delay. Excessive delay causes anxiety and frustration, which becomes one of the major attributing factors to work zone crashes. The reduced roadway capacity, increased congestion, and related safety issues emphasize the importance of conveying prevailing travel conditions to drivers.

In response, an advanced traveler information system (ATIS) can be implemented in a work zone to communicate real-time traffic information to roadway users and facilitate drivers’ decision making. The ATIS was implemented on I-39/90, a Wisconsin suburban freeway work zone, where the system’s performance was assessed quantitatively. The system included two major components: real-time delay information and advance speed warning. The system was designed to advise and guide motorists to drive through the work zone safely and efficiently. It was assumed that drivers might take an alternative route to avoid congestion according to the delay information they received on the portable changeable message signs (PCMSs). As a result, the congestion on the reduced capacity road could be mitigated if reliable delay time was available. Besides the delay information, another PCMS provided a warning message of either slowed or stopped traffic ahead when travelers
approached the work zone where the queue was present. The advance speed warning message was aimed at reducing the risk of rear-end crashes. The entire system was based on a series of detectors which continuously collected and relayed real-time traffic information through wireless communication to the PCMSs. The key objectives of the study are to estimate the driver’s tolerance threshold for delay, to evaluate the system performance, as well as to identify the contributing factors in driver’s detour decision making.

**LITERATURE REVIEW**

With the advancement of intelligent transportation systems (ITS) and the growing applications in transportation management, substantial studies have been conducted to evaluate the effectiveness of real-time traveler information. In the 1990s, several studies found that the process of individual decision making is complicated, depending on the alternative route availability, the route preference, the value of time, the traveler information reliability, driver’s gender and age, and other socio-economic factors (Khattak et al. 1993a, Khattak et al. 1993b, Lotan 1997). The topic continues to draw a significant amount of research interest and attention. In Minnesota, researchers developed a route choice model to predict how drivers respond to the information provided by variable message signs (VMSs) and whether drivers will divert to avoid incidents (Levinson and Huo 2003). The study identified the percentage of drivers diverting to alternative routes, network-wide travel time benefits, and delay time savings as the main performance measures. Empirical traffic flow and vehicle density data were collected from pavement sensors on freeway and freeway ramps, as well as the messages on VMSs for one month, and a detailed incident log for 10 years. The study revealed that the diversion rate was significantly impacted by factors such as alternative exit availability, nature of incident (congestion or crash), time period, type of message, and the interaction between alternative exit availability and type of message. VMS was shown to be less effective under heavy traffic due to the difficulty in lane changing and merging.

Compared to the urban setting in Minnesota, several real-time information systems were applied and evaluated in work zones with no recurrent-congestion environments (Horowitz et al. 2003, Tudor et al. 2003, Chu et al. 2005a, and Lee and Kim 2006). The influence of VMS on alternative route selection for rural Wisconsin freeways was examined through the travel information prediction system (TIPS) implemented to warn drivers of estimated real-time delay (Horowitz et al. 2003). TIPS provided drivers with real-time travel time information through a collection of PCMSs, two signs on the freeway before two off-ramps and two signs on the local streets before the on-ramps. Each sign had two message frames indicating the distance to the end of the work zone and estimated travel time. The impact was measured mainly by traffic volume changes before and after the implementation of the travel time signage system. It was reported that alternative route selection did not occur prior to the work zone after the first freeway sign on both weekdays and Sunday. However, the PCMSs boosted the alternative route use from 7% to 10% after the second freeway sign.

Two smart work zone management systems, automated data acquisition and processing of traffic information in real-time (ADAPTIR™) and computerized highway information processing system (CHIPS™), were implemented and evaluated in five Arkansas work zones (Tudor et al. 2003). The comparison between work zones with and without the systems suggested that these systems improved safety by decreasing both fatal and rear-end crashes.

In addition, an automatic work zone information system (AWIS) was implemented in southern California and evaluated via the resulting traffic diversion and safety impacts (Chu et al. 2005a, Lee and Kim 2006). Chu et al. (2005a) observed the decrease in the maximum freeway delay and further suggested that AWIS improved safety by smoothing traffic flow. Another AWIS in Southern California was implemented in an effort to reduce peak hour delay in work zones by changing road user’s travel patterns and diverting traffic to detour routes. The commuter survey indicated that approximately 90% of travelers thought the estimated travel time was accurate, and more than 70%
of drivers changed their travel pattern, such as travel schedules, trip routes, and modes (Lee and Kim 2006).

In addition to field evaluations, several studies applied simulation models to demonstrate the benefit of implementing a real-time traveler information system in terms of reducing queue length and maximum user delay (Bushman et al. 2004 and Chu et al. 2005b). Bushman et al. (2004) used QuickZone 1.0 software to evaluate the delay time system based on the scenarios of without and with the traveler information system. Chu et al. (2005b) studied the diversion under AWIS using PARAMICS simulation models. The simulation evaluation concluded that the system can effectively reduce traffic delay by comparing the delay reduction on the freeway between before and after periods.

**STUDY DESIGN**

Project Background

The Wisconsin Department of Transportation (WisDOT) performed a bridge repair from September 29 to October 10, 2006, a total of 12 days of construction operations, near the interchange of I-39/90 and WIS59 at Edgerton, Wisconsin. The purposes of this work zone included replacement of the deteriorating back walls on the bridge abutments and resurfacing for a one-half mile segment on I-39/90 south of the Rock River. Therefore, during the rehabilitation, the northbound bridge was completely closed, and traffic was routed to the southbound by a median crossover, converting the southbound segment from one-way to two-way traffic. This segment of I-39/90 is a four-lane divided roadway (two-lane in each direction) carrying over 54,000 vehicles per day. The reduction from two-lane to one-lane in each direction will cause congestion. Hence, WisDOT provided an alternative route allowing drivers to divert from I-39/90 to avoid excessive delay. The designated alternative route in Figure 1 included US 14 and US 51, both two-lane undivided highways. Northbound drivers can take an exit ramp to US 14 and return to I-39/90 via an entrance ramp from US 51. Southbound drivers can divert to US 51 and return to I-39/90 from US 14. In addition, a real-time ATIS was implemented to facilitate drivers’ detour decision making.

Advanced Traveler Information System (ATIS)

The system evaluated was designed and deployed by a Minnesota-based traffic consulting firm. It consisted of four key components: 1) microwave/Doppler radar traffic sensors, 2) master controller (the central controller that processes and transmits all the signals received), 3) portable changeable message signs (PCMSs), and 4) communications. Two types of communication links were used to transfer data among detectors, master controller, and PCMSs: a radio-based communication between the detectors and master controller and a modem-based communication channel between the master controller and PCMSs. The delay time was defined as the difference between the estimated travel time based on real-time traffic data and the travel time under free-flow condition. The sensors continuously collected speed data and relayed them to the master controller. The algorithm in the master controller calculated the instantaneous travel time based on the collected speed data from which the delay time was derived as the difference between the congestion and free-flow conditions.
The approaching area was divided into several segments by the sensors. For each segment, the travel time was calculated by dividing the distance between two sensor locations with the average speed of the sensors. Next, the total travel time before entering a work zone (the sum of all the travel times in individual segments) was compared against the travel time under free flow condition to calculate the delay time. The actual delay time posted was further calibrated through the travel time studies and observed queue length.

\[
DT = \sum_{i=1}^{n} \frac{l_i}{(v_i + v_{i-1})/2} - \sum_{i=1}^{n} l_i / v_f
\]
Where:

- $DT$ – Delay time
- $l_i$ – Length of segment $i$
- $v_f$ – Free flow speed
- $v_i$ – Speed in $i$th segment
- $v_{i-1}$ – Speed in $(i-1)$th segment

Six remote traffic microwave sensors (RTMS) and eight Doppler radars were deployed in both northbound and southbound directions. The locations and types of sensors are listed in Table 1. The location of each PCMS was carefully designed in the effort to maximize system performance. Prior to the detour ramp, three PCMSs were placed successively along the approaching areas in each direction to provide real-time information, including one displaying only the delay time and two displaying the delay time along with the orange detour signs. After the detour ramp, two PCMSs were used to suggest drivers adjust their speed according to the work zone speed ahead, with the messages cycling between two phases: “Slow traffic ahead/Drive with caution” and “Stopped traffic ahead/Be prepared to stop.” The displayed information was based on speed detected through the speed sensors.

| Sensor Location Distance Between Sensors (mi) Type |
|-----------------------------------------------|-----------------------------------------------|
| Sensor | Location | Distance Between Sensors (mi) | Type |
| NB sensor 1 | 0.25 miles away from work zone | 0.0 | Doppler radar |
| NB sensor 2 | 0.75 miles away from work zone | 0.5 | Doppler radar |
| NB sensor 3 | 1.5 miles away from work zone | 0.75 | RTMS |
| NB sensor 4 | 2.5 miles away from work zone | 1.0 | Doppler radar |
| NB sensor 5 | 3.5 miles away from work zone | 1.0 | Doppler radar |
| NB sensor 6 | 4.5 miles away from work zone | 1.0 | RTMS |
| NB sensor 7 | 5.5 miles away from work zone | 1.0 | Doppler radar |
| NB sensor 8 | 8.7 miles away from work zone | 3.2 | RTMS |

| SB sensor Location Distance Between Sensors (mi) Type |
|-----------------------------------------------|-----------------------------------------------|
| Sensor | Location | Distance Between Sensors (mi) | Type |
| SB sensor 1 | 0.25 miles away from work zone | 0.0 | Doppler radar |
| SB sensor 2 | 0.75 miles away from work zone | 0.5 | Doppler radar |
| SB sensor 3 | 1.5 miles away from work zone | 0.75 | RTMS |
| SB sensor 4 | 3.5 miles away from work zone | 2.0 | Doppler radar |
| SB sensor 5 | 4 miles away from work zone | 0.5 | RTMS |

**DATA COLLECTION**

An extensive data collection was conducted to obtain freeway and freeway ramp traffic volume, speed, traffic density, queue length, message board information, and delay time. Each data point was time-stamped. The data collection was coordinated between the research team, WisDOT, and the vendor who provided the system. Data collection lasted for two weeks: one week before implementing ATIS from September 27, 2006, to October 4, 2006, and one week during the implementation from October 5, 2006, to October 12, 2006.

**Analysis and Discussion**

It is an effective approach to mitigating work zone congestion by moving traffic from congested roadway sections to alternative routes where the capacities are still underutilized. The diversion
rate, defined as the percentage of traffic taking the alternative routes, is frequently referred to as a performance measure of the system effectiveness. The diversion rate was calculated as follows:

\[
R_d = \left( \frac{V_{off \_ramp}}{V_{mainline}} \right)_a - \left( \frac{V_{off \_ramp}}{V_{mainline}} \right)_b
\]

Where:
- \( R_d \) – Diversion rate
- \( \left( \frac{V_{off \_ramp}}{V_{mainline}} \right)_a \) – Proportion of exiting traffic with ATIS
- \( \left( \frac{V_{off \_ramp}}{V_{mainline}} \right)_b \) – Proportion of exiting traffic without ATIS

Using the diversion rate in combination with the delay message and other variables, driver’s tolerance for delay can be decided through statistical analysis. Driver’s decision making is a stochastic and complex process, often mixed with other factors such as the preference of the routes, familiarity with the routes, trip purposes, driver’s own perception of congestion, belief in the PCMS message, and random errors. Rather than taking the detour, some drivers would remain on the freeway to avoid getting lost in alternative routes. However, once the excessive congestion reflected through the delay time exceeds driver’s tolerance level and becomes the dominant factor in the detour decision-making process, more traffic is expected to leave the freeway. Note that all the comparison and analysis, except for the speed analysis in this section, were based on 15-minute intervals.

Publishing real-time delay time information would encourage drivers to divert to alternative routes, thereby alleviating freeway congestion. Therefore, the diversion analyses were only conducted during congestion in both southbound and northbound directions. The discrepancy in the traffic taking exit ramps with and without the system presence was the measure of the effectiveness.

**Southbound Direction**

To ensure the comparability, only data available during the same period and on the same day of the week with and without ATIS were used. September 29 (Friday) and October 1 (Sunday) were two days with congestion without ATIS presence, and October 6 (Friday) and October 8 (Sunday) were two days with congestion with ATIS. Hence, one pair of weekday (Friday) and one pair of weekend (Sunday) days were compared in two different scenarios, with the results shown in Table 2 and Table 3, respectively.
Table 2: Southbound Diversion Rate With and Without ATIS (Friday)

<table>
<thead>
<tr>
<th>Time</th>
<th>Without ATIS*</th>
<th>With ATIS</th>
<th>Detour Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detour</td>
<td>Estimated Delay (min)</td>
<td>Volume</td>
</tr>
<tr>
<td>12:00</td>
<td>33%</td>
<td>1</td>
<td>1758</td>
</tr>
<tr>
<td>13:00</td>
<td>16%</td>
<td>5</td>
<td>1608</td>
</tr>
<tr>
<td>14:00</td>
<td>24%</td>
<td>5</td>
<td>1781</td>
</tr>
<tr>
<td>15:00</td>
<td>28%</td>
<td>5</td>
<td>2060</td>
</tr>
<tr>
<td>16:00</td>
<td>29%</td>
<td>6</td>
<td>2043</td>
</tr>
<tr>
<td>17:00</td>
<td>27%</td>
<td>6</td>
<td>2015</td>
</tr>
<tr>
<td>18:00</td>
<td>12%</td>
<td>5</td>
<td>1556</td>
</tr>
<tr>
<td>19:00</td>
<td>23%</td>
<td>1</td>
<td>1120</td>
</tr>
<tr>
<td>Average</td>
<td>24%</td>
<td>4</td>
<td>1742</td>
</tr>
</tbody>
</table>

*shaded values are estimated delay times which are not displayed to drivers

Table 3: Southbound Diversion Rate With and Without ATIS (Sunday)

<table>
<thead>
<tr>
<th>Time</th>
<th>Without ATIS*</th>
<th>With ATIS</th>
<th>Detour Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detour</td>
<td>Estimated Delay (min)</td>
<td>Volume</td>
</tr>
<tr>
<td>11:00</td>
<td>12%</td>
<td>3</td>
<td>1748</td>
</tr>
<tr>
<td>12:00</td>
<td>25%</td>
<td>7</td>
<td>2005</td>
</tr>
<tr>
<td>13:00</td>
<td>31%</td>
<td>8</td>
<td>2165</td>
</tr>
<tr>
<td>14:00</td>
<td>28%</td>
<td>10</td>
<td>2125</td>
</tr>
<tr>
<td>15:00</td>
<td>30%</td>
<td>10</td>
<td>2123</td>
</tr>
<tr>
<td>16:00</td>
<td>31%</td>
<td>11</td>
<td>2190</td>
</tr>
<tr>
<td>17:00</td>
<td>30%</td>
<td>7</td>
<td>2190</td>
</tr>
<tr>
<td>18:00</td>
<td>14%</td>
<td>5</td>
<td>1623</td>
</tr>
<tr>
<td>19:00</td>
<td>26%</td>
<td>3</td>
<td>1385</td>
</tr>
<tr>
<td>20:00</td>
<td>33%</td>
<td>0</td>
<td>1153</td>
</tr>
<tr>
<td>Average</td>
<td>27%</td>
<td>8</td>
<td>1976</td>
</tr>
</tbody>
</table>

*shaded values are estimated delay times which are not displayed to drivers

The tables illustrate the interactive relations among delay (minutes), exiting traffic diversion, and arrival vehicle count (15-minute interval). It was unexpected to observe a higher exiting traffic percentage without ATIS than with ATIS on both Friday and Sunday. Further analysis revealed that the displayed delay time ranges from two to four minutes on Friday and five to seven minutes on Sunday, which were not intolerable to most road users. Both tables show that the exiting traffic decreased when ATIS was present, suggesting that acceptable short delay time encouraged drivers to stay on the freeway rather than taking alternative routes.

Northbound Direction

Northbound traffic presented a reversed scenario of ATIS performance because the displayed delay times in the northbound direction were much higher than southbound due to the higher traffic flow,
ranging from 18 to 22 minutes. The proportions of exiting traffic with ATIS shown in Table 4 were approximately 2 to 8% higher than without ATIS. It indicates that delay time played an important role in drivers’ diversion decision.

Table 4: Northbound Diversion Rate With and Without ATIS (Friday)

<table>
<thead>
<tr>
<th>Time</th>
<th>Without DTIS*</th>
<th>With DTIS</th>
<th>Detour Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detour</td>
<td>Estimated Delay(min)</td>
<td>Volume</td>
</tr>
<tr>
<td>10:00</td>
<td>36%</td>
<td>1</td>
<td>1653</td>
</tr>
<tr>
<td>11:00</td>
<td>38%</td>
<td>5</td>
<td>1913</td>
</tr>
<tr>
<td>12:00</td>
<td>40%</td>
<td>13</td>
<td>1904</td>
</tr>
<tr>
<td>13:00</td>
<td>37%</td>
<td>17</td>
<td>2008</td>
</tr>
<tr>
<td>14:00</td>
<td>41%</td>
<td>19</td>
<td>2099</td>
</tr>
<tr>
<td>15:00</td>
<td>37%</td>
<td>19</td>
<td>2228</td>
</tr>
<tr>
<td>16:00</td>
<td>39%</td>
<td>18</td>
<td>2364</td>
</tr>
<tr>
<td>17:00</td>
<td>44%</td>
<td>22</td>
<td>2335</td>
</tr>
<tr>
<td>18:00</td>
<td>22%</td>
<td>19</td>
<td>1745</td>
</tr>
<tr>
<td>Average</td>
<td>37%</td>
<td>15</td>
<td>2028</td>
</tr>
</tbody>
</table>

*shaded values are estimated delay times which are not displayed to drivers

ANOVA Test for Delay Tolerance Threshold

The preceding analysis indicates that displayed travel time may encourage drivers to stay on the freeway instead of taking the alternative routes if the delay time is tolerable. However, it was difficult to identify the driver tolerance threshold through the experimental data plots. More rigorous analysis was required to determine the delay time that can cause roadway users to make one of the two distinctive decisions, below which the majority of drivers will choose to stay on the freeway, and vice versa. A set of one-way ANOVA tests were designed to identify the value of the driver tolerance threshold. The general ANOVA model is shown as follows:

\[ Y_{ij} = \mu_i + \epsilon_{ij} \quad i = 1, 2; \ j = 1, 2, \cdots, n \]

Where:
- \( Y_{ij} \) – Proportion of exiting traffic in the \( j \)th case for delay time \( i \)
- \( \mu_i \) – Mean proportion of exiting traffic associated with delay time \( i \)
- \( \epsilon_{ij} \) – random error

Essentially, the test was used to detect if there were any significant differences among the average proportions of exiting traffic associated with different levels of delay time. The null hypothesis was that the average proportions of exiting traffic were the same at different delay levels. Each ANOVA test was conducted for two levels: delay time either less than or more than or equal to the tolerance threshold. P-values in Table 5 suggest that no significant discrepancies are detected for the thresholds of five minutes and 10 minutes, respectively. The results for 15 and 20 minute thresholds, however, present a statistically significant difference at the 5% significance level. The smaller value, 15 minutes, is considered to be more practical for displaying the delay time. In other words, there is no need to display the delay time less than 15 minutes in the actual operations because drivers are inclined to remain on the freeway instead of taking alternative routes when a shorter delay time is displayed.
Table 5: One-Way ANOVA Analysis for Delay Tolerance Threshold

<table>
<thead>
<tr>
<th>Delay Level (Minutes)</th>
<th>&lt;5</th>
<th>≥ 5</th>
<th>&lt;10</th>
<th>≥10</th>
<th>&lt;15</th>
<th>≥15</th>
<th>&lt;20</th>
<th>≥20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.246</td>
<td>0.342</td>
<td>0.267</td>
<td>0.364</td>
<td>0.275</td>
<td>0.369</td>
<td>0.289</td>
<td>0.393</td>
</tr>
<tr>
<td>Variance</td>
<td>0.028</td>
<td>0.029</td>
<td>0.030</td>
<td>0.026</td>
<td>0.033</td>
<td>0.020</td>
<td>0.031</td>
<td>0.020</td>
</tr>
<tr>
<td>Observations</td>
<td>203</td>
<td>320</td>
<td>321</td>
<td>202</td>
<td>356</td>
<td>167</td>
<td>444</td>
<td>79</td>
</tr>
<tr>
<td>df</td>
<td>202</td>
<td>319</td>
<td>320</td>
<td>201</td>
<td>355</td>
<td>166</td>
<td>443</td>
<td>78</td>
</tr>
<tr>
<td>F</td>
<td>0.990</td>
<td>1.171</td>
<td>1.631</td>
<td>1.553</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P(F&lt;=f)</td>
<td>0.472</td>
<td>0.111</td>
<td>0.000</td>
<td>0.009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Contingency Table Analysis for Exiting Traffic Distribution

Contingency table analysis is one of the most commonly used techniques to identify whether the characteristics of two or more sets are independent (Washington et al. 2003). The contingency chi-square statistic in Equation 4 can be applied to examine the relationship between row variables and column variables in the contingency table for statistical significance. In the context of exiting traffic analysis, chi-square statistic $\chi^2$ can be used to determine whether the ATIS presence makes a statistically significant impact on the distribution of the proportion of exiting traffic. The typical hypothesis of the test is:

$H_0$: The ATIS presence and proportion of exiting traffic are independent.

$H_1$: The ATIS presence and proportion of exiting traffic are not independent.

The chi-squared statistic $\chi^2$ is calculated as follows:

$$\chi^2 = \sum_{i=1}^{R} \sum_{j=1}^{C} \left( \frac{(a_{ij} - e_{ij})^2}{e_{ij}} \right)$$

Where:

- $a_{ij}$: Observed proportion of exiting traffic
- $e_{ij}$: Expected value and $e_{ij} = \frac{R_i C_j}{T}$

Since drivers may make different decisions when delay time was less than 15 minutes compared with more than 15 minutes, the analysis was performed for both scenarios. The results are shown in Table 6. P-values for both congestion scenarios are less than 0.01, indicating that the ATIS presence always significantly affected the proportion of exiting traffic distribution regardless of the delay time threshold.
Table 6: Chi-Square Test for Exiting Traffic Distribution

<table>
<thead>
<tr>
<th>Congestion Level</th>
<th>Cumulative Distribution of the Portion of Exiting Traffic</th>
<th>Number of Observation (Before)</th>
<th>Number of Observation (After)</th>
<th>Chi-square Value</th>
<th>DF</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≤10%</td>
<td>31</td>
<td>61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤20%</td>
<td>88</td>
<td>140</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤30%</td>
<td>159</td>
<td>206</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay Less than 15 Minutes</td>
<td>≤40%</td>
<td>234</td>
<td>281</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤50%</td>
<td>319</td>
<td>310</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤60%</td>
<td>357</td>
<td>331</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤70%</td>
<td>393</td>
<td>337</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤80%</td>
<td>406</td>
<td>343</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤100%</td>
<td>413</td>
<td>352</td>
<td>65.7</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>≤10%</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤20%</td>
<td>5</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay more than or Equal to 15 Minutes</td>
<td>≤30%</td>
<td>21</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤40%</td>
<td>36</td>
<td>49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤50%</td>
<td>45</td>
<td>99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤60%</td>
<td>66</td>
<td>137</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤70%</td>
<td>84</td>
<td>160</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤100%</td>
<td>86</td>
<td>167</td>
<td>20.3</td>
<td>7</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Under the first scenario with delay time less than 15 minutes, only 71 out of 352 observations have a higher than 40% portion of the exiting traffic with the system presence, while there were 179 out of 413 with the system absence. In other words, the ATIS encouraged drivers to stay on the freeway when estimated delay time was less than 15 minutes. When the delay time was larger than or equal to 15 minutes, 118 out of 167 observations (almost three quarters of the proportions of exiting traffic) were above 40% when the system was activated, while there were only 50 out of 86 observations with system absence. These facts reinforce the preliminary conclusion from the simple comparisons between with and without the ATIS in previous sections.

Regression Analysis for Diversion

Preceding analyses uncovered that the exiting traffic after work zone presence was impacted by several factors, such as volume, congestion level indicated by displayed delay time, the number of days after the ATIS implementation, and exiting traffic before work zone presence. A linear regression analysis was conducted to investigate the relationship between the diversion and these factors. The linear regression model is expressed as follows:

\[
Y = \beta_0 + \beta_1 X_1 + \cdots + \beta_m X_m + \gamma_1 X_1 X_2 + \cdots + \gamma_{m-1} X_{m-1} X_m + \epsilon
\]

Where:
- \(Y\) – Proportion of exiting traffic with lane closures
- \(X\) – Predictor variables
- \(B\) – Coefficients for main factors
- \(\gamma\) – Coefficients for interaction factors
The delay time factor was treated as a dummy variable in the regression model and was categorized into two levels: less than 15 minutes and more than or equal to 15 minutes. The number of days after the ATIS factor was also a dummy variable. Freeway volume in 15-minute intervals and exiting traffic without lane closures were continuous variables. The purpose of the regression analysis was to identify the main factors as well as the interactions affecting exiting traffic. Further, the statistical model was developed to estimate the possible exiting traffic under a given work zone traffic condition, including volume (vehicles per hour) and displayed delay time. Regression results are presented in Table 7.

Table 7: Linear Regression Model Result

| Variable                           | Estimate | Std. Error | t value | Pr(>|t|) |
|------------------------------------|----------|------------|---------|---------|
| Constant                           | -0.893   | 0.288      | -3.102  | 0.002   |
| **Main Effect**                    |          |            |         |         |
| Volume (freeway)                   | 0.002    | 0.0006     | 3.384   | 0.000   |
| Delay level 2 (≥15 minutes)        | 0.392    | 0.18       | 2.172   | 0.031   |
| PCT of exiting volume (without lane closures) | 2.542    | 0.746      | 3.408   | 0.001   |
| **Interaction Effect**             |          |            |         |         |
| Volume × PCT of exiting volume     | -0.003   | 0.0015     | -2.453  | 0.015   |

Fit: Multiple R-Squared = 0.6195, Adjusted R-squared = 0.6042
Model Test: F-statistic [6, 149] =40.43, p-value: < 2.2e-16

As indicated in Table 7, the predictors with p-value less than 0.05 include the traffic volume, delay level, exiting traffic under conditions without work zones, and interaction between volume and exiting traffic under conditions without work zones, which indicates that the four factors significantly affected the exiting traffic with the ATIS presence. Recall that the delay level was treated as a dummy variable and the positive coefficient of delay level 2 (≥ 15 minutes) implied that longer delay increased the traffic diversion compared with shorter delay (< 15 minutes). This result corresponded with the ANOVA analysis and chi-square test and is consistent with the previous studies (Levison and Huo 2003, Horowitz et al. 2003)

**Work Zone Queue Analysis**

It was envisioned that the length of the queue might be shorter if more drivers chose alternative routes. Recall that the sensors were installed along the approaching area and the space of two adjacent sensors was either one-half or one mile. The approximate queue length was determined solely by where the traffic sensors were located. For instance, when observing a sudden drop of speed at one specific sensor location, it was assumed that the queue extended to or beyond the location of the sensor. The comparison of maximum queue length in 15-minute intervals for the ATIS presence (October 6) and absence (September 29) in the southbound direction is presented in Table 8. The number of 15-minute intervals with maximum queue length equal to or longer than 3.5 miles before the implementation was 12, while none of 15-minute intervals reached 3.5 miles after the implementation.
### Table 8: Maximum Queue Length in Southbound (Friday)*

<table>
<thead>
<tr>
<th>Time</th>
<th>Max Queue Length (miles)</th>
<th>Traffic Volume</th>
<th>Diversion Rate</th>
<th>Delay**</th>
<th>Max Queue Length (miles)</th>
<th>Traffic Volume</th>
<th>Diversion Rate</th>
<th>Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:30</td>
<td>1.5-3.5</td>
<td>458</td>
<td>24%</td>
<td>5</td>
<td>1.5-3.5</td>
<td>458</td>
<td>11%</td>
<td>5</td>
</tr>
<tr>
<td>14:45</td>
<td>3.5</td>
<td>469</td>
<td>30%</td>
<td>5</td>
<td>1.5-3.5</td>
<td>425</td>
<td>18%</td>
<td>6</td>
</tr>
<tr>
<td>15:00</td>
<td>3.5</td>
<td>473</td>
<td>8%</td>
<td>5</td>
<td>1.5-3.5</td>
<td>433</td>
<td>5%</td>
<td>4</td>
</tr>
<tr>
<td>15:15</td>
<td>3.5</td>
<td>475</td>
<td>32%</td>
<td>6</td>
<td>1.5-3.5</td>
<td>373</td>
<td>2%</td>
<td>5</td>
</tr>
<tr>
<td>15:30</td>
<td>3.5</td>
<td>455</td>
<td>24%</td>
<td>5</td>
<td>1.5-3.5</td>
<td>433</td>
<td>6%</td>
<td>5</td>
</tr>
<tr>
<td>15:45</td>
<td>3.5</td>
<td>658</td>
<td>44%</td>
<td>6</td>
<td>1.5-3.5</td>
<td>448</td>
<td>18%</td>
<td>4</td>
</tr>
<tr>
<td>16:00</td>
<td>3.5</td>
<td>543</td>
<td>34%</td>
<td>6</td>
<td>1.5-3.5</td>
<td>488</td>
<td>25%</td>
<td>4</td>
</tr>
<tr>
<td>16:15</td>
<td>&gt;3.5</td>
<td>518</td>
<td>34%</td>
<td>7</td>
<td>1.5-3.5</td>
<td>493</td>
<td>17%</td>
<td>4</td>
</tr>
<tr>
<td>16:30</td>
<td>&gt;3.5</td>
<td>520</td>
<td>34%</td>
<td>7</td>
<td>1.5-3.5</td>
<td>335</td>
<td>16%</td>
<td>4</td>
</tr>
<tr>
<td>16:45</td>
<td>&gt;3.5</td>
<td>463</td>
<td>14%</td>
<td>5</td>
<td>1.5-3.5</td>
<td>518</td>
<td>9%</td>
<td>4</td>
</tr>
<tr>
<td>17:00</td>
<td>3.5</td>
<td>533</td>
<td>33%</td>
<td>6</td>
<td>1.5-3.5</td>
<td>465</td>
<td>17%</td>
<td>5</td>
</tr>
<tr>
<td>17:15</td>
<td>&gt;3.5</td>
<td>543</td>
<td>32%</td>
<td>6</td>
<td>1.5-3.5</td>
<td>405</td>
<td>1%</td>
<td>4</td>
</tr>
<tr>
<td>17:30</td>
<td>&gt;3.5</td>
<td>508</td>
<td>24%</td>
<td>5</td>
<td>1.5-3.5</td>
<td>400</td>
<td>10%</td>
<td>4</td>
</tr>
<tr>
<td>17:45</td>
<td>1.5-3.5</td>
<td>433</td>
<td>16%</td>
<td>5</td>
<td>1.5-3.5</td>
<td>443</td>
<td>18%</td>
<td>4</td>
</tr>
<tr>
<td>18:00</td>
<td>1.5-3.5</td>
<td>413</td>
<td>12%</td>
<td>5</td>
<td>1.5-3.5</td>
<td>390</td>
<td>1%</td>
<td>4</td>
</tr>
</tbody>
</table>

* Bold fonts represent the maximum queue length exceeding the farthest detector
** Shaded values are estimated delay times which are not displayed to drivers

A similar process was applied to generate maximum queue length for northbound traffic shown in Table 9. With the ATIS presence on October 6, the queue never exceeded the farthest sensor location, which was 8.7 miles away from the work zone. The effectiveness of the ATIS was demonstrated once again by controlling maximum queue length within a given range.

### Table 9: Maximum Queue Length in Northbound (Friday)*

<table>
<thead>
<tr>
<th>Time</th>
<th>Max Queue Length (miles)</th>
<th>Traffic Volume</th>
<th>Diversion Rate</th>
<th>Delay**</th>
<th>Max Queue Length (miles)</th>
<th>Traffic Volume</th>
<th>Diversion Rate</th>
<th>Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>15:00</td>
<td>5.5-8.7</td>
<td>493</td>
<td>14%</td>
<td>21</td>
<td>5.5-8.7</td>
<td>541</td>
<td>42%</td>
<td>18</td>
</tr>
<tr>
<td>15:15</td>
<td>5.5-8.7</td>
<td>561</td>
<td>44%</td>
<td>18</td>
<td>5.5-8.7</td>
<td>582</td>
<td>45%</td>
<td>19</td>
</tr>
<tr>
<td>15:30</td>
<td>5.5-8.7</td>
<td>590</td>
<td>41%</td>
<td>17</td>
<td>5.5-8.7</td>
<td>555</td>
<td>39%</td>
<td>17</td>
</tr>
<tr>
<td>15:45</td>
<td>5.5-8.7</td>
<td>584</td>
<td>44%</td>
<td>18</td>
<td>5.5-8.7</td>
<td>640</td>
<td>47%</td>
<td>20</td>
</tr>
<tr>
<td>16:00</td>
<td>5.5-8.7</td>
<td>573</td>
<td>43%</td>
<td>21</td>
<td>5.5-8.7</td>
<td>644</td>
<td>59%</td>
<td>24</td>
</tr>
<tr>
<td>16:15</td>
<td>5.5-8.7</td>
<td>596</td>
<td>42%</td>
<td>18</td>
<td>5.5-8.7</td>
<td>589</td>
<td>42%</td>
<td>16</td>
</tr>
<tr>
<td>16:30</td>
<td>5.5-8.7</td>
<td>567</td>
<td>41%</td>
<td>13</td>
<td>5.5-8.7</td>
<td>622</td>
<td>30%</td>
<td>21</td>
</tr>
<tr>
<td>16:45</td>
<td>5.5-8.7</td>
<td>628</td>
<td>47%</td>
<td>18</td>
<td>5.5-8.7</td>
<td>634</td>
<td>42%</td>
<td>19</td>
</tr>
<tr>
<td>17:00</td>
<td>5.5-8.7</td>
<td>594</td>
<td>44%</td>
<td>20</td>
<td>5.5-8.7</td>
<td>678</td>
<td>51%</td>
<td>19</td>
</tr>
<tr>
<td>17:15</td>
<td>&gt;8.7</td>
<td>601</td>
<td>47%</td>
<td>22</td>
<td>5.5-8.7</td>
<td>651</td>
<td>59%</td>
<td>20</td>
</tr>
<tr>
<td>17:30</td>
<td>&gt;8.7</td>
<td>588</td>
<td>49%</td>
<td>23</td>
<td>5.5-8.7</td>
<td>601</td>
<td>40%</td>
<td>20</td>
</tr>
<tr>
<td>17:45</td>
<td>5.5-8.7</td>
<td>552</td>
<td>39%</td>
<td>24</td>
<td>5.5-8.7</td>
<td>666</td>
<td>30%</td>
<td>25</td>
</tr>
<tr>
<td>18:00</td>
<td>5.5-8.7</td>
<td>462</td>
<td>40%</td>
<td>23</td>
<td>5.5-8.7</td>
<td>616</td>
<td>50%</td>
<td>23</td>
</tr>
</tbody>
</table>

* Bold fonts represent the maximum queue length exceeding the farthest detector
** Shaded values are estimated delay times which are not displayed to drivers
Impact of Advance Speed Warning

Work zone crash facts show that the most common work zone crashes are rear-end caused by abruptly slow or stopped traffic (Hall and Lorenz 1996, Qin et al. 2007). As part of ATIS, the PCMSs and sensors collectively operated to inform drivers of the slow/stopped traffic in front of them so that they can be better prepared and adjust their speed accordingly. A two-phase message was displayed on the PCMSs according to the real-time traffic conditions (see study design section). A speed comparison was conducted to assess the effect of advance speed warning in controlling the speed in work zone approaching area. The impacts were measured by comparing the speed values between two sensors with the PCMS in the middle.

The southbound PCMS was 2.5 miles away from the work zone taper and placed between southbound sensor 3 (1.5 miles away from the work zone) and sensor 4 (3.5 miles away from the work zone). One hundred eight speed samples (5-minute average) and the displayed messages during the sign activation were collected. The speed samples were further split into two groups by different messages. Additionally, 50 speed samples without any displayed messages were used as the baseline. The results shown in Table 10 present the speed reduction in three scenarios, including the baseline condition. Although it was not sufficient to conclude that speed reduction was completely correlated to the message, the speed sensor data did indicate that drivers received the warning messages.

<table>
<thead>
<tr>
<th>Display Message</th>
<th>Sensor 3</th>
<th>Sensor 4</th>
<th>Difference</th>
<th>STDV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null (Baseline)</td>
<td>60.8</td>
<td>64.3</td>
<td>3.6</td>
<td>4.0</td>
</tr>
<tr>
<td>Slow Traffic Ahead</td>
<td>61.2</td>
<td>66.1</td>
<td>4.9</td>
<td>5.5</td>
</tr>
<tr>
<td>Stopped Traffic Ahead</td>
<td>62.4</td>
<td>65.1</td>
<td>2.8</td>
<td>4.4</td>
</tr>
</tbody>
</table>

CONCLUSIONS

An advanced traveler information system was implemented in a bridge reconstruction project on I-39/90 in Wisconsin to mitigate work zone congestion and improve safety. Through the suite of detectors, PCMSs, computers and communication technologies, ATIS effectively communicated real-time traffic information to drivers, assisted them with objective decision making, and promoted the utilization of alternative routes.

Field comparison between ATIS presence and absence uncovered different diversion patterns in the northbound and southbound directions. The proportion of exiting traffic was irrelevant to the actual delay when there was no delay information while the proportion of exiting traffic increased as displayed delay time increased. It was further discovered that travelers may choose to stay in or join the work zone queue if the delay time was tolerable. A 15-minute delay tolerance was found in the study, which implies that only displaying delay time larger than or equal to 15 minutes may improve the system effectiveness. The discrepancy of exiting traffic with and without ATIS fostered further examination of traffic condition related variables and driver behavior, which may affect the proportion of exiting traffic. More investigations were performed to derive the relationship between diversion and other factors, including estimated delay level, freeway volume, number of days after system implementation, and exiting traffic before work zone presence. The regression analysis suggested that traffic volume and proportion of exiting traffic without lane closure significantly impacted diversion.

Other performance measures, such as maximum queue length, were used to test how the work zone can accommodate the demand challenge with the assistance of the delay time system. It can be observed that ATIS performed relatively effectively in controlling the maximum queue length while accommodating similar traffic in work zones.
As part of ATIS, one of the PCMSs was designated to disseminate the real-time advance warning message of traffic ahead to drivers. The warning message aimed to reduce the risk of rear-end crashes by alerting drivers of the slow or stopped traffic in front of them. The surrogate safety performance was measured by the speed reduction measured from two sensors with the PCMS in the middle. The speed sensor data did indicate that drivers received the warning messages.

References


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Yali Chen is a research associate in the Geography Department at the University of California, Santa Barbara. She graduated from the University of Wisconsin Madison, and her Ph.D. study focused on safety and operation in construction zones. After graduation, she conducted a few traffic impact studies using micro-simulation to evaluate the performance of roadway segments for proposed construction design alternatives. Currently, she is involved in developing the travel demand forecasting system, the Simulator of Activities, Greenhouse Emissions, Networks, and Travel (SimAGENT), for the Southern California Association of Governments (SCAG).

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Dr. Noyce is a member of the Institute of Transportation Engineers (ITE) where he serves as past-chair of the Pedestrian and Bicycle Council. He is also the ITE student chapter advisor at UW-Madison. Dr. Noyce chaired several NCHRP project panels and has conducted NCHRP research. He is the current chair of TRB’s AHB50 Traffic Control Devices Committee.
Pricing in Retail Gasoline Markets

by Scott Russell, B. Starr McMullen, Santosh Mishra and Andrew Stivers

Although fuel costs represent over half of the per mile cost of driving an automobile, vehicle miles traveled are relatively inelastic with respect to changes in gasoline prices. Thus, when there are large increases in gasoline prices as there have been on occasion over the past few years, there have been concerns raised regarding the possibility of anti-competitive behavior on the part of gasoline retailers. The purpose of this paper is to examine price-cost margins for retail gasoline stations in local markets and to determine whether movements in these margins indicate the presence of such behavior.

This study uses a unique proprietary data set from an extensive pricing survey that was collected twice weekly for 25 local markets in Oregon. Using a VAR specification, evidence of tacit collusion is tested for and found as indicated by downward price stickiness. Price leadership is observed in several markets, but this behavior is not found to have a significant impact on price-cost margins when compared with markets in which price leadership is not observed. This result supports the hypothesis that price leadership serves to signal price changes in the face of volatile costs in very competitive retail gasoline markets. Other factors, such as whether the firm was a known low-price firm, located in an isolated area, whether the firm was selling unbranded or branded gasoline, and whether the firm was located on an interstate exit, are found to be important and significant determinants of price-cost margins for retail gasoline stations.

INTRODUCTION

Although fuel costs represent over half of the per mile cost of driving an automobile, vehicle miles traveled are relatively inelastic with respect to changes in gasoline prices (CBO 2008). Thus, when there are large increases in gasoline prices as there have been on occasion over the past few years, there have been concerns raised regarding the possibility of anti-competitive behavior on the part of gasoline retailers.

When studying the gasoline industry, it is important to distinguish between retail gas stations and the major oil companies. In general, retail outlets are independently owned franchises that purchase wholesale gasoline from a major oil company. The focus of this study is on the retail market.

Increases in retail gasoline prices over the last few years have resulted in public outcry and questions as to whether these higher prices reflect some sort of anti-competitive collusion on the part of retail stations (Associated Press 2005). It is usually suggested that the tendency for retail gas stations to change prices together (often the same day) may mean that firms are setting price as a joint profit-maximizing monopoly. However, as Marvel (1978) observes, a retail gasoline cartel would be nearly impossible to sustain in most of these markets due to the highly informed gasoline consumer. A member of the cartel would be rewarded greatly by deviating from the monopoly price.

In a market where costs are highly volatile and firms may mistakenly interpret cost-based price changes for non-competitive price movements, price wars are a possible result. In this situation some form of tacit collusion may be a way for firms to clearly signal other market participants that a price change is cost based.

When firms tacitly collude, they are usually in a situation where competitors will quickly match price cuts, and thus try to avoid price reductions. Downward price stickiness has been used as an indicator of tacit collusion — although not necessarily market power. For example, Borenstein and Shepard (1996) argue that U.S. retail gas firms engage in tacit collusion as evidenced by the fact that
retail gasoline prices are sticky - slow to move in the downward direction, but quick to increase - a finding also consistent with that of Davis and Hamilton (2004).

In an effort to explain the root of sticky retail gasoline prices, several studies have examined the rate at which upstream cost shocks are realized in downstream markets. Borenstein et al. (1997) study the pass-through rates for cost shocks in the crude oil market as they trickle down to the retail gasoline market. They find asymmetry between the speed at which cost increases and decreases pass through nearly every transaction point between crude oil and retail gasoline prices. Prices are observed to respond quite quickly to increases in costs and to respond slower to cost decreases.

The intent of this study is twofold. First we test for a specific form of tacit collusion, price leadership, in individual retail gasoline markets in Oregon. Determinants of price-cost margins for such firms are then examined to see whether price leadership behavior has resulted in the exertion of market power. While the study finds that price leadership behavior is not significantly associated with price-cost margins, other factors, such as whether the firm is a known low-price firm, located in an isolated area, whether the firm was selling unbranded or branded gasoline, and whether the firm was located on an interstate exit, are found to be important and significant determinants of price-margins for retail gasoline stations.

Two things distinguish this paper from the research efforts of others. First, a proprietary data set of individual local retail gasoline markets collected by a multi-station, multi-branded retail gasoline firm operating in Oregon was made available to the researchers. This provides a unique perspective as the firm itself identified the firms it considered to be competitors in each market rather than relying on the researcher to infer which firms were competitors. Second, the empirical part of this analysis is the first to use a VAR specification to test for evidence of downward stickiness of prices and tacit collusion in the form of price leadership in retail gasoline markets.

The model used in this paper follows the sticky pricing literature as gas station managers react to changes in both wholesale gasoline prices and competitors’ price-cost margins. Model specification and the test method used for the presence of price leadership are explained in the following section.

MODEL SPECIFICATION

To motivate a model of tacit collusion and examine the industry in terms of price leadership, it is important to note that in retail gasoline markets, price, costs, and market demand are fairly transparent. Prices are easily monitored because gas stations post prices on large signs easily seen by motorists and rival firms. Cost information is readily available from private data companies that keep track of wholesale prices for all brands of gasoline. Slade (1987, 1992) argues that rival firms know demand for each station implicitly by monitoring the number of cars fueling at each station. While stations are well informed about each other’s activities, each retail gas station also enjoys some form of market power based on brand, location, service quality, and amenities (such as car washes or convenience stores) offered in addition to gas (Netz and Taylor 2002, Van Meerbeek 2003, Hastings 2004).

In a price leadership model, one firm takes the role of the price leader, and the other firm(s) takes the role of the price follower(s). It is implicitly agreed that all changes in price will be first made by the price leader and followed by the price follower(s). It is important for all price changes to be instigated by the price leader, or else this could lead to pricing wars in which firms undercut each other until they eventually arrive at zero economic profit Nash equilibrium where price is equal to marginal cost.

The retail gasoline market can be modeled following Slade (1987) where:

1. There are \( m \) firms in the market, and each firm knows every other firm’s costs.
2. Firms set price in each of \( n \) periods. The number of periods, \( n \), is infinite. A discount rate of \( \delta<1 \) ensures that the discounted value of the sequence of profits over time is finite.
3. Each firm knows the past history of prices for every firm in the market.
4. Each firm implicitly knows the underlying demand for each brand of gasoline for any vector of market prices. This demand is downward sloping, and of functional form:

\[ D_i(p, g(x)) \]

Where: \( D_i \) = the demand for station \( i \)'s gasoline.
\( p \) = the vector of \( m \) prices \( (p_1, p_2, \ldots, p_m) \), where \( p_i \) is included as the price of the \( i \)th station.
\( g(x) \) = function of consumer gasoline preference, assumed to be exogenous.

The inclusion of \( \overline{p} \) captures the extremely competitive nature of the gasoline industry across geographically contiguous areas. Because retail gasoline markets are local markets, they have to price in such a way as to keep customers from traveling to another market to buy gasoline. Since retail gas prices are very transparent to the consumer, they will likely travel to a different market to buy gasoline if \( p = \overline{p} \). For example, if the \( m \) firms were to attempt to set \( p = \) the monopoly vector of prices, \( p_m \), they would run the risk that \( p_m = \overline{p} \) and customers would simply refuse to buy gasoline from any station in the market.

Suppose that all firms attempt to maximize their stream of profits by solving the problem:

\[ \text{Max} \sum_{i=1}^{\infty} \pi_i \delta^i \]

\[ \pi_{i,t} = (p_i - c_i)D_i(p,g(x)) - F_i \]

Where:
\( \delta \) = Discount rate attached to future profits.
\( p_i \) = Price charged by firm \( i \).
\( c_i \) = Marginal cost of firm \( i \).
\( F_i \) = Fixed costs of firm \( i \).

Because equation (2) is a function of not only station \( i \)'s price, but all \( m \) prices in the market, oligopoly theory suggests that firms in a market such as this may be motivated to tacitly collude and to earn a higher profit margin on each gallon of gasoline. To simplify the argument, \( \delta \) is assumed to be a value that would make cooperative pricing worthwhile to all firms (Vives 1999).

Given that firms have nearly complete information regarding competitors’ prices, costs, and demand for all \( m \) brands of gasoline, one would expect station managers to take into account past history of rivals, along with their expected future actions. Because station managers expect their competitors to react to their own price changes, they must take these reactions into account before setting their own price.

In this study, current price-cost margins for each firm are modeled based on knowledge of past margins earned by all firms in the market. By modeling margin instead of price, only the non-cost based changes in price are captured since these are the types of changes that are most likely to be interpreted as a change from current pricing behavior. By defining margin as price less marginal cost, equation (3) can be rewritten as:

\[ \pi_{i,t} = (M_i)D_i(p,g(x)) - F_i \]

Where:
\( M_i \) = price less marginal cost for firm \( i \).

The traditional price leadership model suggests that firms assume the role of price leader and follower(s) through repeated interactions (Vives 1999; Besanko, Dranove, and Shanley 2000). Consider a model of price leadership where the strategic choice variable is price-cost margin. Firms
assume either the role of “margin leader” or “margin follower” based on repeated signaling and previous successful past tacit collusive efforts. Therefore, in a given the market with \( m \) competitors, each firm has self-selected itself into one of two categories: leaders or followers.

This price leadership can be tested empirically using the following vector autoregression (VAR):

\[
M_{i,t} = \alpha_i + \sum_{j=1}^{m} \sum_{k=1}^{3} \theta_{j,k} M_{j,t-k} + \Psi_i INC + \beta_i DEC + \epsilon
\]

- \( M_{i,t} \) = Margin of firm \( i \) at time \( t \), defined as \( p_{i,t} - c_{i,t} \)
- \( INC \) = Increasing Pacific Northwest Spot Price (Spot). Dummy variable equal to unity if \( \text{Spot}_{t} > \text{Spot}_{t-1} > \text{Spot}_{t-2} \)
- \( DEC \) = Decreasing spot trend. Dummy variable equal to unity if \( \text{Spot}_{t} < \text{Spot}_{t-1} < \text{Spot}_{t-2} \)
- \( \theta_{j,k} \) = parameter that captures the reaction of firm \( i \) to margin changes of each of the \( m \) firms for the \( k \)th period lag.
- \( \alpha_i \), \( \Psi_i \), and \( \beta_i \) are firm specific parameters to be estimated.
- \( \epsilon \) is a normal and i.i.d. error term.

Note that changes in the spot price of gasoline are used as a proxy for changes in retail gasoline station costs. Equation (5) is estimated for each of the \( m \) firms in each market.

To check for behavior compatible with tacit collusion sticky downward pricing is estimated by including dummy variables to signal whether input costs are trending upwards or downwards. If sticky downward pricing is present, the value of \( \beta_i \) is expected to be positive. This method of sticky price detection is similar to the approach used in studies such as Borenstein et al. (1997) and Borenstein and Shepard (1996, 2002). Borenstein et al. (1997) and others have suggested that margins may be lower when costs are increasing. If this is the case, \( \Psi_i \) should be negative. This would imply that there is implicit price competition stemming from station managers not wanting to be the first one to raise their price. Asplund et al. (2000) found that consumers were especially unreceptive to price increases, suggesting that firms may take a short-run loss (lower margin) to keep their customer base compliant.

The parameter that indicates price leadership behavior is \( \theta_{j,k} \). To illustrate the role of \( \theta_{j,k} \) in detecting potential collusion or otherwise, consider a simple two firm market and rewrite equation 4 omitting the other relevant regressors and control variables as follows:

\[
(4') M_{1,t} = \alpha_1 + \theta_{2,1} M_{2,t-1} + \epsilon_{1,t}
\]

The signs of \( \theta_{2,1} \) and \( \theta_{1,2} \) dictate the nature of competition in this market as illustrated by the following cases:

Case 1: \( \theta_{2,1} > 0 \) and \( \theta_{1,2} > 0 \): In this case each firm sets its margin following the lagged margin of the other firm. Thus, it is not possible to identify a market margin leader.

Case 2: \( \theta_{2,1} > 0 \) and \( \theta_{1,2} \leq 0 \): In this case margin changes by firm 2 are matched by firm 1 but not vice versa. This indicates price leadership by firm 2. Similarly, \( \theta_{1,2} > 0 \) and \( \theta_{2,1} \leq 0 \) would indicate price leadership by firm 2. Leaders are identified in different markets when estimates of \( \theta_{j,k} \) exhibit these patterns and are statistically significant.

Case 3: \( \theta_{2,1} \leq 0 \) and \( \theta_{1,2} \leq 0 \): In this situation there is no apparent strategic interaction between the firms. Here the price setting appears to be driven by reasons other than the margin movement of competitors. This case calls for a separate theoretical treatment of strategic interaction beyond the scope of this paper.
Each system of equations generated by (4) is inspected for price leaders and price followers in each market. If the $i$th firm is taking the role of margin follower, $\theta_{j,k}$ is expected to be positive and significant for the $j$th firm taking the role of margin leader.

**DATA DESCRIPTION**

This study uses a unique proprietary set of data on local market level gas prices in a sample of Oregon markets along with regional wholesale gasoline prices. The proprietary dataset was collected by a multi-station, multi-branded retail gasoline firm twice weekly to keep track of its competitors’ pricing trends. These data include retail stations in 25 geographic markets that the firm presorted into competitive markets and identified the other firms that it considered to be competitors. This is unique as the firm itself identified the firms it considered to be competitors in each market rather than relying on the researcher to infer which firms were competitors. These proprietary data were given for use under the condition that individual stations and markets were not to be named explicitly in this paper. Accordingly, individual firms are referred to as “1”, “2”, “3”, etc. and markets as “A”, “B”, “C”, etc.

The pricing survey was collected in each market every Monday and Thursday. Price survey data were collected for the entire study period in some markets (markets D, E, and F) but most markets had data collected for only a part of that time span (Table 1.)

Data on wholesale (spot) prices were obtained from the U.S. Energy Information Administration via special request. The Pacific Northwest spot price represents the average price of large volume wholesale gasoline transactions that took place each day. The Pacific Northwest spot price is used as a proxy for marginal cost for each firm since the cost adjustment period from spot gasoline to wholesale gasoline is nearly instantaneous (Borenstein et al. 1997). In reality, each firm has slightly different wholesale costs, but such cost information is unavailable for all firms. Following informal conversations with industry participants and also for simplicity, it is assumed that the relative markup of each brand (over wholesale) is constant for each period.

Daily margin is calculated by taking the daily price of the $i$th firm at time $t$ and subtracting the spot price at time $t$, along with a constant $0.464$ per gallon to represent per gallon transportation costs and taxes incurred by each firm. The sum of state and federal gasoline tax in Oregon was a constant $0.424$ per gallon for the time period for this study. According to the firm that supplied the pricing data, all stations located within these markets were charged a market rate of $0.04$ per gallon for delivery. Margin is therefore calculated as:

$$M_{i,t} = price_{i,t} - spot_t - 0.464$$

Where:

- $M_{i,t} =$ The margin of firm $i$ in time $t$.
- $price_{i,t} =$ The retail price charged by firm $i$ in time $t$.
- $spot_t =$ The wholesale price of gasoline in time $t$.
- $t =$ Monday and Thursday of each week.

By modeling margin, price changes that are made to keep a constant markup over cost can be distinguished from price changes that represent a higher (lower) margin. This approach is attractive because it lets us consider only price changes that are the most likely to be scrutinized by competing station managers in the markets. If managers are making cost-based changes, rival managers will likely not interpret these as either aggressive actions or signals that a new margin is being earned given the market demand.
**Table 1: Individual Market Data Set Summary**

<table>
<thead>
<tr>
<th>Market Code</th>
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<th>Observation Ending Date</th>
<th>Number of Observations</th>
<th>Number of Gas Stations</th>
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<tbody>
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</tr>
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<td>3</td>
</tr>
<tr>
<td>C</td>
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<td>9/26/05</td>
<td>207</td>
<td>4</td>
</tr>
<tr>
<td>D</td>
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<td>4</td>
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<tr>
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<td>276</td>
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</tr>
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<td>276</td>
<td>6</td>
</tr>
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<td>H</td>
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<td>276</td>
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<td>9/26/05</td>
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<tr>
<td>O</td>
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<td>3</td>
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<td>Y</td>
<td>10/23/2003</td>
<td>9/26/05</td>
<td>201</td>
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<td><strong>2/3/2003</strong></td>
<td><strong>9/26/05</strong></td>
<td><strong>5371</strong></td>
<td><strong>108</strong></td>
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</table>

**EMPIRICAL RESULTS**

The VAR (4) was estimated for 25 markets, resulting in 108 separate equations. (Results for each of the 25 individual markets available from the authors upon request.) In 24 of the 25 markets, dummy variables were statistically significant at the 5% level with the majority of the parameter estimates significant at the 1% level. The significance of the dummy variable DEC suggests that nearly every market exhibited some form of tacit collusion, as margins appear to be higher when costs are decreasing. Similarly, the significance and size of the estimated coefficient for INC suggests that firms are reluctant to raise price when costs are increasing. While individual markets are not directly comparable due to the different time periods for which data were available, stations generally earned an extra $0.05-$0.06 per gallon when costs were in a decreasing period and $0.04-$0.05 less when costs were in an increasing period.

These findings support the hypothesis that gasoline retailers engage in sticky downward pricing behavior as they earn higher margins in periods when costs are falling and margins are less when
costs are rising. These results are consistent with those of Borenstein et al. (1997), Borenstein and Shepard (1996, 2002), Slade (1987) and others.

Twelve of the 25 markets exhibited evidence consistent with price leadership as summarized in Table 2. No single brand of gas stood out as the margin leader in all markets. In fact, there are several cases of a brand being a margin leader in one market and a margin follower in another market. Consider markets P and B: Brand 7 is the price leader in market P, but in market B, Brand 7 is a follower of Brand 1. This should not come as a surprise as the manager of the station selling Brand 7 in market P is not likely to manage the station selling Brand 7 in market B.

Table 2: Markets Where Price Leadership Present

<table>
<thead>
<tr>
<th>Market A:</th>
<th>Market N:</th>
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<tbody>
<tr>
<td>Brands Present: 1, 2, 3, 4, 5</td>
<td>Brands Present: 1, 2, 4, 6, 7a, 7b, 9, 12</td>
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<tr>
<td>Leader Brand: Brand 2</td>
<td>Leader Brand: 9</td>
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<tr>
<td>Followers of Brand 2: 1, 3, 4, 5</td>
<td>Followers of Brand 9: 1, 2, 4, 6, 7a, 7b, 12</td>
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<tr>
<td></td>
<td>Followers of Brand 7a: 1, 2, 4, 6, 7b, 9, 12</td>
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<tr>
<th>Market B:</th>
<th>Market P:</th>
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<tbody>
<tr>
<td>Brands Present: 1, 4, 7</td>
<td>Brands Present: 1, 2, 7, 16</td>
</tr>
<tr>
<td>Leader Brand: Brand 1</td>
<td>Leader Brand: 7</td>
</tr>
<tr>
<td>Followers of Brand 1: Brands 4, 7</td>
<td>Followers of Brand 7: 1, 2</td>
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</table>

<table>
<thead>
<tr>
<th>Market F:</th>
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<tbody>
<tr>
<td>Brands Present: 1, 4, 6, 8, 9, 7</td>
<td>Brands Present: 1, 4a, 4b, 4c</td>
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<tr>
<td>Leader Brand: 4</td>
<td>Leader Brand: 4a</td>
</tr>
<tr>
<td>Followers Brand of 4: 1, 6, 7, 8, 9</td>
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<td>Leader Brand: 1</td>
<td>Leader Brand: 1</td>
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<tr>
<td>Followers of Brand 1: 4, 6, 7, 8, 9</td>
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<td>Followers of Brand 9: 1, 2, 7</td>
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<table>
<thead>
<tr>
<th>Market I:</th>
<th>Market X:</th>
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</thead>
<tbody>
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<td>Brands Present: 1, 6, 10</td>
</tr>
<tr>
<td>Leader Brand: 1</td>
<td>Leader Brand: 6</td>
</tr>
<tr>
<td>Followers of Brand 1: 2, 7</td>
<td>Followers of Brand 6: 1, 10</td>
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<td></td>
<td>Leader Brand: 1</td>
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<td></td>
<td>Followers of Brand 1: 6, 10</td>
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<table>
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<th>Market K:</th>
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<tbody>
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<tr>
<td>Followers of Brand 1: 1, 7, 14</td>
<td>Followers of Brand 1: 2, 4, 7</td>
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</table>

Each market had a margin leader with different characteristics. In some markets, the firm that earned the lowest average margin led the margin changes, while in other markets the firm with the highest average margin led the margin changes. Estimation results suggest that the brand of fuel sold is not important when choosing a margin leader; it seems to be the individual managers who dictate whether or not to establish margin leadership.

While some suggest that tacit collusion is more easily sustained as the number of firms in the market decreases (Vives 1999; Besanko et al. 2000), this does not appear to be supported by the results. There are some markets with relatively few gas stations that do not appear to be exhibiting
a leader-follower pattern, whereas other markets with relatively numerous stations exhibit leader-follower patterns.

Detecting collusive behavior is a useful first step, but policy makers should be more interested in whether or not this collusion leads to higher margins. If collusive behavior results in higher price-cost margins, then it could be classified as anti-competitive, and policymakers may wish to take a closer look to see whether some sort of government intervention might be called for to protect consumers. However, in the retail gasoline market it has been argued that collusion represents a way for market participants to signal cost changes in a volatile industry where price wars are an undesirable but possible outcome. In this second case, margins are not expected to be positively related to collusive behavior; rather the collusion is actually helping organize an essentially competitive market.

An examination of the determinants of price-cost margins is next conducted to see whether stations engaging in price leadership patterns earn a greater margin than stations that do not. Accordingly, a simple regression model is specified with the dependent variable defined as the average margin earned by each station and the independent variables represent station characteristics generally expected to influence price-cost margins.

\[ M_i = \beta_0 + \beta_1 \text{MAV} + \beta_2 \text{ISO} + \beta_3 \text{F} + \beta_4 \text{L} + \beta_5 \text{IS} + \beta_6 \text{MET} + \beta_7 \text{TT} + \beta_8 \text{UB} + \varepsilon \]

Where:

- \( M_i \) = The average margin of the ith station between 4/1/04 and 4/28/05. This date range is consistent for all markets.
- MAV = Dummy equal to one if station is a “maverick” brand, a well-known low-price firm, known as an aggressive pricer. (Eckart and West 2004a, b).
- ISO = Dummy equal to one if the station is located on the Oregon Coast.
- F = Dummy equal to one if the station exhibited a margin follower pattern.
- L = Dummy equal to one if the station exhibited margin leadership patterns.
- IS = Dummy equal to one if the station is located on an interstate exit ramp.
- MET = Dummy equal to one if the station is located in a city with population > 100,000.
- TT = Dummy equal to one if the station sells “top tier” branded gasoline (www.toptier.com).
- UB = Dummy equal to one if the station sells unbranded gasoline.

The regression results reported in Table 3 are consistent with what one would expect to find in the retail gasoline market: firms selling fuel with a perceived lower quality charge a lower margin than do other “major” brands of gasoline. This is indicated by the negative sign on the variable UB. Eckart and West (2004a, b) noticed that a certain “major” brand had a reputation of being the lowest priced gasoline. This firm is included in the regression as MAV for maverick since this particular brand engaged in cutthroat pricing behavior.

The variable TT is used as a quality indicator to test whether or not stations selling gasoline on the “top tier” list earn a greater margin when compared with other brands of gasoline that do not appear on the list. The fact that the coefficient on TT has a low level of significance suggests that this designation has not allowed “top tier” branded stations to earn higher margins.

The variable MET is used to capture two market effects on margins. First, MET captures the higher station density observed in the larger population regions. As station density increases, one would expect market power to decrease because there are more local competitors (Barron et al. 2008). Second, MET captures the additional benefit of lowering one’s price because there are more people living in large metropolitan areas so the expected gain from undercutting rivals increases. As expected, MET is negative, suggesting that the average margin earned in large cities is lower than average although the significance of this variable is low.
Table 3: Average Station Margin Regression Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>t-Statistic</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.1682**</td>
<td>0.0143</td>
<td>11.764</td>
<td>0.0000</td>
</tr>
<tr>
<td>MAV</td>
<td>-0.0845**</td>
<td>0.0171</td>
<td>-4.9281</td>
<td>0.0000</td>
</tr>
<tr>
<td>ISO</td>
<td>0.0727**</td>
<td>0.0143</td>
<td>5.0584</td>
<td>0.0000</td>
</tr>
<tr>
<td>F</td>
<td>0.0064</td>
<td>0.0088</td>
<td>0.7250</td>
<td>0.4701</td>
</tr>
<tr>
<td>L</td>
<td>0.0099</td>
<td>0.0121</td>
<td>0.8202</td>
<td>0.4140</td>
</tr>
<tr>
<td>IS</td>
<td>0.0383*</td>
<td>0.0167</td>
<td>2.2896</td>
<td>0.0242</td>
</tr>
<tr>
<td>MET</td>
<td>-0.0131</td>
<td>0.0089</td>
<td>-1.4777</td>
<td>0.1427</td>
</tr>
<tr>
<td>TT</td>
<td>0.0203</td>
<td>0.0124</td>
<td>1.6356</td>
<td>0.1051</td>
</tr>
<tr>
<td>UB</td>
<td>-0.0474**</td>
<td>0.0156</td>
<td>-3.0442</td>
<td>0.0030</td>
</tr>
</tbody>
</table>

* = significant at the 5% level  
** = significant at the 1% level

The variable ISO is used to capture the isolated nature of the coastal communities relative to the other cities in this sample. Because of the increased cost incurred by customers wishing to drive to an alternate market to purchase gasoline, one would expect the value of $\overline{p}$ to be larger in these cities, and therefore the average margin earned should be larger in coastal cities. Consistent with theory, the average margin earned by coastal stations is about $0.07 greater than other stations in the sample. As indicated by the positive coefficient on the dummy variable IS, stations located on an interstate highway ramp were also found to have significantly higher margins than firms located elsewhere.

The variables L and F were included to test whether or not firms exhibiting margin leadership or margin follower patterns were able to earn an average margin greater than that earned by firms not exhibiting this type of pricing behavior. Both estimates were statistically insignificant. This supports the hypothesis that the price leadership practiced in retail gas stations in Oregon is not being done in a manner that suggests the exercise of market power. Rather, such behavior seems to be more a form of tacit collusion used to stabilize pricing in a competitive market where costs are volatile.

CONCLUSION

This paper examines 25 retail gasoline markets in the Willamette Valley region of Oregon using a unique set of proprietary data and time series econometric techniques. Statistically significant evidence is found that firms in these markets are tacitly colluding in the sense they charge higher margins when prices are decreasing and lower margins when prices are increasing. This finding is consistent with previous studies involving tacit collusion and sticky pricing in gasoline markets.

Although evidence of price leadership is found in several markets, the results indicate that participation in this behavior does not significantly impact firm margins. However, other factors, such as whether the firm was a known low-price firm, located in an isolated area, whether the firm was selling unbranded or branded gasoline, and whether the firm was located on an interstate exit, are found to have a significant impact on margins.

Given the results found here for retail gasoline stations, there does not seem to be any pressing need for government intervention to protect consumers from monopoly pricing at the retail level. Indeed, it could be argued that the price leadership and tacit collusion observed in these markets
serve the purpose of sustaining market order and competitive results rather than causing the adverse impacts often associated with collusive behavior.

**Endnotes**

1. The fact that this is not a random sample of Oregon gasoline markets but only those selected as competitive means that we do not *a priori* expect to find evidence of non-competitive behavior. However, there is still the possibility of price leadership that is being exerted in these markets to coordinate price changes in the face of fluctuating costs.

**References**


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Public-Private Partnerships (PPP) in Transportation: An Analysis of Alternatives

by Anthony M. Pagano

Public-Private Partnerships (PPP) are in the forefront of approaches to funding transportation infrastructure improvements. Highlighted in the highway area by long-term leases of the Chicago Skyway and Indiana Toll Road, a variety of states are investigating the use of public private partnerships either as “Brownfield” leases like the Chicago and Indiana cases, or “Greenfield” Design, Build, Operate, Transfer arrangements. These and other PPP projects raise a variety of issues, including the length of the lease, toll escalation permitted, and use of funds. This paper develops a rationale for PPPs in transportation, evaluates several approaches to PPPs using this rationale, and analyzes some of the difficult issues that can surface.

INTRODUCTION

The world of public private partnerships (PPP’s) changed in the United States in 2004 with the Chicago Skyway long-term lease agreement. In exchange for an up front payment of $1.83 billion, the Skyway Concession Company comprised of Cintra and Macquarie Infrastructure Group will operate the facility for 99 years. This lease was followed in 2005 with the lease of the Indiana Toll Road. The deal involved an up front payment of $3.8 billion to the State of Indiana for the right to operate the road for 75 years, Ortiz and Buxbaum (2008). The City of Chicago has been pursuing a lease of Midway Airport. These types of deals are numerous in Europe and developing countries, but have not been used very much in the United States. This paper develops a rationale for PPPs in transportation, evaluates several approaches to PPPs using this rationale, and analyzes some of the difficult issues that surface.

THE RATIONALE FOR PUBLIC INVOLVEMENT IN TRANSPORTATION DECISIONS

In order to understand the rationale for public-private partnerships in transportation, it is necessary to begin with an understanding of the rationale for public involvement in transportation decisions. To begin, it is necessary to make a distinction between government involvement in transportation decisions and public provision of transportation facilities and services. Government involvement does not mean that government must actively develop and operate transportation facilities. A variety of reasons can be cited for government involvement in transportation decisions. These reasons center on market failure in transportation markets. This means if left to the private sector only, transportation services would not be produced in socially optimal amounts.

One reason for government involvement concerns the nature of transportation markets. Either because of institutional reasons, the lumpiness of productive factors used to produce transportation, or because of decreasing costs with greater density along given routes, free entry into the production of transportation facilities and services may be precluded to the point that monopoly may result. Without governmental involvement, market forces may fail to provide an optimal allocation of resources to transportation. Exclusive private provision may result in only one or a few providers, producing a level and quality of transportation services that is less than desirable.

A second reason concerns the externalities resulting from transportation, both positive and negative. These include land use impacts, economic development impacts, and air, noise, and water pollution, among others. If left solely to private providers, the social costs and benefits of transportation may not be fully taken into account.
Public-Private Partnerships

To the extent that transportation services are public goods, then public involvement in transportation decisions can be justified as a third reason. Public goods have two characteristics which result in lack of private supply in adequate amounts. The first characteristic is non-exclusion. Individuals can be excluded from the consumption of private goods provided by the free market if they do not pay for them. The characteristic of non-exclusion means that if private business would attempt to supply public goods, they could not obtain payment from all consumers of the service. Although altruism may motivate some businesses, the lack of adequate revenues is a powerful deterrent to private provision of transportation services.

The second characteristic of public goods is joint supply. This means that if the good or service is provided to one individual, it is jointly provided to everyone. The marginal cost of supplying one additional consumer is very low or zero. If price is set equal to marginal cost, private provision would not be forthcoming.

Other reasons for government involvement include the high risk and payback periods associated with large transportation projects, equity considerations (providing access to employment opportunities, shopping, and other opportunities), and the mobility options provided by access to alternative modes of transportation.

These reasons suggest that government should be involved in decisions concerning transportation facility and service levels. The public sector may need to subsidize some services. It should also participate in the planning and coordination of such services.

RATIONALE FOR PUBLIC PRODUCTION OF TRANSPORTATION SERVICES

While a case for government involvement in transportation decisions can be made, it is less obvious why government should be involved in the actual production of transportation services.

First, some functions require such elaborate supervision that even if they were produced by private firms, the situation would be the equivalent of public production. In his classic book on public finance, Musgrave (1959) cites the operations of military establishments and the administration of justice as examples. Services such as these require close control on the part of the electorate or representatives of the people in a democratic society. However, transportation is not quite like the military, police, or the courts. The necessity for close supervision does not seem to be a valid reason to justify public operation of transportation facilities.

A second reason for public production of transportation services concerns the problems of natural monopoly. Public production is an alternative to regulated or unregulated private monopoly. This justification rests on the premise that public production results in better outcomes than the other two alternatives. It is a matter of judgment whether this premise is correct.

Inertia may also explain why some services are produced in the public sector. Education and the postal monopoly are good examples.

As can be seen from this discussion, public production of services in general, and production of transportation services in particular, may not be justified in many situations.

RATIONALE FOR PRIVATE SECTOR INVOLVEMENT

An important question to ask is why would private sector involvement be more desirable? The answer centers on the two types of efficiency. Allocative efficiency exists if resources are devoted to the highest value in use. In the case of transportation, allocative efficiency exists if the amount and quality of transportation produced is at an optimal level. Allocative efficiency thus concerns what and how much to produce. The previous discussion of why government should be involved in transportation decisions involves allocative efficiency.

The second type of efficiency is called productive, managerial, cost or X-efficiency in Leibenstein’s (1966) terms. Efficiency in this sense implies that production is maximized for a given level of inputs.
This type of efficiency is concerned not with how much to produce, but rather with how to produce it. A given level of transportation is provided efficiently in this sense if production costs are minimized.

In the private sector, competitive forces and the desire to maximize profit and stay in business provide incentives for firms to achieve this second type of efficiency. In a purely competitive situation, only those firms that have maximized cost efficiency can survive.

In the public sector, on the other hand, the incentives to achieve efficiency in the provision of public services are indirect. Incentives are provided through the political system by voters, legislators and appointed commissions. If efficiency in the provision of these services is not achieved, then this indirect process may take some time to make adjustments. In many situations, adequate adjustments may never be made.

This indirect process may involve voting a party or elected official out of office. However, many issues are usually involved in a decision as to which candidate to vote for. Waste and inefficiency in the provision of public services may be hidden under an array of other problems and issues. The process may also involve legislatures passing laws which attempt to provide incentives for the efficient administration of government programs. However, dedicated public administrators must implement these laws and deal with an entrenched bureaucracy protected by civil service status. This bureaucracy may remain largely unaffected by attempts to streamline public programs.

Special commissions perform studies and make recommendations to produce government services more efficiently. However, in many cases these reports seem to end up on a bookshelf rather than being implemented. The problem is that the direct incentives of profit, loss, and competition in the private sector are not present in the public sector.

RATIONALE FOR PUBLIC-PRIVATE PARTNERSHIPS

This discussion suggests that a combination of public-private sector involvement in transportation would result in a better achievement of both types of efficiencies. If sole reliance is placed on the private sector, market failure may result. Allocative efficiency may not be attained. If sole reliance is placed on government to provide transportation services, cost efficiency may not result.

However, if the public sector maintains a role in transportation such as planning, coordination, and possibly subsidy, and the private sector is used to actually operate the system, then possibly both types of efficiency could be attained. This is especially true if private sector partners can be obtained through competitive markets or a competitive bid process.

This public-private partnership is what Osborne and Gaebler (1993) called Steering vs. Rowing. In their view, government and the private sector should specialize in what each sector does best. Government is best at steering – deciding what to produce, how much to produce, and allocating resources to production. The private sector is best in actually producing the service. Each sector specializes in its core business function.

There are other rationales for public-private partnerships that include capital shortages of financially strapped jurisdictions, ability to access value in the facility, the ability to raise tolls independent of political considerations, and transfer of risk from the public sector to the private. For details on the kinds of risks that can be transferred see FHWA (2007). The implementation of a PPP based on these rationales may also have an effect on both allocative and cost efficiency potential.

TYPES OF PUBLIC-PRIVATE PARTNERSHIPS

There are a variety of public-private partnerships that have been practiced in transportation. Some are designed to achieve the allocative and X-efficiency goals outlined above. Others, however, may have far different motivations. Table 1 shows a categorization of alternative public-private partnership approaches to the provision of transportation services. This table shows broad categories of approaches. Within each category, there could be several alternative ways in which the public and private sectors interact.
### Table 1: Alternative Public-Private Partnership Approaches in Transportation

<table>
<thead>
<tr>
<th>Approach</th>
<th>Private Sector Role</th>
<th>Public Sector Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Design Build</td>
<td>Design and Construction of Facility</td>
<td>Planning, Operation and Subsidy of Facility</td>
</tr>
<tr>
<td>2. Build, Operate Transfer (BOT) or DBOT – Greenfield Concession</td>
<td>Build, Operate, Finance, Maintain, Transfer</td>
<td>Negotiation with private companies, regulation, contract enforcement, quality assurance</td>
</tr>
<tr>
<td>3. Long Term Lease of Existing Facility – Brownfield Concession</td>
<td>Finance, Operate, Maintain, Transfer</td>
<td>Negotiation with private companies, regulation, contract enforcement, quality assurance</td>
</tr>
<tr>
<td>4. Competitive Contracting</td>
<td>Operation and Maintenance</td>
<td>Negotiation with private companies, regulation, contract enforcement, quality assurance, subsidy</td>
</tr>
<tr>
<td>5. Asset Sales</td>
<td>Finance, Operate, Maintain</td>
<td>Negotiation with private companies or no role</td>
</tr>
<tr>
<td>6. Vouchers</td>
<td>Finance, Operate, Maintain</td>
<td>Negotiation with private companies, subsidy, quality assurance</td>
</tr>
<tr>
<td>7. Deregulation</td>
<td>Build, Operate, Finance, Maintain</td>
<td>None</td>
</tr>
<tr>
<td>8. Publicization</td>
<td>Build, Operate, Finance, Maintain</td>
<td>Planning, Subsidy</td>
</tr>
</tbody>
</table>

The first approach is Design-Build. The private sector designs and constructs the new facility. The public sector role is planning, operation, and subsidy of the facility. This is the classic approach to public-private partnerships by which most of the highway system in the United States was constructed.

The second approach is Build, Operate Transfer (BOT) or Design, Build, Operate Transfer (DBOT). In this approach, the private sector builds, operates, finances, and maintains the facility, and then over a period of years, transfers the facility to the public sector. This is called a “Greenfield Concession” since a brand new facility is built. There are a variety of roles that the private sector can play in this type of PPP. The private sector can finance the facility or financing can be done by the public sector. One important question is should these roles be performed by the same or different firms. Marimort and Pouyet (2008) analyze whether building infrastructure and managing assets should be bundled or not. They conclude that a technology-driven reason is the basis for this decision.

The public sector is involved in negotiation with private companies, possible regulation of prices, contract enforcement, and quality assurance. This approach has been widely used in developing countries where there is a capital scarcity. The length of the concession can vary up to 99 years. Most typical are concessions that last for 30–50 years. Details on various alternatives within this approach can be found in Buxbaum and Ortiz (2009).

A long term lease of an existing facility, called a “Brownfield Concession,” is the third approach. This is the approach that has gained much notoriety after the leases of the Chicago Skyway and the Indiana Toll Road. The possible lease of Midway Airport is also this type. The Chicago Skyway lease was the first in the United States. This type of PPP has raised many questions, which will be discussed later in this paper.

Competitive Contracting is the fourth approach. In this approach, the public sector contracts with the private sector to operate and maintain a service. The public sector is involved in negotiation with the private sector, regulation, contract enforcement, quality assurance, and subsidy of the service. This type
Public-Private Partnerships

of PPP is prevalent in public transit throughout the country, including service in Denver, Phoenix, Los Angeles suburbs, and Chicago suburbs. Much of the paratransit service in the United States is provided through this approach. For a discussion of a variety of contracted services in transit see Richmond (2001).

The fifth approach is Asset Sales. This approach is used to privatize State Owned Enterprises (SOE). The private sector takes the role of financing, operating, and maintaining the facility. The public sector role is either to negotiate a sales price with private companies or no role. There are two types of asset sales. One is a Citizen Share Purchase, in which the asset is sold to an individual company or shares are sold in the marketplace. In this approach, the government keeps all the proceeds from the sale. The privatization of Conrail was done in this manner. The second approach is called “Voucher Privatization” by Pool (1996). In this approach, the SOE is privatized by distributing shares to citizens of the country. Citizens are free to sell or keep their shares. In this case, the proceeds from the sale accrue to individuals rather than to the government. British Columbia used this approach in the privatization of its state-owned forest products and natural gas companies. Pool (1996) notes that this approach was also used by the Czech Republic in privatizing its SOEs. Asset sales are similar to “Brownfield Concessions,” except the facility is permanently transferred to the private sector.

The next PPP approach is Vouchers. In this approach, vouchers are provided to users of the service to purchase the service from private operators. Private companies are responsible for all aspects of their service, while the public sector negotiates with the private companies on the basis of price and quality of service. The public sector also subsidizes the service and monitors quality. This approach has been used extensively in paratransit operations in the United States and in school vouchers in several cities.

In Deregulation, the public sector allows private competition with a formerly monopoly public sector operation. The private sector is responsible for all aspects of their service, while the public sector plays no role in the private sector operation. The U.S. postal service, which allows competition from FedEx and UPS for overnight and package delivery, is a good example of this approach. While not necessarily a public-private partnership, the private sector competition can result in the public sector becoming more efficient and effective in the provision of its services.

The last PPP approach can be called “Publicization.” In this approach, the public sector becomes involved in what was an exclusive private operation. Publicization is not nationalization, since there is a very large role played by the private sector. Examples include the CREATE project in Chicago, where the public sector is working with the railroads to reduce time spent in the Chicago terminal, and the Wisconsin and Southern Railroad in Wisconsin, in which the state has acquired the trackage on which the private railroad operates. Other examples include the Alameda Corridor project in Southern California, the BNSF Flyover in Kansas, the FAST project in the state of Washington, and the Sauk Village Logisticenter development in suburban Chicago. In each of these cases, the public sector has become involved in what has traditionally been a strictly private sector endeavor to build, maintain, and operate freight transportation infrastructure. Also included in this category are various approaches to transit-oriented development and joint development agreements.

Other PPP approaches are strictly financial, such as Business Improvement Districts (BID), which involves assessing businesses which are adjacent to a transportation development, and Tax Increment Financing (TIF), in which increased property tax revenues pay for current infrastructure investment (FHWA 2007).

EVALUATION OF THE ALTERNATIVE APPROACHES

Given the variety of alternative public-private partnerships, the next question is how well do each of these achieve society’s transportation goals. In order to answer this question, each approach is analyzed for its potential in achieving allocative and cost efficiency. This potential may or may not be achieved in practice. However, it is more likely that efficient operations would result if a high potential approach were implemented, rather than one with poor potential. The results of this analysis are shown in Table 2.
Table 2: Evaluation of Public-Private Partnership Approaches in Transportation

<table>
<thead>
<tr>
<th>Approach</th>
<th>Allocative Efficiency Potential</th>
<th>Cost Efficiency Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Design Build</td>
<td>Excellent</td>
<td>Poor</td>
</tr>
<tr>
<td>2. Build, Operate Transfer (BOT) or DBOT – Greenfield Concession</td>
<td>Depends on Specifics of the Contract</td>
<td>Excellent</td>
</tr>
<tr>
<td>3. Long Term Lease of Existing Facility – Brownfield Concession</td>
<td>Depends on Specifics of the Contract</td>
<td>Excellent</td>
</tr>
<tr>
<td>4. Competitive Contracting</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>5. Asset Sales</td>
<td>Good – Depends on Details</td>
<td>Good</td>
</tr>
<tr>
<td>6. Vouchers</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>7. Deregulation</td>
<td>Excellent</td>
<td>Good to Poor</td>
</tr>
<tr>
<td>8. Publicization</td>
<td>Excellent</td>
<td>Good</td>
</tr>
</tbody>
</table>

The potential for an approach to achieve allocative efficiency would be present if the alternative has a strong potential to achieve an optimal allocation of resources to transportation services. This includes the potential to take externalities into account in production decisions, the public goods nature of some facilities, and the avoidance of private monopoly. In addition, allocative efficiency results if equity considerations can be dealt with and if the approach can provide a funding mechanism for large, risky projects with long payback periods. Cost efficiency potential is present if the implementation of an approach results in the creation of incentives to be efficient.

Each of the approaches is ranked as excellent, good, or poor in potential to achieve these efficiencies. For allocative efficiency, excellent implies that implementing an approach will most likely lead to effective use of resources in transportation. The socially desirable amount and type of transportation has the best chance of being achieved under these alternatives. Allocative efficiency is ranked as good if the alternative can lead to a social optimum in transportation, but this really depends on the details of the contract between the public and private sectors.

A cost efficiency potential is ranked according to the extent to which incentives to be efficient are present in an alternative. Excellent implies that market mechanisms are operating efficiently in that alternative. Alternatives ranked as good imply that the market may have an effect on cost efficiency, but other factors such as monopoly provision may hinder cost efficiency goals. Those ranked as poor imply that political rather than market mechanisms determine the efficiency of delivery of services.

The traditional approach, Design Build, involves the public sector actually planning, operating, and subsidizing the facility. The private sector role is design and construction of the facility. The allocative efficiency potential is excellent since the public sector can deal with externalities, public goods effects, and equity. However, the cost efficiency potential is quite low. The incentives to be efficient are indirect with this approach.

Greenfield Concessions have been used for many years in less developed countries. They directly deal with the problem of capital scarcity by being able to access private capital markets. The cost efficiency potential is excellent since the incentives of the marketplace are at work in this approach. However, the allocative efficiency potential depends on the specifics of the contract with the private sector. This is also the case for the Brownfield Concession approach. However, both of these approaches raise many troubling issues which must be dealt with. In the next section of this paper, several of these issues will be discussed.

Approach 4 is competitive contracting. This approach has an excellent potential to achieve both types of efficiencies. The public sector can take a large role in planning services, internalizing external
effects, and taking equity considerations and other allocative efficiency effects into account. Relying on competitive bids, inefficient operators would be underbid by better managed firms. As long as many operators are competing, the potential for cost efficiency is excellent.

Asset sales have a good chance of achieving both allocative efficiency and cost efficiency goals. However, like Greenfield and Brownfield Concessions, the devil is in the details. If the sale results in monopoly private operation of the facility, then cost efficiency goals may not be fully obtained. However, if the SOE is highly inefficient, with many layers of bureaucracy and unneeded workers and infused with corruption, then a private monopoly may be preferable. Allocative efficiency potential depends on a variety of details, including the amount and type of government regulation.

Since Vouchers rely on the public sector to do the “Steering” and the private sector to do the “Rowing” the potential for achieving both allocative and cost efficiency goals are excellent.

Deregulation, approach 7, can lead to excellent allocative efficiency potential since both the private sector and the public sector are providing the service. However, since the public sector is providing a competing service, cost efficiency can suffer because of the lack of incentives for the public sector operation to be efficient, especially if the public operation is subsidized.

Finally, Publicization has the potential to achieve allocative efficiencies since the public sector involvement can take a variety of external effects into account, including economic development and pollution. Cost efficiency potential is good since the private sector is still very actively involved in the provision of service.

**SOME DIFFICULT ISSUES**

There are many difficult issues that must be dealt with in the implementation of PPPs. In this section of the paper, a few of these issues will be discussed. This is not a comprehensive list. The focus is on problems that affect Greenfield and Brownfield concessions.

**Length of the Contract Period**

The first issue concerns the length of the contract period. This is especially the case for Brownfield Concessions. The Chicago Skyway concession is for 99 years. The Indiana Toll Road contract period is 75 years. The Midway Airport concession was proposed to last for 99 years. Private companies prefer a longer payback period for two reasons. One is that the company has a longer period in which to earn revenues to offset the initial investment. Second, for tax purposes, the IRS treats such a long term lease as ownership of the facility. The company can then depreciate investments as if they own the facility. So, private sector risk is reduced the longer the length of the contract.

From a public sector standpoint, the longer the contract period, the more likely the facility will be able to generate higher up front payments. But there is a risk involved for longer contract periods. There are many societal, technological, and developmental changes that can occur in 99 years. Suppose a facility was leased in 1910, with a 99-year lease, coming due in 2009. The United States is fundamentally different in almost all aspects over those 99 years. A facility that was leased in 1910 could stand in the way of new development today. So could be the result in 2108, when a 99-year lease written today would be completed. The public sector may have new uses for the facility that may not be easily implemented if it is in private hands. This risk can be mitigated through the use of contract language that gives the public sector the right to purchase the lease at fair market value in the future. This, however, may lower the amount that firms would be willing to pay up front. Additionally, in the long term, technology or development patterns may make the facility obsolete. This could affect the private sector risk in the later years of the lease as well.

The private firm that is leasing the facility would prefer a longer contract period to a shorter one. However, the present value of earnings far in the future will be less than near-term earnings. Thus, the private profitability curve flattens out over very long contract periods. The present value of the future income stream can be greater, the greater the amount of cost efficiency savings from private ownership.
Public-Private Partnerships

To the extent that the public sector can bargain away some of these savings, the initial lease payment will be larger and the time that it takes to recoup the lease payment will be longer.

To simplify the analysis, let us assume an initial lease payment with constant revenues and operations costs each year. Then let:

- \( L \) = the lease payment
- \( R \) = yearly revenues from the lease
- \( C_f \) = yearly costs of operating the facility for the firm
- \( n \) = length of the contract period
- \( r \) = appropriate private sector discount factor
- \( t \) = time

\[ TP_n = \text{Present value of profit stream to be derived from operating the lease over } n \text{ years} \]

Then:

\[ TP_n = \sum_{t=1}^{n} \frac{R - C_f}{(1 + r)^t} - L \]

The total profit that accrues to the private company leasing the facility is a transfer from road users to the company. It can be considered the total social cost of the lease. This is not the social cost of operating the facility. Rather, it is the social cost of leasing the facility to a private company. This is shown in Figure 1 as \( TP_n \). As shown in the figure, the present value of the total profits to be derived from leasing the facility increases at a decreasing rate, reflecting the declining present value of profits over time. Point B in the figure is the breakeven number of years of the lease.

**Figure 1: Present Value of Future Private Sector Profits from Lease**

A reasonable approximation to the marginal profits accruing to the firm of leasing the facility for one more year is:

\[ MP_t = \frac{R - C_f}{(1 + r)^t} \]
This is shown in the figure as MP<sub>t</sub>. Marginal profits, and thus the marginal social cost of leasing the facility, decline over time. In making decisions as to the total upfront lease payment, and the length of the contract period, the private sector firm would use this function in the process of negotiation.

The marginal social cost of a private firm operating the facility for one more year is equal to the marginal profits plus the yearly cost of operation. So:

\[ MSC_t = \frac{R}{(1 + r)^t} \]

Society benefits from the operation of the facility. Initially, the public sector receives the lease payment \( L \) from the private company. This payment could include any cost efficiency gains that are bargained away from the private contractor. In addition, there is the continuation of an allocative efficiency gain from continual use of the facility. However, this allocative efficiency gain declines over time. The allocative efficiency gains are discounted by the appropriate social rate of discount and by a risk factor as alternative uses for the facility develop. Thus, the total public sector benefit curve declines over time as the length of the contract is extended. To simplify, assume the allocative efficiency gains are a constant amount over time, and that the social discount factor is the same as the private sector discount factor. Then:

\[ SB_n = \sum_{t=1}^{n} \frac{AE}{(1 + r + U)^t} + L \]

where:
- \( SB_n \) = Total Social Benefits from leasing the facility
- \( AE \) = Allocative Efficiency gains from the use of the facility
- \( U \) = Public sector risk factor

Then the marginal social benefits of leasing the facility are given by:

\[ MSB_t = \frac{AE}{(1 + r + U)^t} \]

Marginal social benefits and costs are shown in Figure 2. Initially, allocative efficiency benefits from the use of the facility are greater than the private sector costs of operation of the facility. Otherwise, the facility would be abandoned. Both benefits and costs of operation decline the longer the facility is operated. This is shown as the declining curves in the figure. However, as displayed in the figure, \( MSB_t \) declines at a faster rate than \( MSC_t \), reflecting the public sector risk factor. If the public sector risk factor is very low, the two functions may not intersect for many if not hundreds of years. In that case, the facility is best sold to the private sector as an asset sale.

The optimal length of the contract is shown as the intersection of these two lines, LC. If the length of the contract is less than this, it would be advantageous to expand the contract length. Contract periods greater than LC would involve a social loss. Depending on the public sector risk factor, contract periods of 75 – 99 years may not be socially desirable. For example, PIROG has argued that contracts should be no longer than 30 years (Baxandall 2007). While this may be too short for some concessions to break even, it indicates that the longer contract periods may not be beneficial. Ortiz and Buxbaum (2008) note that in other countries, concession agreements are typically for 30–40 years.
The Chicago Skyway concession agreement allows for toll increases after the first five years. The increases can be at the highest of 2% per annum, increase in the CPI or increase in nominal GDP (Enright 2006). Each of these possible toll increases results in a different revenue stream for the private contractor and thus a different marginal social cost function. This is shown in Figure 3. In the figure, it is assumed that nominal GDP growth is greater than the CPI, which is greater than 2%. The greater the toll increases allowed, the greater the total revenues generated and the shorter the optimal contract period. If traffic grows at faster rates, thus generating more revenues, then the optimal length of the contract would be less. However, increases in traffic may also result in increased operating costs, thus changing the cost function.

This analysis assumes that public sector decision makers attempt to maximize social welfare. This may not always be the case. Maskin and Tirole (2008) consider situations when government officials have preferences that differ from those of a social welfare maximizer, such as preference for pork barrel projects. They develop a model to analyze the implications of these situations and suggest ways in which the negative effects on social welfare can be minimized.

Use of Funds from Initial Lease Payment

If a Greenfield Concession is implemented, the initial costs of the project are utilized to design and build the planned facility. Brownfield Concessions are different. A large upfront lease payment is made to the government entity by the private company. The government entity could use the proceeds for other transportation improvements or to pay for general government. There is a tendency to view this large payment as a windfall to be used to balance budgets, pay down debt, or fund new government services.

In the case of the Chicago Skyway, proceeds were used to repay project debt, create reserve accounts, and provide for programs unrelated to transportation. The Indiana Toll Road proceeds were completely dedicated to funding a 10-year transportation capital program (FHWA 2009).

The lease payment must be paid back to the private company over time by users of the facility. If it is used to finance transportation improvements, then users of the facility help to finance improvements elsewhere in the system. On the other hand, if the proceeds are used for general government, then users of the facility in the future will pay for general government today. This is an intergenerational transfer.
that may not be socially desirable, especially since users of the facility years hence have no say in the matter.

**Non-Compete Provisions**

Several of the contracts have non-compete provisions, giving the private sector contractor a monopoly over the provision of the service. The inclusion of these provisions is a two-edged sword. On the one hand, some of the market power that is transferred to private hands can be bargained away and may result in larger upfront payments, especially for Brownfield Concessions. On the other hand, such market power can lead to much higher tolls over time. Thus, it may be necessary to counter such provisions with strict price regulation, which carries a whole host of problems which are well documented in the public utility literature.

In the case of the Chicago Skyway, alternative routes currently exist, but are very circuitous. The existence of these routes would tend to keep a cap on toll increases. There are several alternatives to Midway Airport, including O’Hare, Mitchell Airport in Milwaukee, and Gary Airport, which currently has no commercial service, but could host such service in the future. The Peotone Airport, which has been a source of contention for many years, could also serve as an alternative. Thus, there exists much potential competition for a Midway Airport concession outside the city of Chicago. There are slower, but more scenic alternatives to the Indiana Toll Road, so competition already exists. Thus, in these three cases, non-compete provisions would have little or no practical effect.

**Facilities Requiring Subsidy**

Public transit offers unique problems with regard to PPPs. These facilities usually require subsidy, so it would not seem feasible to ask private operators to engage in a long-term concession and pay an upfront fee. After all, who would pay to operate a money-losing facility? The usual approaches in public transit are competitive contracting or vouchers, in which the private operator receives compensation from the public transit provider to operate routes or facilities.
One approach that has been used in the United Kingdom is an “Availability Payment.” The private company is responsible for one or more functions of design, build, finance, operate and maintain a “Greenfield” project. In return, the public agency provides a monthly payment to the company during the operations and maintenance phase of the project. In the United States, this approach has been used in the Port of Miami truck tunnel project. The FTA has selected three cities (Denver, Houston, and Bay Area) to implement such PPP projects (Fishman 2009).

There are possibilities for other forms of PPPs in public transit as well. One alternative is for the private company to pay an upfront fee to the public transit provider to operate an existing route or facility for a certain number of years. The private operator could either control the fares charged with government vouchers for low income riders, receive an agreed upon shadow fare for each customer served, or receive an availability payment. A shadow fare is a payment to the private operator usually on a per rider basis as compensation for providing the service. Typically, it would exceed the actual fare collected. Shadow fares provide an incentive to increase ridership.

Such approaches have not been tried in the United States, but may offer many of the benefits of PPPs to transit.

CONCLUSIONS

Public-private partnerships offer the prospect of achieving desired social benefits of transportation in the most efficient manner possible. The planning, coordination and possibly subsidy provided by the public sector is combined with the incentives of the free market. There are a variety of approaches to PPPs that have been implemented either in the United States or in other countries. Most offer outstanding prospects of achieving both allocative and cost efficiency goals. The most problematic approach is the “Brownfield Concession,” which is most well known today. However, with carefully crafted agreements, shorter contract periods, and upfront payments that are used to enhance transportation, such an approach can also achieve social goals at lowest cost.

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References


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Application and Comparison of Regression and Markov Chain Methods in Bridge Condition Prediction and System Benefit Optimization

by Yi Jiang

The maximization of a bridge system is achieved using mathematical optimization techniques, such as linear programming and dynamic programming. For each bridge, the input data of the bridge project selection model includes the predicted bridge condition in future years, the recommended bridge repair action, the estimated cost of recommended bridge repair action, and the expected improvement or benefit from the repair action. Through mathematical manipulation, bridge projects are selected to maximize the total expected benefit of the bridge system while a number of constraints are simultaneously satisfied. This optimization process is based on the predicted bridge conditions. Therefore, the accuracy of bridge condition predictions is vital to the effectiveness of bridge project selection. This paper shows that bridge condition predictions will affect bridge project selections and the corresponding system benefits.

INTRODUCTION

The ultimate objective of a bridge management system is to select bridge projects for a multiyear period so that the total system benefit will be maximized through performing the scheduled maintenance, rehabilitation, and replacement activities to the selected bridges. In a bridge management system, the maximization of a bridge system benefit is achieved using mathematical optimization techniques, such as integer linear programming and dynamic programming (Winston 2003). For each bridge, the input data of the bridge project selection model include the predicted bridge condition in future years, the recommended bridge repair action, the estimated cost of recommended bridge repair action, and the expected improvement or benefit from the repair action. Through mathematical manipulation, bridge projects are selected to maximize the total expected benefit of the bridge system while a number of constraints are simultaneously satisfied. Bridge condition rating is the most important variable considered in the process of bridge project selection. Decision making, either at the system level or at the project level, is based on bridge conditions at present and in the future. The accuracy of the future condition prediction directly affects the outcome of optimization in selecting bridge projects. Therefore, the accuracy of bridge condition predictions is vital to the effectiveness of bridge project selection. If the predicted bridge conditions are not accurate, the selected bridge projects will not result in a truly maximized system benefit.

The purpose of this study was to help highway engineers and planners identify and choose an appropriate method for bridge condition predictions. The statistical regression theory (Neter et al. 1985) and the Markov chain theory (Winston 2003) have been applied to predict structural conditions in bridge management systems. In this paper, the accuracies of condition predictions based on the two theories are compared with the Indiana highway bridge condition data. Under a limited budget for bridge repair and rehabilitation, bridge projects can be selected from a given group of bridge candidates through mathematical optimization so that a maximum system benefit can be achieved. A key requirement for the optimization in bridge project selection is the ability to obtain reliable bridge condition predictions. As the available budget decreases, fewer bridges will be selected for repair and rehabilitation. Less bridge repair or rehabilitation now will lead to higher cost in the future because of further bridge condition deteriorations.
CONDITION PREDICTION MODELS

Regression Methods

There are various types of bridge condition prediction models based on statistical regression theory. Applications of piecewise linear regression in bridge condition prediction can be found in Fitzpatrick et al. (1981) and Hymon et al. (1983). Linear regression with two independent variables, bridge age and average daily traffic (ADT), was applied to predict the conditions of bridge deck, superstructure, and substructure (Busa et al. 1985).

According to the FHWA bridge rating system, bridge inspectors use a range from 0 to 9, with 9 being the maximum rating number for an excellent condition and 0 being the rating for a failed and out of service condition (USDOT 2006). The objective of developing regression equations was to find the relationship between condition rating and bridge age. The polynomial regression method was applied to predict bridge conditions in Indiana (Jiang and Sinha 1989). A third order polynomial model was used to obtain the regression function of the relationship. The polynomial model is expressed by the following formula (Neter et al. 1985).

\[ Y(T_i) = \beta_0 + \beta_1 T_i + \beta_2 T_i^2 + \beta_3 T_i^3 + \varepsilon_i \]

Where:

- \( Y(T_i) \) – Condition rating of bridge i, \( 0 \leq R \leq 9 \), with rating 9 as the rating of a perfect condition;
- \( T_i \) – Age of bridge i;
- \( \beta_0, \beta_1, \beta_2, \beta_3 \) – Regression coefficients;
- \( \varepsilon_i \) – Error term.

The Indiana inspection includes ratings of individual components such as deck, superstructure, and substructure as well as of the overall bridge condition. The complete data base included about 5,700 state owned bridges in Indiana. Through statistical analysis and regression, the regression equations were developed for concrete and steel bridges and bridge components (deck, superstructure, and substructure) on Indiana interstate highways and non-interstate highways (Jiang and Sinha 1989). As examples, some of the developed regression equations developed for Indiana bridges are listed below.

- Deck conditions of steel bridges on interstate highways:
  \[ Y(T_i) = 9 - 0.41141790 T_i + 0.02116563 T_i^2 - 0.00040387 T_i^3 \]
- Superstructure conditions of concrete bridges on non-interstate highways:
  \[ Y(T_i) = 9 - 0.29095931 T_i + 0.00860726 T_i^2 - 0.00008815 T_i^3 \]
- Substructure conditions of concrete bridges on interstate highways:
  \[ Y(T_i) = 9 - 0.34508455 T_i + 0.01575857 T_i^2 - 0.00026681 T_i^3 \]

As can be seen, the condition rating \( Y(T_i) \) can be predicted based on the bridge age with the regression equation once the bridge type and highway type are identified.

Markov Chain Approach

The Markov chain is a special case of stochastic processes (Winston 2003). The theory of stochastic processes has been applied in many areas of engineering and other applied science. For example, the theory was used by Li and Zhang (2007) for soil mapping from irregularly distributed point samples.
Caleyo et al. (2009) developed an empirical Markov chain-based stochastic model for predicting the evolution of pipeline pitting corrosion depth and rate distributions from the observed properties of the soil. The Markov model was also applied to analyze the impact of Wal-Mart on the grocery market and to develop the competitive strategies of grocery retailers (Yang et al. 2010).

A stochastic process is said to be Markovian if given the value $X(t)$, the value of $X(s)$ for $s > t$ does not depend on the value of $X(\mu)$ for $\mu < t$. In other words, the future behavior of the process depends only on the present state but not on the past. In formal terms, a process is said to be Markovian if

$$P[a < X(t) \leq b/X(t_0) = x_0, \ldots, X(t_n) = x_n] = P[a < X(t) \leq b/X(t_n) = x_n]$$

where $t_0 < t_1 < \ldots < t_n < t$.

The theory was applied in pavement management systems (Butt et al. 1987, Li et al. 1996), storm water pipe deterioration modeling (Micevski et al. 2002), and bridge management systems (Jiang and Sinha 1989). Essentially, a stochastic process is a probability-based process describing the changes of random variables in time. The Markov chain as applied to bridge performance prediction is based on the concept of defining states in terms of bridge condition ratings and obtaining the probabilities of bridge condition changing from one state to another. These probabilities are represented in a matrix form that is called the transition probability matrix or simply, transition matrix, of the Markov chain. Knowing the present state of bridges, or the initial state, the future conditions can be predicted through multiplications of the initial state vector and the transition probability matrix.

Ten bridge condition ratings are defined as 10 states with each condition rating corresponding to one of the states. For example, condition rating 9 is defined as state 1, rating 8 as state 2, and so on. Without repair or rehabilitation, the bridge condition rating decreases as the bridge age increases. Therefore, there is a probability of condition changing from one state, say $i$, to another state, $j$, during a given period of time, which is denoted by $p_{ij}$.

$$P = \begin{bmatrix} p_{1,1} & p_{1,2} & p_{1,3} & \ldots & \ldots & \ldots & p_{1,10} \\ 0 & p_{2,2} & p_{2,3} & \ldots & \ldots & \ldots & p_{2,10} \\ 0 & 0 & p_{3,3} & \ldots & \ldots & \ldots & p_{3,10} \\ 0 & 0 & 0 & p_{4,4} & \ldots & \ldots & p_{4,10} \\ 0 & 0 & 0 & 0 & p_{5,5} & \ldots & p_{5,10} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & \ldots & p_{10,10} \end{bmatrix}$$

In the transition matrix, $p_{1,1}$ is the probability of condition changing from state 1 (rating 9) to state 1 (rating 9) in one year, $p_{1,2}$ from state 1 (rating 9) to state 2 (rating 8), and so on. As shown in the transition matrix, some of the transition probabilities are equal to 0. This is because the bridge condition ratings will not increase without repair or rehabilitation actions. To simplify the transition matrix, Jiang and Sinha (1989) made some realistic assumptions according to actual bridge condition data. First, it is assumed that the bridge condition rating would not drop by more than one in a single year. This is reasonable because the bridge condition rating in Indiana seldom drops more than one in a single year as found by the research team that developed the Indiana Bridge Management System (Sinha et al. 1989). Second, it is assumed that the lowest bridge condition rating is 3, because it is an FHWA requirement that a bridge be repaired or replaced when its condition rating reaches 3. Any bridge with a condition rating below 3 must be closed due to safety concerns. With the two assumptions, the transition matrix of condition ratings has the following form:
Bridge Condition Prediction

(4)

\[
P = \begin{bmatrix}
p(1) & q(1) & 0 & 0 & 0 & 0 & 0 \\
0 & p(2) & q(2) & 0 & 0 & 0 & 0 \\
0 & 0 & p(3) & q(3) & 0 & 0 & 0 \\
0 & 0 & 0 & p(4) & q(4) & 0 & 0 \\
0 & 0 & 0 & 0 & p(5) & q(5) & 0 \\
0 & 0 & 0 & 0 & 0 & p(6) & q(6) \\
0 & 0 & 0 & 0 & 0 & 0 & 1 
\end{bmatrix}
\]

where:
- \( p(i) \) – Transition probability from state \( i \) to state \( i \);
- \( q(i) \) – Transition probability from state \( i \) to state \( i-1 \), \( q(i) = 1 - p(i) \).

In the matrix, \( p(1) \) is the transition probability from rating 9 (state 1) to rating 9, and \( q(1) \), from rating 9 to rating 8 (state 2), and so on. It should be noted that the lowest rating number before a bridge is repaired or replaced is 3. Consequently, the corresponding transition probability \( p(7) \) equals 1.

Knowing the present condition of a bridge, or the initial state, the future conditions can be predicted through multiplications of initial state vector \( Q(0) \) and the transition matrix \( P \). The state vector for year \( T \), \( Q(T) \), can be obtained by the multiplication of initial state vector \( Q(0) \) and the \( T \)th power of the transition probability matrix \( P \):

(5)  \[ Q(T) = Q(0) P \cdot P \cdot \ldots \cdot P = Q(0) P^T \]

Equation 5 is equivalent to the following:

(6)  \[ Q(T) = Q(T-1) P \]

Thus, a Markov chain is completely specified when its transition matrix \( P \) and the initial state vector \( Q(0) \) are known. Since the initial state vector \( Q(0) \) is usually known, the main problem of the Markov chain approach in this study is to determine the transition probability matrix. The detailed description of the transition probability matrix development is given in Jiang and Sinha (1989).

The maximum rating of bridge condition is 9 and it represents a near-perfect condition. It is almost always true that a new bridge has condition rating 9. In other words, a bridge at age 0 has condition rating 9 with unit probability. Thus, the initial state vector \( Q(0) \) of a new bridge is always \([1, 0, 0, 0, 0, 0, 0]\), where the numbers are the probabilities of having condition rating of 9, 8, 7, 6, 5, 4, and 3 at age 0, respectively.

An essential property of Markov chain is that the future behavior of the process depends only on the present state but not on the past. As long as the bridge condition is known at any time, the state vector at that time can be used as the initial vector \( Q(0) \) to predict the future condition. For example, if a bridge is 10 years old with a condition rating 7, then the initial state vector \( Q(0) \) should be \([0, 0, 1, 0, 0, 0, 0]\). That is, the unit probability corresponds to condition rating 7 and the current time (age 10) is used as the starting time (time 0). With this initial state vector and a transition probability matrix, future condition ratings of this bridge can be estimated from age 10.
Let $R$ be a vector of condition ratings, $R=[9 \ 8 \ 7 \ 6 \ 5 \ 4 \ 3]$, and $R'$ be the transform of $R$, i.e.,

\[
R' = \begin{bmatrix}
9 \\
8 \\
7 \\
6 \\
5 \\
4 \\
3
\end{bmatrix}
\]

Then the estimated condition rating at year $t$ by Markov chain is

\begin{equation}
E(t) = Q(t) R'
\end{equation}

Equation 7 can also be expressed as:

\begin{equation}
E(t) = Q(0) P^t R'
\end{equation}

An example set of computations is given in the following. The transition matrix for deck conditions of concrete bridges on non-interstate highways was obtained (Jiang and Sinha 1989):

\[
P = \begin{bmatrix}
0.700 & 0.300 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 \\
0.000 & 0.780 & 0.220 & 0.000 & 0.000 & 0.000 & 0.000 \\
0.000 & 0.000 & 0.874 & 0.126 & 0.000 & 0.000 & 0.000 \\
0.000 & 0.000 & 0.000 & 0.600 & 0.400 & 0.000 & 0.000 \\
0.000 & 0.000 & 0.000 & 0.000 & 0.500 & 0.500 & 0.000 \\
0.000 & 0.000 & 0.000 & 0.000 & 0.400 & 0.600 & 0.000 \\
0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 1.000
\end{bmatrix}
\]

For illustration, $p(1)=0.700$ indicates that the probability of bridge deck condition changing from state 1 (condition rating 9) to state 1 (remaining in state 1) in a one-year period is 0.700, and the probability of changing from state 1 to state 2 (condition rating 8) is $q(1)=0.300$. Similarly, $p(2)=0.780$ indicates that the probability of transitioning from state 2 to state 2 (remaining in state 2) in a one-year period is 0.780, and the probability of transitioning from state 2 to state 3 (condition rating 7) is $q(2)=0.220$.

Assuming there is a new concrete bridge with a condition rating 9, the initial state vector should be $Q_{(0)} = [1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]$. The bridge deck’s condition rating can be predicted by Equations 6 and 7 with the matrix $P$ (Equation 9). For example, the state vectors and condition ratings for year 0 through year 6 are given as follows:
Bridge Condition Prediction

\[ R = [9 \ 8 \ 7 \ 6 \ 5 \ 4 \ 3] \]

\[ Q(0) = [1 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0] \]
\[ E(0) = Q(0) \ R' = 9.0 \]

\[ Q(1) = Q(0) \ P = [0.70 \ 0.30 \ 0.00 \ 0.00 \ 0.00 \ 0.00 \ 0.00] \]
\[ E(1) = Q(1) \ R' = 8.70 \]

\[ Q(2) = Q(1) \ P = [0.49 \ 0.44 \ 0.07 \ 0.00 \ 0.00 \ 0.00 \ 0.00] \]
\[ E(2) = Q(2) \ R' = 8.42 \]

\[ Q(3) = Q(2) \ P = [0.34 \ 0.49 \ 0.16 \ 0.01 \ 0.00 \ 0.00 \ 0.00] \]
\[ E(3) = Q(3) \ R' = 8.17 \]

\[ Q(4) = Q(3) \ P = [0.24 \ 0.49 \ 0.24 \ 0.03 \ 0.00 \ 0.00 \ 0.00] \]
\[ E(4) = Q(4) \ R' = 7.94 \]

\[ Q(5) = Q(4) \ P = [0.17 \ 0.45 \ 0.32 \ 0.05 \ 0.01 \ 0.00 \ 0.00] \]
\[ E(5) = Q(5) \ R' = 7.72 \]

\[ Q(6) = Q(5) \ P = [0.12 \ 0.40 \ 0.38 \ 0.07 \ 0.02 \ 0.01 \ 0.00] \]
\[ E(6) = Q(6) \ R' = 7.50 \]

The above example used age 0 as the starting time. However, it should be pointed out that the Markov prediction can be performed using any point in time as the starting time as long as the condition rating is known. This is because the future behavior of the Markov process depends only on the present state but not on the past.

Some states have started to use element-level bridge inspections for bridge condition ratings (FHWA 2009). The element-level bridge inspection system was proposed by the American Association of State Highway and Transportation Officials (AASHTO) in 1995 (AASHTO 1995). The element-level inspection divides bridge structural components into sub-elements. Therefore, it contains more bridge elements for inspection and provides more detailed bridge condition information. However, the Federal Highway Administration (FHWA) has found widespread variability in the elements used by states. The lack of uniformity in states’ use of element-level data has impeded federal efforts to collect and use element-level bridge data (FHWA 2009). Nonetheless, if it is needed, the prediction methods described in this paper can be readily applied to the element-level bridge data because the general principles remain the same.

**BRIDGE PROJECT SELECTION AND SYSTEM BENEFIT OPTIMIZATION**

Optimization techniques manipulate the tradeoffs between the objective and constraints systematically or mathematically, so that an optimal solution to the problem among many possible solutions can be obtained. In managing a bridge system, optimization techniques can be applied to produce optimal strategies in project selection by maximizing the system benefit subject to the constraints, such as available resources. An integer linear programming model is used in the following to demonstrate the effects of bridge condition predictions on system benefits. The optimization model is formulized as follows:
Objective function:

\[
(10) \quad \max \sum_{t=1}^{T} \left( \sum_{i} \sum_{a} X_{i,t} \times E_{i} \right)
\]

Subject to the following constraints:

(a) available budget:

\[
(11) \quad \sum_{t=1}^{T} \left( \sum_{i} \sum_{a} X_{i,t} \times c_{i} \right) \leq B
\]

(b) one activity cannot be undertaken more than once on one bridge in T years:

\[
(12) \quad \sum_{t=1}^{T} X_{i,t} \leq 1
\]

(c) zero-one integer decision variable:

\[
(13) \quad X_{i,t} = 0 \text{ or } 1
\]

where:

\[X_{i,t} = 1, \text{ if bridge } i \text{ is chosen for the proposed rehabilitation or replacement;}
\]
\[X_{i,t} = 0, \text{ otherwise;}
\]
\[E_{i} = \text{effectiveness gained by bridge } i \text{ if the proposed rehabilitation or replacement activity is conducted;}
\]
\[B = \text{total available budget for the program period;}
\]
\[c_{i} = \text{estimated cost of activity } a \text{ on bridge } i;
\]

The effectiveness of a bridge improvement activity is defined as follows:

\[
(14) \quad E_{i} = ADT_{i} \times \Delta A_{i} \times (1 + \text{Csafe}_{i}) \times (1 + \text{Cimpci}_{i})
\]

where:

\[ADT_{i} = \text{average daily traffic on bridge } i.
\]
\[\Delta A_{i} = \text{area under regression curves of bridge } i \text{ obtained by the proposed rehabilitation activity; as shown in Figure 1.}
\]
\[\text{Csafe}_{i} = \text{coefficient of safety condition of bridge } i, \text{ converted from bridge safety utility value; as shown in Figure 2.}
\]
\[\text{Cimpci}_{i} = \text{coefficient of community impact of bridge } i, \text{ converted from community impact utility value in terms of detour length; as shown in Figure 3.}
\]
Figure 1: Condition Improvement by Rehabilitation

Figure 2: Coefficient of Safety Condition

Figure 3: Coefficient of Community Impact
As $E_i$ is defined as the effectiveness gained by bridge $i$ if the proposed rehabilitation or replacement activity is conducted, it is actually the benefit to be realized if bridge $i$ is chosen. As indicated in Figure 1, the benefit begins right after the bridge is repaired or replaced and lasts until the end of the average service life. There are several ways that the effectiveness of a bridge activity can be defined. Because ADT is the number of vehicles served by a bridge, the inclusion of ADT and $\Delta A$ in the effectiveness function (Equation 14) can be interpreted as the measure of the improvement that can be experienced by the users or vehicles passing the bridge. Traffic safety condition and community impact of a bridge are two other factors affecting decisions on bridge rehabilitation or replacement activities in addition to structural condition. Bridge safety index and bridge detour length were used as variables reflecting bridge traffic safety and community impact, respectively. The coefficients, $C_{\text{safe}}$ and $C_{\text{imp}}$, were used to modify the effectiveness of individual bridge projects depending on site specific impacts.

As shown in Figure 1, a particular rehabilitation activity causes a jump in the bridge condition rating. As the bridge age increases, the condition rating gradually decreases from the new condition rating. The area between the regression curves with and without rehabilitation, $\Delta A$, represents an improvement in terms of condition rating and service life of the bridge. Figure 2 shows the Indiana coefficient of traffic safety index, $C_{\text{safe}}$, ranging from 0.0 to 1.0. The traffic safety index is primarily based on bridge geometrics and it ranges from 1 to 10 with 10 being the index of no potential safety problem (Jiang and Sinha 1989). The coefficient of community impact ($C_{\text{imp}}$) of bridges is shown in Figure 3 and ranges from 0 to 1.0. The community impact coefficient is based on detour length (Jiang and Sinha 1989). As detour length increases the community impact coefficient increases. Therefore, the effectiveness ($E_i$) gained by a bridge project is the benefit that the motorists ($ADT_i$) will enjoy through the improved bridge condition ($\Delta A_i$), the enhanced safety ($1+C_{\text{safe}}i$), and the positive community impact due to avoided bridge closure ($1+C_{\text{imp}}i$).

In Indiana, bridge rehabilitation activities mainly include deck reconstruction and deck replacement. Deck reconstruction work includes shallow and/or full-depth patching of deteriorated deck spots and an overlay of the deck after scarifying the wearing surface. In order to increase bonding between the bridge deck and the overlay materials, the worn and polished deck surface is scarified by grinding to create rough textures. Along with this reconstruction, curbs, railing, and expansion joints are replaced in most cases. Other related work includes guardrails, approach slab reconstruction, approach shoulder reconstruction, and small amounts of substructure repairs. The deck replacement alternative is a more extensive rehabilitation than deck reconstruction. Deck replacement consists of a replacement of the entire deck, including rehabilitation of parts of the superstructure and the top portion of the substructure. The replacement of the entire bridge is considered when reconstruction and rehabilitation cannot adequately correct the existing deficiencies. Thus, bridge rehabilitation and replacement activities were grouped into three options: deck reconstruction, deck replacement, and bridge replacement.

**CONDITION RATING PREDICTIONS**

Forty bridges were selected from the Indiana’s bridge condition database in 2004 to illustrate bridge condition predictions with polynomial regression and Markov chain methods. The Indiana bridge condition database is used for the Indiana Bridge Management System. It should be pointed out that the main function of a bridge management system is to select bridge projects that will provide maximum system benefit under budget constraint. Therefore, it is a decision-making tool at the system level rather than at the project level. The information pertaining to these selected bridges is shown in Table 1. The proposed activity for each bridge in the table is the result of closer field inspection and engineering decision at the project level. The project level decision is used as an input of the system optimization.
As can be seen in Table 1, each of the selected bridges has four consecutive condition ratings. That is, the actual condition ratings of these bridges are known. Since each bridge was observed and rated once every two years, the four ratings represent bridge conditions observed in 1997, 1999, 2001, and 2003. For example, the condition ratings of the first bridge were (6, 6, 6, 5), meaning that the condition rating was 6 in 1997, 6 in 1999, 6 in 2001, and 5 in 2003.

To compare the condition predictions of the two prediction methods, the condition ratings of the 40 bridges were calculated with the polynomial regression method and the Markov chain method. With the polynomial regression method, each bridge condition rating was calculated using the bridge age as the input. With the Markov chain method, the condition rating in 1997 of each bridge was utilized as the “current” condition to predict the conditions in 1999, 2001, and 2003. The actual and predicted condition ratings for the three years are shown in Tables 2 and 3. Table 2 shows the results from the polynomial regression method and Table 3 shows those from the Markov chain method. As shown in the two tables, each condition prediction error was calculated by the predicted rating subtracting its responding actual rating. To compare the two methods, the prediction errors for 1999, 2001, and 2003 are plotted in Figures 4, 5, and 6, respectively. As clearly illustrated in the three figures, the magnitudes of Markov chain prediction errors are smaller than those of polynomial regression predictions for a majority of the 40 bridges. In other words, for most of the 40 bridges the Markov chain predictions are more accurate than the polynomial regression predictions.

As demonstrated in Tables 2 and 3 as well as in Figures 4, 5, and 6, there are positive and negative errors in the condition predictions. The positive errors represent the overestimates and the negative errors are the underestimates of condition ratings. To quantitatively compare the magnitudes of prediction errors, the absolute values of the prediction errors were used to compute the averages and standard deviations. The reason for using absolute values of the prediction errors was to eliminate the effects of negative values on the magnitudes of the averages and standard deviations. As illustrated in Figures 7 and 8, the Markov chain method produced much better condition rating predictions than the polynomial regression method in terms of both average errors and standard deviations.
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Note: DRC = Deck Reconstruction  
BRP = Bridge Replacement
Table 2: Accuracy of Bridge Condition Predictions by Regression Method

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<th>Error (B-A)</th>
<th>Actual Rating in 2001 (C)</th>
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### Table 3: Accuracy of Bridge Condition Predictions by Markov Method

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Figure 4: Condition Rating Prediction Errors (1999)

![Figure 4](image)

Figure 5: Condition Rating Prediction Errors (2001)

![Figure 5](image)

Figure 6: Condition Rating Prediction Errors (2003)

![Figure 6](image)
Figure 7: Average Prediction Errors

![Average Prediction Errors Chart]

Figure 8: Standard Deviations of Prediction Errors

![Standard Deviations Chart]
SYSTEM OPTIMIZATION

Since bridge project selection and system benefit optimization depend on bridge conditions, the accuracies of bridge condition predictions would certainly affect the optimization results. As shown in the integer linear programming optimization model (Equations 10 through 14), available budget also has major impact on project selections. To analyze the effects of condition predictions on bridge system optimization, the optimization program was run based on the actual condition ratings and the condition predictions from the two prediction models. In addition, to examine the effects of available budget, 40%, 80%, and 100% of needed budgets were used as input constraints of the integer linear programming.

The optimization program determines which bridges should be rehabilitated or replaced at each time period. The optimization results are presented in Table 4. As can be seen in the table, the selected bridge projects and the total expected benefits are different for actual, regression predicted, and Markov chain predicted condition ratings. With 100% needed budget, all of the 40 bridges are selected in the six-year period for each of the three sets of condition ratings. However, the sequences of the bridges to be rehabilitated or replaced are different. With sufficient budget, the total benefit values are 409,642, 417,476, and 413,805 for actual, regression predicted, and Markov chain predicted condition ratings, respectively. With 80% and 40% needed budgets, each optimization selects less than 40 bridges because of the insufficient amount of funds. As a result, the maximized system benefits under insufficient funds are also different for the three sets of condition ratings as shown in Table 4. The results in the table indicate that the total system benefits fall for all of the three conditions as the available budget decreases. The function of the optimization program is to maximize the total benefit based on the predicted bridge conditions with the limited budget.

The total benefits shown in Table 4 are plotted in Figure 9 to illustrate the benefit values based on the actual, regression predicted, and Markov predicted condition ratings. The figure indicates that, compared with the regression based total benefits, the Markov based total benefits are closer to the actual total benefits. If the total benefit based on the actual condition rating is called the “true benefit,” the benefit deviation can be defined as the difference between the optimized total benefit and the true benefit. A positive benefit deviation represents an overestimate of system benefit and a negative value means an underestimate of system benefit. For example, with a 100% needed budget, the true benefit is 409,642, the benefit deviation for the polynomial regression predictions can be calculated as 417,476-409,642=7,834, and for the Markov chain predictions, 413,806-409,642=4,163. That is, the optimization based on regression predictions resulted in greater benefit deviation from the true benefit than the Markov chain predictions. The benefit deviations are shown in Figure 10. As depicted in Figure 10, as the budget increases, the magnitude of benefit deviation for each optimization decreases. In all cases, the optimizations based on the regression predictions generate greater magnitudes of benefit deviations than those based on the Markov chain predictions. In other words, the optimization based on Markov chain predictions would result in more accurate and more realistic system benefits and project selections.
### Table 4: Project Selections and System Benefits with Different Available Budgets

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<tr>
<td>2002, 2003</td>
<td>Bridge Numbers: 2, 4, 9, 11, 12, 21, 22, 27, 28, 29, 35, 36, 40</td>
<td>Bridge Numbers: 4, 9, 11, 12, 22, 27, 28, 30, 36, 37, 40</td>
<td>Bridge Numbers: 2, 9, 11, 22, 27, 28, 34, 36, 37, 40</td>
</tr>
<tr>
<td></td>
<td><strong>Total Benefit = 409,642</strong></td>
<td><strong>Total Benefit = 417,476</strong></td>
<td><strong>Total Benefit = 413,805</strong></td>
</tr>
<tr>
<td>Time</td>
<td>Bridges Selected Using Actual Rating</td>
<td>Bridges Selected Using Regression Predicted Rating</td>
<td>Bridges Selected Using Markov Predicted Rating</td>
</tr>
<tr>
<td>2000, 2001</td>
<td>Bridge Numbers: 1, 3, 5, 8, 17, 23, 29, 30, 37, 39</td>
<td>Bridge Numbers: 1, 2, 3, 8, 17, 18, 23, 29, 37, 38</td>
<td>Bridge Numbers: 1, 3, 4, 5, 6, 8, 10, 11, 12, 17, 23, 29, 30, 34, 39</td>
</tr>
<tr>
<td>2002, 2003</td>
<td>Bridge Numbers: 2, 4, 9, 10, 11, 12, 21, 27, 28, 34, 35, 36, 40</td>
<td>Bridge Numbers: 4, 5, 10, 11, 12, 21, 27, 28, 30, 34, 35, 39, 40</td>
<td>Bridge Numbers: 2, 21, 27, 28, 35, 37, 40</td>
</tr>
<tr>
<td></td>
<td><strong>Total Benefit = 391,904</strong></td>
<td><strong>Total Benefit = 378,206</strong></td>
<td><strong>Total Benefit = 397,163</strong></td>
</tr>
<tr>
<td>Time</td>
<td>Bridges Selected Using Actual Rating</td>
<td>Bridges Selected Using Regression Predicted Rating</td>
<td>Bridges Selected Using Markov Predicted Rating</td>
</tr>
<tr>
<td>1998, 1999</td>
<td>Bridge Numbers: 6, 7, 13, 14, 15, 16, 18, 19, 26, 31, 32, 33, 38</td>
<td>Bridge Numbers: 6, 13, 14, 15, 16, 18, 19, 20, 26, 31, 32, 33, 38, 39</td>
<td>Bridge Numbers: 6, 7, 13, 14, 15, 16, 18, 19, 26, 31, 32, 33, 38</td>
</tr>
<tr>
<td>2000, 2001</td>
<td>Bridge Numbers: 24, 25</td>
<td>Bridge Numbers: 24, 25</td>
<td>Bridge Numbers: 1, 3, 4, 8, 10, 12, 17, 20, 25, 30, 39</td>
</tr>
<tr>
<td>2002, 2003</td>
<td>Bridge Numbers: 1, 3, 9, 17, 20, 23, 30</td>
<td>Bridge Numbers: 1, 3, 7, 8, 23, 30</td>
<td>Bridge Numbers: 2, 5, 11, 24, 34, 35</td>
</tr>
<tr>
<td></td>
<td><strong>Total Benefit = 319,905</strong></td>
<td><strong>Total Benefit = 259,932</strong></td>
<td><strong>Total Benefit = 310,996</strong></td>
</tr>
</tbody>
</table>
Figure 9: System Benefits with Different Available Budgets

CONCLUSIONS

It is demonstrated that the Markov chain method yields more accurate condition predictions than the polynomial regression method. The accuracy of condition prediction affects the optimization results greatly, in terms the number of selected projects and their schedules as well as the total system benefit. A less accurate condition prediction will consequently produce a greater benefit deviation from the true system benefit. It is essential for a bridge management system to have a capability to provide highly accurate condition predictions. Otherwise, the optimization techniques would not provide meaningful results that would truly maximize the system benefits. Although this study focused on bridges, the study results and findings can also be applied in similar areas, such as pavement management systems and other transportation infrastructure management systems.

The results of this paper were obtained using Indiana bridge condition data. Although the author believes that the Markov method should produce better bridge condition predictions in general, the findings from this study should not be generalized without validation with bridge data from other...
states. Nonetheless, the analysis method discussed in this paper could be used by other highway agencies to choose a more accurate estimation technique.

References


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Estimation of Railroad Capacity Using Parametric Methods

by Subhro Mitra, Denver Tolliver, Sushil Mitra, Khalid Bachkar and Poyraz Kayabas

This paper reviews different methodologies used for railroad capacity estimation and presents a user-friendly method to measure capacity. The objective of this paper is to use multivariate regression analysis to develop a continuous relation of the discrete parameters identified for capacity estimation. The algorithm developed in this paper can be used for managerial decision making regarding railroad capacity by various state agencies and state DOTs. This paper illustrates the relationship between the parameters and section capacities, which can be used to improve the throughput of the transportation system. The paper also illustrates the application of the model to estimate capacity of a statewide railroad network.

INTRODUCTION

A major concern for transportation planners and many decision makers is whether or not the nation’s freight transportation system, especially the freight railroad system, can keep pace with the expected growth of the economy for the next 20 years. The freight rail system carries 16% of the nation’s freight by tonnage, accounting for 28% of total ton-miles and 40% of intercity ton-miles (Cambridge Systematics 2003). If there is no growth in railroad capacity by 2020, there will be a shift of about 900 million tons of freight and 31 billion truck vehicle miles of travel (VMT) to the nation’s highways (Cambridge Systematics 2003). Assessing freight railroad capacity and its flexibility to accommodate the increased demand of freight transport seems to be an urgent requirement for transportation planners. As infrastructure expansion is an expensive and long term proposition, optimizing available infrastructure resources would be an important goal for transportation planners and decision makers.

There are two methods for estimating railroad capacity: analytical and simulation. This paper reviews literature, on both techniques, for the estimation of freight railroad capacity. Analytical and simulation methods each have their advantages and shortcomings, but these methods can be integrated to give better results (Pachal and White 2004). The vast majority of literature on railroad capacity refers to the train-dispatching computer simulation model developed by Peat, Marwick, Mitchell and Co. (Prokopy and Rubin 1975). This research, undertaken by Prokopy and Rubin (1975) under a Federal Railroad Administration (FRA) grant, examines the relationship between railroad capacity and different operating parameters, such as speed, siding spacing, signal spacing, and siding capacity. The Prokopy and Rubin (1975) research was the foundation for other research in railroad capacity. The parametric capacity model in the Prokopy and Rubin (1975) study looks at capacity from a perspective different from that of theoretical capacity. In the Prokopy and Rubin (1975) study, delay is used as a primary component of capacity measurement. Computer software developed by the Canadian National Railroad for faster estimation of railroad capacity is based on the research done by Prokopy and Rubin (1975). Neither this software, developed by the Canadian National Railroad, nor its results, are available to the public.

The objective of the paper is to gain insight into the Prokopy and Rubin study. The contribution of the paper to the literature is the development of a computer algorithm to measure railroad section capacity that would be available to state DOTs and other state agencies for planning and managerial decision making. This algorithm can be part of a decision support system that can be used to identify bottlenecks and measure system capacity of a railroad network. In this study multivariate regression
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analyses is used to develop a continuous relationship between railroad capacity and various parameters affecting capacity.

LITERATURE REVIEW

Hyman (1998) estimates railroad capacity for two major subtypes: transit railroad capacity and freight railroad capacity. Hyman (1998) states that for freight rail, trains per day are a more appropriate measure of capacity, unlike transit capacity, which is measured in trains per hour. The Hyman (1998) report refers to the work done by Prokopy and Rubin (1975), where a simulation model was developed to estimate capacity based on different parameters associated with train movement (Hyman 1998).

In a freight corridor capacity study for the Upper Midwest, the Prokopy and Rubin (1975) method is used to estimate capacity (Srimantula 1999). In this study the parametric method, as proposed by Prokopy and Rubin (1975), serves as an effective tool for capacity estimation. The findings of this research indicate that the most important factors for determining capacity are number of tracks and operating speed. This paper also states that a double track experiences less delay than a single track.

A parametric model similar to the one used by Prokopy and Rubin (1975) is used by the Canadian National (CN) Railway to assess railroad capacity (Krueger 1999). In this CN model, similar to that in the Prokopy and Rubin (1975) model, delay is used as a measure of capacity. A Windows-based user-interface is developed in the CN model for quick and easy capacity estimation of railroad subdivisions. The inputs required to run the model are divided into three categories of parameters, namely plant, traffic, and operational. The plant parameters include length of subdivision, meet pass planning point spacing, meet pass planning point uniformity, intermediate signal spacing ratio, and percentage of double track. The traffic parameters consist of traffic peaking factor, priority probability, speed ratio, and average minimum run time. The operating parameters are track outages, temporary slow orders, train stop time, and maximum trip time threshold.

White (2006) examined the suitability of delay as a measure of capacity. He is of the opinion that delay is not a suitable indicator of capacity. In his paper, White (2006) states that time is a better indicator of capacity than delay. He mentions that a blocking time diagram is an efficient method of capacity estimation.

Capacity estimation research can be divided into analytical research and simulation research. Blocking time theory is an analytical approach to estimation of capacity. Blocking time has its advantages and disadvantages (Pachal and White 2004). A big advantage of the blocking time method is the detailed evaluation of a line or section and identification of the critical location of delay. In this paper, the author believes that building a blocking time model is less complex than a simulation model, but a blocking time model works only on the scheduling level and cannot evaluate running operation. Pachal and White (2004) also point out that the blocking time method can be used in conjunction with a simulation model.

A paper by Leilich (1998) discusses the applicability of simulation models in capacity estimation. Leilich (1998) discusses four basic types of rail operation simulation models, namely, the route seeking models, optimization models, computer assisted dispatching models, and event-based simulation models.

DIFFERENT MEASURES OF RAILROAD CAPACITY

The railroad capacity concept can be broadly categorized as transit railroad capacity and freight railroad capacity (Hyman 1998). Railroad transit includes commuter rail line, urban rapid transit, street cars, and light rail transit. Station and line haul are linear facilities, and capacity of the combination will be the minimum capacity of the link or the station (Transportation Research Board 2000). Transit capacity is dependent upon the number of passengers who can be accommodated in a
car and the number of cars in a train. Capacity also depends on the acceleration and deceleration of the train. Lang and Soberman (1964) included the loading coefficient of passengers in their transit rail capacity equation. Unlike transit rail capacity, which is measured in number of passengers per hour in one direction, freight rail capacity is measured in trains per day. Oftentimes, planners who have to relate the traffic forecast in tons per year to train requirement measure freight rail capacity in tons/day.

Capacity measure of transit and freight railroad can be theoretical and practical. Theoretical railroad capacity is calculated for idealized conditions, which are a) trains operated at the same speed, b) train movement is one direction only, and c) there is no significant grade which would result in variation of train speed. Under these conditions, the capacity is the number of hours of train operation divided by the time headway. In this idealized situation, the maximum line throughput is the measure of the capacity of the track.

\[
\text{Throughput}_{\text{max}} = \frac{24V}{L_B (N_S - 1) + L_t}
\]

where:
- \(L_B\) = Block length (in miles)
- \(L_t\) = Train Length (in miles)
- \(N_S\) = Number of signal aspects
- \(V\) = Speed (in miles per hour)

The American Railway Engineering and Maintenance of Way Association (AREMA) (1998) presents capacity equations in the Manual for Railway Engineering. The AREMA equation of the theoretical capacity of a line segment is:

\[
C_t = \frac{T \times N}{H_n}
\]

- \(T\) = Number of time units in the period for which capacity is being calculated.
- \(N\) = Number of directions run on a single track.
- \(H_n\) = Maximum gross headway in \(N\) directions.

The idealized conditions assumed for the estimation of theoretical capacity is realistically not possible for any actual scenario. Practical capacity is a more sensible measurement of the number of trains that can actually move through a track with an acceptable amount of delay, level of service, and reliability. According to AREMA, practical rail-line capacity for freight operation can be expressed as:

\[
C_p = C_t \times E
\]

- \(C_p\) = Practical line segment capacity
- \(C_t\) = Theoretical line segment capacity
- \(E\) = Dispatching efficiency for line segment

The dispatching efficiency depends on a) type of signal, b) type of traffic, c) class of line, and d) terrain. A study by Kraft (1982) states that practical capacity is 60-70% of theoretical capacity. Krueger (1999) defines capacity as a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific plan. In this definition, the specific plan could mean speed of trains, on-time performance, available track maintenance time, service reliability, and train handling power of the subdivision. In NCHRP Report 399 (Hyman
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1998), line capacity is defined in terms of delay instead of maximum theoretical throughput. According to this report, capacity should not be measured by how many trains can be moved in a segment of track; instead, what is more important for capacity measurement is the movement of trains without undue delay.

**REVIEW OF THE PARAMETRIC ANALYSIS METHOD**

The literature review on railroad capacity estimation reveals that the parametric analysis method, which is based on the computer train dispatching simulation model developed by Prokopy and Rubin (1975), is the most comprehensive analysis of capacity. Simulation results published in Prokopy and Rubin’s (1975) report enable one to estimate capacity without getting engaged in the actual simulation. Acknowledging the importance of this report, an attempt is made here to scrutinize the report piecemeal, suggest some minor changes in the estimation steps, and, finally, use the methodology in the report to develop a computer algorithm.

The parametric analysis of railroad line capacity has five main steps:

- Modification of Prokopy and Rubin’s (1975) train dispatching simulation (TDS)
- Identify key parameters affecting capacity
- Procedure for parametric analysis
- Evaluation of the parameters
- Validation of the model and verification of the accuracy

**Simulation Model**

In the core of the parametric analysis of rail line capacity is the computer based train dispatching simulation model. The simulation model is used here to replicate train dispatching and movement in a system, with different parameters, consisting of several hundred different combinations of track, signal, and train combinations and operation policies. In this study, an event based computer simulation model is used to create a relationship between numbers of trains dispatched and the train delay. This simulation method also analyzes the sensitivity of delay to various parameters individually and combinations of parameters simultaneously. The logic diagram of event based simulation is shown in Figure 1. In this event-based simulation, state change takes place at discrete points of time, which is prompted by events happening. These states are known as discrete change state variables. In this study, a representative line segment of 150 miles is used. The Train Dispatching Simulation (TDS) model starts with the first train entering the system at the pre-assigned time. This is the first event, which triggers a change of state in the system. The aggregate states of all elements in the model specify the state of the model as a whole. When the second train enters the system, it triggers a new event and is accompanied by change in the state of the elements in the system. In this TDS model, a time resolution of one-tenth of a minute is used, which is good enough to replicate the train movements. A train performance calculator (TPC) is used in combination with the TDS to quantify the train movement and delay. In this simulation model, statistics of train performance are gathered from the moment a train enters the system until it leaves the system. Some trains may not be dispatched at the stipulated time because of unavailability of track. In this situation they have to wait in a siding or yard. In this model there are two stages of control: micro-resource, which is the signal system control, and the macro-resource, which is the dispatcher control.

The automatic block signal system, which is part of the signal system control, maintains train separation. Block signal spacing and number of signal aspects are parameters which can be set in the model to measure its effect on delay. The macro-level control in the model regulates the dispatching of trains and discharging of trains at stations. The macro-level control also prioritizes trains based on their preference of one train over another, physical characteristics, and availability of track facilities. The dispatching is controlled to ensure required spacing between two successive trains. In a multiple track facility, automatic block signal control is used to impose the required spacing between trains.
in one or both directions. In the junction between double and single tracks, trains are kept in waiting for track availability to move from double to single track. In a section of the system where double track is available, fast trains are allowed to overtake slower trains. The condition set for overtaking is to try for no delay; the next option would be to overtake with imposition of delay on the overtaken train provided it is not a high priority train.

In this event based simulation there are three types of events: arrival event, departure event, and termination event. Arrival and departure event is the time when a train enters the system and the time the train reaches the final destination. The termination event is the end of the simulation after the completion of a predefined period of simulation. The simulation can also terminate if all scheduled trains depart the system. In this event based simulation, the parameters and the operating conditions can be set to values which are within the admissible range. Different categories of data are required to run the simulation model. Basic parameters of the model consists of start and stop time of trains and duration of simulation. Track configuration parameters include number of tracks, direction of movement on tracks, and siding and yard capacity. Train characteristics which take into account the class of train, number of locomotives and running time between stations. Signal system parameters deal with the description of blocks in the segment, number of signal aspects, and the minimum distance between trains. The dispatching schedule parameter specifies the train length, train class, train priority, and the dispatching time.
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Analysis of the Simulation Result

The outcome of the simulation model is a relationship of train delay to the number of trains dispatched, sensitivity of average delay to various parameters, sensitivity of delay to combination of parameters, and model for measuring line capacity.

In this parametric method of capacity measurement, the relationship between dispatching delay per train to train volume is considered a constant value, and this relationship is considered linear in most cases. In some instances, this relationship is a square function and gives a higher measure of delay. The $K$ value (delay slope), which is equal to the delay per train divided by the number of trains per day (delay per train/trains per day), is dependent on train speed, siding spacing, siding capacity, siding length, signal block length, crossover spacing, and line profile. The basic relationship between delay and number of trains is:

$$A = K_o n$$

where:

- $A$ = Average delay per train
- $K_o$ = Delay slope
- $n$ = Number of trains per day

The single modification table in the Prokopy and Rubin (1975) report, as shown in Table 1, furnishes the value of $K$ for the base case and also $K$ values for different modification runs. $K_s$ given in Table 1 is for the square of the slope coefficient. The column $P_i$ is the percentage change of parameters from the base case. The second to last column is the value of $f_{oi}$ (delay slope adjustment factor) for the test cases. The $K_i$ of the test case is the product of the $K_o$ value in the base case and the delay slope ($f_{oi}$) $P_i$ raised to the percentage change in parameters.

$$K_i = K_o (f_{oi})^{P_i}$$

where:

- $K_i$ = delay slope for change in parameter $i$
- $f_{oi}$ = delay slope adjustment factor
- $P_i$ = Percentage change in parameter $i$

**Table 1: An Extract of the Modified “Case Summary” of Simulation Result**

<table>
<thead>
<tr>
<th>Modification from Primary Base</th>
<th>No of tracks</th>
<th>Base case no.</th>
<th>$K$</th>
<th>$k_s$</th>
<th>$P_i$</th>
<th>$f_{oi}$</th>
<th>$f_{oi}^p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single track base case</td>
<td>1</td>
<td>.</td>
<td>.045</td>
<td>.001</td>
<td>-.561</td>
<td>1.775</td>
<td>.724</td>
</tr>
<tr>
<td>5-mile segment</td>
<td>1</td>
<td>1</td>
<td>.031</td>
<td>.001</td>
<td>+.51</td>
<td>1.948</td>
<td>1.406</td>
</tr>
<tr>
<td>15-mile segments</td>
<td>1</td>
<td>1</td>
<td>.060</td>
<td>.003</td>
<td>+.353</td>
<td>2.855</td>
<td>1.448</td>
</tr>
<tr>
<td>21.4-mile segments</td>
<td>1</td>
<td>3</td>
<td>.087</td>
<td>.004</td>
<td>+.353</td>
<td>2.855</td>
<td>1.448</td>
</tr>
<tr>
<td>Uniform segments</td>
<td>1</td>
<td>1</td>
<td>.033</td>
<td>.001</td>
<td>+1</td>
<td>.789</td>
<td>.789</td>
</tr>
<tr>
<td>33% decrease in speeds</td>
<td>1</td>
<td>1</td>
<td>.064</td>
<td>.004</td>
<td>-.395</td>
<td>.415</td>
<td>1.414</td>
</tr>
<tr>
<td>40% increase in speeds</td>
<td>1</td>
<td>1</td>
<td>.022</td>
<td>.0003</td>
<td>+.333</td>
<td>.139</td>
<td>.518</td>
</tr>
</tbody>
</table>

(Prokopy and Rubin 1975)
The parameters that affected delay and in turn capacity can be classified in three broad sub-groups (Figure 2). A simulation run was done to vary the parameters; some are continuous parameters while some are discrete deviations from the base case. There are slope (K) increasing and decreasing parameters. The slope increasing parameters decrease capacity while the slope decreasing parameters increase capacity. The three broad subgroups are as follows:

- **Infrastructure parameters:** This includes siding spacing, distribution of siding, siding capacity, siding length, signal spacing, type of signal, portion of multiple track, crossover spacing, and subdivision length. Siding distance, which is the distance between yards or crew change points, increases delay with increase in length. Sidings, location where trains meet, overtake, or switching takes place, have a vital role in affecting capacity. The siding length should be enough to accommodate the crossing train, and an increase of siding length increases the section capacity. Increasing siding spacing and non-uniformity of distribution of sidings increase delay and decrease capacity. Signal type has a marked effect on section capacity. Automatic block signaling is an improvement over track warrant control, and a centralized traffic control system is an improvement over automatic block signaling. Multiple tracks significantly increase the capacity of railroad sections.

- **Traffic parameters:** These include speed distribution, speed limit, directional imbalance, and train priority. Increase in speed increases capacity, but non-uniformity of speed decreases capacity. Directional imbalance increases track capacity, whereas train prioritization decreases capacity.

- **Operational parameters:** This includes both planned maintenance and unplanned disruptions. Both planned and unplanned disruptions that might cause a temporary closure of a track for a certain length of time drastically reduces capacity.

In the Prokopy and Rubin (1975) report, there are 24 simulation results for single track cases. Out of these, 10 are slope increasing cases, i.e., increased $K_i$ value, and 14 simulation results are slope decreasing cases. In the slope increasing cases, the value of $K_i$ is more than the $K$ values in the base case, hence the value of $f_{oi}^{\text{pl}}$ is more than one. In the slope increasing cases, the $f_{oi}$ value is

---

**Figure 2: Factors Affecting Capacity of Railroad Section**

![Diagram showing factors affecting capacity of railroad section](image)

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Figure 3: Visual Basic User Interface

Figure 4: Flow Chart for Capacity Estimation
greater than one in all cases except three, in which the $P_i$ value is less than zero. In the slope decreasing cases, the value of $f_{oi}^{pl}$ is less than one and the $f_{oi}$ value is less than one in all cases other than two in which the $P_i$ value is less than zero.

Two methods are used to calculate the effect of changes of multiple parameters. One of the methods is the elasticity method, where exponent of $f_{oi}$ to the degree $P_i$ are summed over $i$, where $i$ is all the multiple change parameters. This compound factor is multiplied by the base case delay slope to get the multiple modification changed slope. In the second method of estimating changed slope for multi parameters, the change in parameter values are treated as fractions and the fractions are normalized by taking the $P$th root of the fraction. The combined effect of parameter changes are computed by normalizing the slope increasing and the slope decreasing factors separately.

USER INTERFACE AND REGRESSION MODEL

The algorithm used in the Prokopy and Rubin (1975) model, along with the details of the research, is not available to the public. In the present project, a computer algorithm and user friendly Visual Basic interface is developed to measure the subdivision capacities of a railroad network (Figure 3). The source code of this Windows program is the Parametric Analysis model with the necessary changes incorporated into it. This program is convenient for measuring railroad capacity, and it can
be programmed to read data directly from GIS databases and assign the estimated capacities as attributes to the railroad links.

In this user interface, the five parameters that the user can change are speed uniformity, average speed, directional imbalance, block length, length of the distance between sidings, and the length of the line segment.\textsuperscript{30} There are two entries to be made for each parameter: the specific value of the parameter and the value of the parameter closest to the test cases. The algorithm used for running the interface is presented in Figure 4. Using this interface, railroad section capacity is estimated for different parameter values, and a plot of capacity versus some of the continuous parameters is shown in Figure 5.

To develop a continuous relationship between capacity and the parameters, a number of multivariate regression analyses are formulated and the goodness of fit examined. The one that gives the best result is:

\begin{equation}
\text{Cap} = \beta_0 + \beta_1 (\text{Uni}) + \beta_2 (\text{Speed}) + \beta_3 (\text{speed}^2) + \beta_4 (\text{D1}) + \beta_5 (\text{D2}) + \beta_6 (\text{D3}) \\
+ \beta_7 (\text{D4}) + \beta_8 (\text{Block}) + \beta_9 (\text{Siding}) + \beta_{10} (\text{Length}) + \beta_{11} (\text{Length}^2) + \epsilon
\end{equation}

The variables in the equation are:
\begin{itemize}
\item Cap = Calculated capacity
\item Uni = Indicator variable, if uniform speed then UNI = 1, or UNI = 0
\item Speed = The average speed
\item D1, D2, D3, D4 = Indicator variables
  \begin{itemize}
  \item if directionality factor\textsuperscript{31} 1 then D1 = 1 or 0
  \item if directionality factor 2 then D2 = 1 or 0
  \item if directionality factor 3 then D3 = 1 or 0
  \item if directionality factor 4 then D4 = 1 or 0
  \end{itemize}
\item Block = Block length
\item Siding = Siding spacing
\item Length = Length of the segment
\end{itemize}

The result of the model seems to be a good fit with high F (493.55) and R-squared (0.8199) values as shown in Table 2. The t values for all the parameters are considerably more than the $t_{\alpha/2, n-k-1}$ value. The high variance inflation\textsuperscript{32} for Speed and Length is because of the presence of the squared term. The Speed term has an estimated parameter that is negative; this suggests that with the increase in speed, capacity will increase at a reducing rate. This pattern can be explained by the curve of delay slope versus speed plotted in the Prokopy and Rubin (1975) report. The relation between delay slope and speed is linear, but a squared function could be introduced to give a higher value of delay. As the delay and capacity are inversely related, the relationship between capacity and speed is linear, and with the introduction of a negative squared term, results in a conservative (lower) estimate of capacity.
Table 2: Regression Result

<table>
<thead>
<tr>
<th>Analysis of Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Source</strong></td>
</tr>
<tr>
<td>Model</td>
</tr>
<tr>
<td>Error</td>
</tr>
<tr>
<td>Corrected Total</td>
</tr>
<tr>
<td>Root MSE</td>
</tr>
<tr>
<td>Dependent Mean</td>
</tr>
<tr>
<td>Coeff Var</td>
</tr>
</tbody>
</table>

Parameter Estimates

| Variable | **DF** | **Parameter Estimate** | **Standard Error** | **t Value** | **Pr > |t|** | **Variance Inflation** |
|----------|--------|------------------------|--------------------|-------------|----------|------------------------|
| Intercept | 1 | 59.590 | 3.957 | 15.06 | <.0001 | 0 |
| Uni | 1 | -11.304 | 0.580 | -19.48 | <.0001 | 1.015 |
| speed2 | 1 | -0.031 | 0.001 | -24.79 | <.0001 | 33.766 |
| Speed | 1 | 3.467 | 0.113 | 30.55 | <.0001 | 34.623 |
| D2 | 1 | -3.658 | 0.807 | -4.53 | <.0001 | 1.553 |
| D3 | 1 | -6.794 | 0.820 | -8.28 | <.0001 | 1.531 |
| D4 | 1 | -11.451 | 0.839 | -13.64 | <.0001 | 1.524 |
| Block | 1 | -1.831 | 0.437 | -4.19 | <.0001 | 1.002 |
| Siding | 1 | -1.796 | 0.047 | -37.96 | <.0001 | 1.016 |
| Length | 1 | -0.625 | 0.043 | -14.38 | <.0001 | 54.894 |
| length2 | 1 | 0.0009 | 0.0001 | 6.91 | <.0001 | 54.261 |

APPLICATION OF THE PARAMETRIC CAPACITY MODEL

The user interface developed in this project is used to measure the capacity of the railroad network for the state of North Dakota. The user interface requires length of segment, number of tracks, speed and its uniformity, block length, siding spacing, and directional imbalance to implement the parametric capacity model. To run the model, data can be fed directly into the user interface or data can be read from a spreadsheet or database file. Before the model is implemented, a GIS database of the railroad network in the state is developed. The prime sources of data are the Bureau of Transportation Statistics’ 1:100,000 scale network (“Rail100K”) and 1:2,000,000 scale network (“Rail2m”) (Bureau of Transportation Statistics 2005), the Federal Railroad Administration’s Crossing Inventory database (Federal Railroad Administration 2007), railroad timetables of major railroad companies operating in the state, and the railroad map of North Dakota prepared by the North Dakota Public Service Commission.

Five major railroad companies (two of these are Class I) operate in North Dakota: the BNSF Railway, Soo Line Railroad (which is owned by the Canadian Pacific Railroad), Dakota Missouri Valley & Western, Northern Plains Railroad, and the Red River Valley & Western Railroad (Figure 6). Inputs from the railroad data base are used to run the parametric capacity model, and the subdivision capacities are estimated (Table 3). The track utilization factor, which is the ratio of observed trains per day and practical capacity are estimated to identify possible bottleneck areas.
Table 3: Parametric Capacity Model Estimation Results

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CONCLUSION

A true assessment of existing capacity is essential to improve utilization of existing tracks and to identify areas of bottleneck in the railroad network. Capacity assessment is also required to prioritize infrastructure (track, signal, and siding) development in capacity expansion projects. The capacity estimation method discussed here can be used to estimate section capacity, which in turn can be used to assess transportation system capacity by state agencies and state DOTs that may not have access to proprietary software for capacity estimation. The algorithm developed here for capacity estimation is presently used in a freight corridor assessment project. The user interface developed in this project provides a reasonably good estimation of the practical capacity.

In a capacity expansion project, other modules that are important are traffic forecasting modules, traffic assessment modules, and cost-benefit modules. To estimate present and future traffic flow in the network, the forecasted traffic is assigned on the railroad network, and the track utilization factor is estimated from the estimated train movement and practical capacity of the track section. System capacity can be estimated from the section capacity (Morlok and Riddle 2000), and this system capacity is a measure of throughput of a transportation system, especially when one is assessing a corridor capacity. In the future, the capacity estimation interfaces can be developed into a GIS based decision-support system that can be used by decision makers to identify locations of bottlenecks in a GIS transportation network. This will require the development of a robust GIS railroad network. The model discussed in this paper is a stride to delve into the complex issues of railroad capacity. There has to be continued research and development in this field of capacity estimation to keep railroad transportation competitive and attractive to shippers and carriers.

Endnotes

1. Section – Distance between last stop signal of a station and first stop signal of the next station.
2. Subdivision – A named section of railroad trackage.
3. Length of subdivision – Distance in miles between the beginning and end limits of the subdivision.
4. Meet pass planning point spacing – Average spacing of locations used to meet or overtake trains. Such locations are essential for the bi-directional, mixed priority, and trains operating at varying speed.
5. Meet pass planning point uniformity – The measure of uniformity or consistency in spacing of meet pass planning points.
6. Intermediate signal spacing ratio – Relates the ratio of signal spacing to the siding spacing. Intermediate signals increase capacity by reducing the required spacing between following trains.
7. Percentage of double track — Ratio of railroad tracks in both directions to total length of the section expressed in percentage.
8. Traffic peaking factor – Ratio of maximum number of trains dispatched in certain period of time to average number of trains dispatched in the same time period.
9. Priority probability – Probability function that identifies the chance of a train meeting another train of higher priority.
10. Speed ratio – Ratio between high and low speed.
Railroad Capacity

11. Average minimum run time – Mean time required by a train to travel from one end to the other of a railroad section.

12. Track outages – Planned and unplanned events that take track out of service.

13. Temporary slow orders – Temporary imposition of speed restriction lower than the normal speed limit.

14. Maximum trip time threshold – Upper time limit to travel the total section length.

15. Blocking time – The total time a section of track is exclusively allotted to a train.

16. Urban rapid transit – Passenger railway in an urban area with high capacity and frequency.

17. Linear facilities – Services which are in the same line.

18. Loading coefficient of passengers – Proportion of passenger space utilized in a passenger train.

19. Time headway – Time taken by a trailing train to cover the distance from its tip to the tip of the train in front of it.

20. Block length – Length of track of defined limits, the use of which is governed by signals.

21. Signal aspects – Appearance of a signal conveying an indication that is viewed from the direction of an approaching train.


23. Automatic block signal (ABS) – In ABS system the signals are controlled by trains instead of by station operator. This allows shorter block lengths.

24. Siding – A short section of railroad track connected by switches with a main track.

25. Signal block length – Length of a block which is governed by signals.

26. Crossover – A pair of switches that connects two parallel rail tracks, allowing a train on one track to cross over to the other.

27. Line profile – Cross sectional shape of the rail line.

28. Track warrant control – A verbal authorization system used to authorize trains to occupy main tracks.

29. Directional imbalance – Disparity of trains dispatched in one direction to those dispatched in the other direction over the course of a day.

30. Segment – Part of rail track between the beginning and end limits of the subdivision.

31. Directionality factor – Ratio of train dispatched in one direction to those dispatched in the other direction over the course of a day.

32. Variance inflation – Quantifies the severity of multicollinearity in an ordinary least squares regression analysis.
References


Subhro Mitra is an associate research fellow at the Upper Great Plains Transportation Institute at North Dakota State University. He is also a faculty member with NDSU’s Transportation Logistics Ph.D. program and an adjunct professor in the civil engineering department. He holds a Ph.D. in transportation and logistics from NDSU and has 14 years of diverse work experience in both operational and technical aspects of transportation and highway engineering. He is a registered Professional Engineer in the state of North Dakota.

Denver Tolliver is the associate director of the Upper Great Plains Transportation Institute and director of the Transportation & Logistics Ph.D. program at North Dakota State University. He is also director of the Mountain-Plains Consortium (MPC) – which is the regional transportation center for federal region 8. Tolliver is a long-time member of TRF and a former president of the Agricultural Transportation chapter. His primary research interests are highway, railroad, and inland waterway planning. Tolliver holds doctoral and master’s degrees from Virginia Tech and a baccalaureate degree from Morehead State. Before joining the faculty of North Dakota State University, he was a transportation planner for the North Dakota Department of Transportation.

Sushil Mitra is retired chief signal and telecom inspector of North East Frontier Railway in India. He served with Indian Railway for 33 years, and during his service was in charge of maintenance and supervision of signaling and associated technology meant for safe train movement. He had been instrumental in expansion of railroad capacity in his division and supervised the installation of signaling equipment during double line construction and railway gauge conversion from meter gauge to broad gauge.

In 1992 he received the outstanding employee award from Indian Railway for his contribution and dedication to the service.

Khalid Bachkar has taught graduate and undergraduate students in logistics and supply chain management since joining Cal Maritime Academy in August 2010. He earned an M.S in management information systems from Shippensburg University and a Ph.D. in transportation and logistics from North Dakota State University. Bachkar focuses on research in transportation logistics and supply chain management, container supply chain logistics, supply chain security, supply chain risk management, with special interest in container supply chain security. He was a member of the NDSU Upper Great Plains Transportation Institute research team that participated in the development of GIS multimodal capacity model for the Northern Tier Freight Corridor.

Poyraz Kayabas is a doctoral graduate research assistant with the Upper Great Plains Transportation Institute at North Dakota State University. He received a B.S. in mathematics and computer science and another B.S. in industrial engineering from Cankaya University in Ankara, Turkey, in 2003. He completed his M.S. in industrial engineering and management at North Dakota State University in 2010. Kayabas is interested in supply chain management, logistics, and safety analysis for transportation.
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
- Marketing and Pricing
- Financial Controls and Analysis
- Labor and Employee Relations
- Carrier Management
- Organization and Planning
- Technology and Engineering
- Transportation and Supply Chain Management
- Urban Transportation and Planning
- Government Policy
- Equipment Supply
- Regulation
- Safety
- Environment and Energy
- Intermodal Transportation

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 U.S. 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 U.S. 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.
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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.

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• 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.
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