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Traffic Flow and Road User Impacts of the Collapse of the I-35W Bridge over the Mississippi River

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16. Abstract (Limit: 250 words)

Major network disruptions have significant impacts on local travelers. A good understanding of behavioral reactions to such incidents is crucial for traffic mitigation, management, and planning. Existing research on such topics is limited. The collapse of the I-35W Mississippi River Bridge (August 1, 2007) abruptly disrupted habitual routes of about 14,000 daily trips and forced even more travelers to adapt their travel pattern to evolving network conditions. The opening of the replacement bridge on November 18, 2008 generated another disturbance (this time predictable) on the network. Such “natural” experiments provide unique opportunities for behavioral studies. This study focuses on the traffic and behavioral reactions to both bridge collapse and bridge reopening and contributes to general knowledge by identifying unique patterns following different events. Three types of data collection efforts have been conducted during the appropriate frame of reference (i.e. before vs. after bridge reconstruction): 1) GPS tracking data and associated user surveys, 2) paper and internet-based survey data gauging travel behavior in the post-bridge reconstruction phase, and 3) aggregate data relating to freeway and arterial traffic flows, traffic control, and transit ridership. Differences in reactions to planned versus unplanned events were revealed. Changes in travel cost were evaluated and their temporal and spatial patterns were analyzed. This report concludes with thorough discussions of findings from this study and policy implications.

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Executive Summary

The collapse, on August 1, 2007, of the I-35W Mississippi River Bridge in Minneapolis, abruptly interrupted the usual route of about 140,000 daily vehicle trips and substantially disturbed the flow pattern of the network. In addition to the heavy losses in life and injury, the network disruption significantly impacted road-users and reshaped travel patterns in the Minneapolis-St. Paul Metropolitan area (Twin Cities), which could generate significant user costs due to longer travel distance, higher levels of congestion, and the resulting opportunity losses. Previous studies on such network disruptions are limited (Giuliano and Golob, 1998). This study provides a brief review of 16 existing studies on behavioral responses after network disruptions in the literature, most of which only provide a limited picture of the impacts generated of such events, and no realistic policy options for such events have been provided. We conclude that the major barrier for a comprehensive analysis is the lack of field data because of the unusual occurrence of large-scale network disruptions and the unpredictability of such events.

To bridge the gap between the need in traffic management and policy and our limited understanding of impacts to traffic flow and road user after major network disruptions, this study explores traffic and behavioral reactions to both bridge collapse and bridge reopening and contributes to general knowledge by identifying unique patterns following different events. This study also comprehensively evaluates the changes in travel cost and their temporal and spatial patterns. In contrast with previous studies on network disruptions, this study is supported by comprehensive data collection initiatives, including:

1. GPS tracking data, report generation and associated user surveys,

2. Paper and internet-based survey data gauging travel behavior in the post-bridge reconstruction phase, and

3. Other aggregate data relating to freeway and arterial traffic flows, traffic control, and transit ridership

during the appropriate frame of reference (i.e. before vs. after bridge reconstruction). The longitudinal GPS data are unavailable for any of such previous studies.

Based on findings from both macroscopic flow patterns and individual reactions, discussions about travel demand modeling and policy implications are provided. The study helps to inform policy choices for Minnesota Department of Transportation (Mn/DOT) and the Metropolitan Council and other relevant agencies and serves as baseline for future studies on network disruption and individual travel behavior modeling.

Findings and policy implications

This study investigates the traffic dynamics following prolonged network disruptions and identifies two distinctive traffic patterns depending on the nature of the disruption. Following an *unexpected disruption*, an avoidance phenomenon is observed, where drivers initially avoid the disruption site until the perceived risk of the area gradually diminishes. Consequently, an oscillation of travel demand occurred surrounding the event sites. The scale and longevity of such oscillation diminishes as the area of analysis becomes larger and the number of meaningful alternative routes increases. After the I-35W Bridge collapse, the traffic stabilized within about six weeks immediately around the bridge site, while the overall demand within the I-494/I-694 beltway never changes too much. A similar phenomenon is observed in the San Francisco Bay Area network after a similar disaster. In contrast, a *preplanned disruption*, even with similar magnitude, generates much smaller impacts. Neither the closure and reopening during the Minnesota Trunk Highway 36 construction nor the reopening of I-35W Bridge generated significant oscillation of traffic. Such difference in flow patterns may be due to the psychological shock brought by unexpected events and unpreparedness during the adaption to new traffic condition. Therefore, this research suggests that a quick and well-designed detour plan could help to improve traffic condition by mitigating the psychological shock and assist travelers in developing alternative travel plan.

A difference is also likely due to the different nature of closure and reopening. A closure requires users to switch routes at the time of closure (and permits them to do so earlier if such a change is planned). An opening on the other hand allows, but does not require, users to switch to the new (or replacement) facility.

Analysis in this study could suggest that travelers can well adapt to the new traffic condition during a relatively short time period after the collapse of I-35W Bridge. Network redundancy, provided by the existence of alternative river crossing, was critical for absorbing the traffic detoured from the collapsed bridge. The ability to create additional travel capacity through traffic restoration measures, such as restriping I-94 and transforming Minnesota Trunk Mn 280, were essential in dampening the negative traffic effects of the bridge collapse. The importance of the fourth through lane on the I-94 Bridge becomes more evident after considering the congestion emerging after that lane was reverted to a bus-only shoulder lane. In short, the I-94 Bridge (coupled with Mn 280) was for many trips a good substitute for the I-35W Bridge. In contrast, because of the asymmetric network configuration, the I-35W Bridge would not be an ideal replacement for the I-94 bridge. This observation may inform future analysis of network robustness and have significant implications for network design.

Analysis based on three different demand tables (which are the most accurate ones available under current practice) consistently suggested that the new I-35W Bridge helped to reduce total travel cost most of the time, but the magnitude of such benefit is limited (0.2% 0.3%). This result based on field observations is consistent with conclusions drawn in a early analysis by Xie and Levinson (2009) based on University of Minnesota developed planning models. Similarities in conclusions drawn in both studies imply that a travel demand model typically used for planning and forecasting, *with elastic demand, i.e. demand varies in response to travel cost* can provide a good, first-order estimate of the overall impacts due to such network disruption scenarios. The assumption of unchanging demand will likely lead to an over-estimate of the impact of such an event, and potentially to a misallocation of scarce resources. Quick-response travel demand models could play a significant role in developing mitigation plans and assist decision-making. Similar procedures could also be applied to analyze future road or bridge closure scenarios with the luxury of time.

Using the Metropolitan Council Planning travel demand tables, the new bridge saved travelers 3500 hours from 6am to 7pm per day (we did not calculate the changes in travel cost outside of this time window because of the lack of speed observations and low demand). If we assume travel time worth \$14/hour, then the new bridge generated a benefit of \$ $49,000$ dollars per day during this time period due to travel time savings. Given the travel demand in early morning and in the late evening is low, the overall travel time savings should be slightly larger but close to this number. This estimate is close to the lower bound of detour costs estimated *ex ante* by Xie and Levinson (2009) immediately after the bridge collapse. Given the longevity (more than 13 months) of this network disruption, some people have changed their travel destinations and frequency, if not residential location and jobs. These changes in origin-destination demand tables, together with inertia in route decisions, may have reduced some potential benefits in travel time savings. In retrospect, the early completion bonus (\$ $200,000/day$) for the contractor of the replacement I-35W Bridge exceed our *ex post* estimate of user costs. Other potential benefits, such as network reliability and robustness in the case of another network disruption or mitigating non-travel time impacts to affected residents and businesses, have not been included in this analysis.

This study also identified that the temporary fourth through lane on the I-94 Bridge was as significant as the entire I-35W Bridge to overall travel times in the morning commute. The redistribution of travel demand from arterial streets to freeway system due to the new bridge is detrimental to the system efficiency and may help to explain the congestion emerging at the upstream of the merging point between I-94 and I-35W.

From an individual perspective, the most common reactions to the I-35W Bridge collapse were changing routes and changing departure time, both of which were reported by more than 70% of survey respondents. Although the increase of public transit usage was detectable in both aggregate ridership data (Zhu et al., 2009) and in survey results after the bridge collapse, such increase was moderate.

By analyzing travel cost analysis across the Twin Cities region, this study found that the travel cost was not been uniformly reduced for all travelers by adding a faster link with high capacity (10 lanes) to the network. Some travelers experienced an increase in travel time due to the redistribution of travel demand and new bottlenecks (re-)emerging after the opening of the replacement bridge. Such observations from macroscopic analysis are echoed by results from individual surveys. Although the scale of travel time increase is small (less than 2 minutes for residents from most census block), it should be considered in future decision making.

The collapse of the I-35W Bridge crossing the Mississippi River arouses concerns about the safety of rebuilding bridges while only partially closing them, i.e. allowing traffic on a bridge which is under construction. Given the flexibility in individual travel patterns and capacity redundancy of the Twin Cities surface transportation network observed in this study, it may be more beneficial to conduct future bridge maintenance with full closure. The travel time savings due to shorter maintenance period and improvement in safety, plus the lower construction costs, may outweigh the users costs due to extra travel distance caused by full closure. A travel demand model can help to weigh the potential benefits and costs under the partial and full closure scenario, respectively, and assist future decision-making.

Chapter 1

Introduction

The collapse, on August 1, 2007, of the I-35W Bridge over the Mississippi River in Minneapolis, abruptly interrupted the usual route of about 140,000 daily vehicle trips and substantially disturbed the flow pattern of the network. In addition to the heavy losses in life and injury, the network disruption also significantly impacted road-users and reshaped travel patterns in the Twin Cities area, which could generate significant cost due to longer travel distance, higher levels of congestion, and the resulting opportunity losses. The Minnesota Department of Transportation (MnDOT) estimated rerouting alone could cost individual travelers and commercial vehicles $400,000 daily. Xie and Levinson (2009) estimated a lower, but still large, road user cost, between $71,000 and $220,000 per day. As a result, a significant financial incentive was given to the contractor for the early completion of the replacement bridge. A similar financial incentive was employed after the Northridge Earthquake in California (the transportation-related costs due to network disruption in Los Angeles basin were estimated to exceed $1.6 million per day (Wesemann et al., 1996)) and a contractor earned $ 14.8 million ($200,000 per day) for completing work on freeway I-10 66 days ahead of initial schedule. Most of these decisions were based on planning models and conclusions were drawn through travel demand assignments on degraded networks, using User Equilibrium (UE) assumptions ("the journey times in all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route" according to Wardrop (1952)). However, behavioral responses to the network disruption are much richer than what could be predicted by planning models. The network disruption forced travelers to explore the network and adjust their travel behavior according to their travel experience and external information resources. Immediately after the network disruption, travelers may:

- change their normal route because of road and ramp closure or congestion caused by traffic re-allocation,
- adjust travel time to avoid congestion,
- satisfy needs at other destinations,
- consolidate trips and travel less frequently,
- switch to alternative travel modes,
- share travel duties among family members.

In the long term, travelers may also adjust their residential and work locations (Cairnes et al., 2002; Goodwin, 1977) . Until a new equilibrium is found (a period sometimes referred to as "the transient phase"), traffic may significantly deviate from the results predicted by planning models. For example, Clegg (2007) showed that a capacity reduction due to road construction generated an initial "over-reaction" effect followed by a "settling down" effect, using license plate match data from the City of York, England. Oscillation of overall traffic and individual route choices was reported. Although network disruptions are mostly temporary as damage is eventually repaired and capacity restored, travel experience accumulated during this time period could lead to permanent changes in travel patterns. van Exel and Rietveld (2001) indicated new patterns could become habitual once travelers explore and accept the driving experience during transit strikes.Cairnes et al. (2002) also argued travel behaviors were conditioned on new experience instead of past history after investigating 70 case studies of road capacity reduction. Most of these day-to-day dynamics in travel demand cannot be captured by aggregate UE models Cairnes et al. (2002). A good understanding of the behavioral changes and decision-making mechanism could not only better assist traffic management and the design of a mitigation plan in response of network disruptions, but also inform future research in travel demand modeling.

However, it is not easy to capture such a day-to-day learning and decision-making process. In an environment with which they are familiar, travelers' route choice decisions may be very stable. Goodwin (1977) argued travelers do not carefully and deliberately evaluate their choices because of "a reluctance to upset an ordered and well-understood routine". As the travel pattern remains unchanged, the role of habit increases and rational factors become less dominant, preventing relevant information from reaching decision makers and rational choices.

Given the unusual occurrence of large-scale network disruptions, there have been few data collection initiatives and empirical studies on behavioral responses. Instead, many studies have focused on the network reliability (e.g. Sumalee and Kurauchi (2006)) or long-term regional and interregional economic impacts (e.g Ham et al. (2005a)) under hypothetical disasters, assuming traffic follows User Equilibrium assumptions. However, evidence suggests that behavioral responses are more complicated than what is predicted by UE assumptions and depends on the nature of the disruption. For example, inbound traffic to Calgary, Alberta dropped 4.4% during the 14 month long closure of that city's Center Street Bridge, and the morning peak period moved forward for 15 minutes (Hunt et al., 2002). A significant learning and adapting processes among travelers has been observed after the I-35W Bridge collapse and traffic counts recorded by nearby freeway detector stations oscillated for about 6 weeks (Zhu et al., 2009). After the traffic pattern stabilized, total river crossing trips reduced by 6.3%. Network disruptions caused by earthquakes usually strike wider areas and have more significant impacts. However, travelers responses were similar to previous cases: most travelers adjusted their route and departure time, while staying loyal to their cars (e.g. Northridge Earthquake (Giuliano and Golob, 1998)).

Consistent with theoretical research on travel behavior (Goodwin, 1977), empirical studies show that travel experience during network disruptions affect travel choices after capacity restoration. For example, Tsuchida and Wilshusen (1991) shows evidence that the conversion of Route 17 to a Carpool facility after the Loma Prieta earthquake led many people to adopt ride sharing, and a significant proportion of the adopters continued to carpool even after the route was opened to general traffic. Psychological impacts and spatial knowledge could also play a significant role in determining travel choices.

Major network disruptions such as the I-35W Bridge collapse could disrupt habitual behavior and provide unique opportunities for behavioral studies. Evidence presented in subsequent chapters of this document suggests it took several weeks for the network to re-equilibrate, during which period, travelers continued to learn and adjust their travel decisions. The reopening of the new I-35W Bridge generated another significant disturbance on the network. Therefore, this research focuses on both the traffic and behavioral reactions to both bridge collapse and bridge reopening and contributes to general knowledge by identifying unique patterns following different events. Three types of data have been collected during the appropriate frame of reference (i.e. before vs. after bridge reconstruction):

1. GPS tracking data, report generation and associated user surveys,
2. Paper and internet-based survey data gauging travel behavior in the post-bridge reconstruction phase, and
3. Other aggregate data relating to freeway and arterial traffic flows, traffic control, transit ridership.

Differences in reactions to planned versus unplanned events were revealed. Changes in travel cost were evaluated and their temporal and spatial patterns were analyzed. Therefore, this report is organized as follows: the next Chapter provides a thorough review of previous studies on network disruption and identifies data needs for this study; three different data collection efforts are then described in detail; patterns in traffic and behavioral reactions are discussed in Chapters 4 and 5, respectively; Chapter 6 evaluates changes in travel cost after bridge reopened and bridges the macro and micro patterns. This report concludes with thorough discussion of findings from this study and policy implications.

Chapter 2

Previous Studies on Disruptive Events

Although there is a vast literature on travel behavior, previous research on behavioral responses to major network disruptions is limited (Giuliano and Golob, 1998). However, large-scale network disruptions are unusual but not unknown. For bridge failure alone, we have in recent years seen the collapse of part of the I-80 San Francisco-Oakland Bay Bridge and I-880 Cypress Street Viaduct in Loma Prieta Earthquake, the Hatchie River Bridge in Tennessee, and the I-40 bridge at Webbers Falls, Oklahoma, among others. The lack of behavioral studies may be partly due to the difficulty of large-scale data collection after major incidents, especially when traffic monitoring devices such as loop detectors and cameras were not widely deployed. For example, the collapse, in 1975, of the Tasman bridge in Hobart, Australia, significantly disrupted the network because the nearest alternative, the Bridgewater bridge, required 50 kilometers extra drive and there was little vehicular ferry service available. During the 14 months of reconstruction, 60% of the 44,000 daily trips before the bridge collapse disappeared (Hunt et al., 2002), creating a major pattern shift. However, no detailed analysis on behavioral changes has been provided in the literature. As individual-based travel demand modeling receives more research interest and more data collection initiatives are implemented, there has been increasing literature focusing on behavioral responses after major network disruptions.

Table 2.1 summarizes 16 existing studies on behavioral responses after network disruptions in the literature. Some of them focused on one specific aspect of behavioral changes (e.g. Ferguson (1992) focused on transit riders), while others were more comprehensive and addressed a wide spectrum of issues in travel demand (e.g. Giuliano and Golob (1998)). Network disruptions caused by different types of incidents exhibited very different effects in travel demand (e.g. route switching may be the most universal after a bridge closure (Hunt et al., 2002; Zhu et al., 2009), while responses to earthquakes have been more diverse), while the underlying behavioral pattern may be quite similar. Therefore, this section briefly reviews existing studies on network disruptions by their causes:

1. transit strikes (summarized in Table 2.2),
2. bridge closures (summarized in Table 2.3),
3. special events, and
4. earthquakes summarized in Table 2.3. Followed are some discussions about behavioral patterns emerging from these events and data needs for future studies.

Table 2.1: Empirical studies of traffic and behavioral response to network disruptions

Event	Year	Focus	Traffic	Transit	Occupancy	Survey Type	Effective Sample	Response Rate
New York City transit strike (van Exel and Rietveld, 2001)	1966	Ridership changes	Traffic survey			Home interview of transit users	8000	
Tasman Bridge, Hobart, Australia (Hunt et al., 2002)	1975	Traffic change						
Pittsburgh transit strike (Blumstein and Miller, 1983)	1976	Comprehensive	Traffic counts		Manual counts	Two telephone surveys, 70% on commuters and 30% on non-commute bus users	1000	
Knoxville transit strike (Wegmann et al., 1979)	1977	Transit ridership losses		Ridership				
Orange County transit strike (Ferguson, 1992)	1981, 1986	Transit ridership losses		Ridership				
SR-17, Loma Prieta Earthquake, California (Tsuchida and Wilshusen, 1991)	1989	Car-sharing				Two mail-in surveys on carpooling passengers	587 and 187	29% and 33%
Northridge Earthquake, California Giuliano and Golob (1998); Wesemann et al. (1996)	1994	Comprehensive	Detectors, Caltrans	Ridership	HOV usage	Telephone survey, random	846	84.60%
Kobe earthquake (Chang and Nojima, 2001)	1995	System performance	Detector counts					
Center Street Bridge, Calgary, Canada (Hunt et al., 2002)	1999	Comprehensive	Two-day traffic survey	Ridership	Manual counts	Telephone survey, bridge users	1500	
I-880 reopening, California (Dahlgren, 2002)	1999	Comprehensive				Mail-in survey, hypothetical questions	822	13%
Amsterdam transit strike, Netherlands (van Exel and Rietveld, 2001)	1999	Transit users				Interview and mail-in survey	166	28.40%
Sydney Olympics (Hensher and Brewer, 2002)	2000	System performance	Revenue at toll roads	Ridership				
Los Angeles transit strike (Lo and Hall, 2006)	2003	Traffic impact	Detectors					
Athens Olympics (Dimitriou et al., 2006)	2004	Public transportation		Ridership		Questionnaire	14000	
Road maintenance, City of York, UK (Clegg, 2007)	2005	Traffic	Video record			Plate match	one hour	$\approx$ 50%
I-35W Bridge collapse, Minneapolis, MN	2007	Comprehensive	Detectors, MnDOT	Metro Transit		Mail-in Questionnaire	141	14.1

Table 2.2: Impacts on traffic and travel behavior of transit strikes

City	Year	Duration	Traffic increase (%)	Peak hours	Leave earlier (%)	Cancel trips (%)	Transit to carpool (%)	Transit to drive (%)	Change route (%)	Long-term lossses in ridership (%)
New York City	1967	13 days		2h to 4h		10(50*)	16.7	50		2.1-2.6
Pittsburgh, PA	1976	5 days	20(40*)	Spread	65		28(37**)	10	18	
Knoxville, TN	1977	6 weeks								7-16
Orange County, CA	1981, 1986	21 days, 15 days								15-20
Netherlands	1995	4 weeks				10		30		0.3-2.0
Amsterdam, Netherlands	1999	1 day			10(18***)	10		15		
Los Angeles, CA	2003	35 days		200%						

* On the first day of strike

** Dropped off by a non-commuter, presumably the spouse

*** Percentage for departure later

Table 2.3: Behavioral changes after bridge closures or bridge collapses after an earthquake

Event	Leave earlier (%)	Leave later (%)	Drive to carpool (%)	Drive to transit (%)	Transit to carpool (%)	Transit to drive (%)	Change route (%)	Cancel trips (%)	Other destinations (%)
Tasman Bridge, Hobart, Australia								60	
SR-17*, California			57						
I-10**, California	21.7	7.9	5.8	0.3	2.4	0	31.2		5.4
Center Street Bridge, Calgary, Canada	39			3.6				2.7	
I-880 reopening*, California		41				7		3	9
I-35W, Minneapolis	17.7	9.9	0	2.63	0	0	39.72	7.8	33.33

* Damaged in Loma Prieta Earthquake, 1989

**Damaged in Northridge Earthquake, 1994

2.1 Summary of previous studies on disruptive events

2.1.1 Transit strike

Public transit strikes disrupted the normal travel of transit riders and disturbed the network by increasing use of personal vehicles. Transit strikes also provide a unique opportunity to understand alternatives transit riders have and how travel decisions are made, both of which are crucial for drafting future transportation policies. Although news coverage and qualitative descriptions about transit strikes are widely seen in the media, quantitative analysis of traffic and behavioral responses are limited.

The 1966 transit strike in New York City (lasting 13 days) significantly affected the network because public transit represented 60% of total trips in New York City. According to a study by the New York City Transit Authority (NYCTA) based on home interviews of 8000 transit users, 67% of commuters switched to private vehicles, 75% as drivers and 25% as passengers. On the first day 50% travelers cancelled their trips but this number reduced to 10% in following days, showing the effects of initial shock and subsequent adaptations among travelers. With more cars on route, the peak period spread from 2 hours to 4 hours. More interestingly, estimates from subsequent studies indicated permanent losses in transit ridership (2.1% for work trips, 2.6% for shopping trips, and 2.4% for other trip purposes) after service was restored. Similarly, the 1981 and 1986 Orange County transit strike in California reduced 15% to 20% of transit trips after the strike according to Ferguson (1992). However, the importance of these numbers should not be exaggerated because public transit only represented 2% of total trips in Orange County. Lo and Hall (2006) investigated the effects of the Los Angeles transit strike based on loop-detector data. They revealed that although overall traffic flow remained almost the same due to the small number of bus riders, the data clearly showed a spread of the morning peak hour and a higher level of congestion during the strike period. Individual behavior, however, was not discussed in this paper due to lack to data.

A more detailed study was provided by Blumstein and Miller (1983), focusing on the 1976 transit strike in Pittsburgh, where 60% of the commuters to the CBD use transit. Both traffic counts and survey data were employed in the analysis. A surge in total traffic (up about 40% on the first day and 20% after), vehicle occupancy (up 50%), downtown garage usage (up about 10%), and taxi revenue (up 9.9%) were observed and there was a spread of the peak period. Two subsequent telephone surveys indicated that most previous transit users were dropped off by a non-commuter (presumably a spouse), while 10% and 28% of previous transit riders decided to drive alone and carpool, respectively. The authors argued that the "dropped-off" trips explained most of the increases in total traffic and vehicle occupancy, and vehicle ownership played a key role in choosing alternative mode (households with no car or only one car were more likely to use "drop-off" compared to households with two or more cars). Impacts on travel patterns of previous single drivers were also reported, including switching route (18%), departure earlier (65%), and changing parking place (31%). However, no modeling work was reported despite the abundance of data.

van Exel and Rietveld (2001) provided a comprehensive review of 13 major strikes in the public transit sector. Their impacts on traffic vary significantly, primarily depending on the importance of public transit among other modes. However, individual travel choices, constrained by long-term factors such as car ownership, working and residential location, seem more sensitive to the length and extent of such strikes.

2.1.2 Bridge closure

Bridge closure damages the network by completely shutting down one important link. Its impacts on traffic and travel behavior depends on alternatives available. The aforementioned case of Tasman bridge represents one extreme where alternatives are almost non-existent, causing severe disruption in normal travel. However, network redundancy is more common in metropolitan areas, where impacts of bridge closure could be moderate.

Hunt et al. (2002) evaluated travelers' responses to a 14 month long closure (from August, 1999) of the Center Street Bridge in the city of Calgary, Alberta, Canada, based on both traffic counts and results from a telephone survey. Traffic observations indicated a minor drop (4.4%) in total daily trips and a 15-minute forward shift of the morning peak period. Public transit ridership increased by 6.6%, while vehicle occupancy declined 1.5%. The traffic count data, however, only included observations of two days, in May 1999 and May 2000, respectively. The limited data prevented them from drawing statistically significant conclusions. Moreover, background conditions may have changed significantly over a year, preventing them from establishing any convincing causal effects. Therefore, a telephone interview survey was conducted to supplement the study, which generally confirmed previous findings. Although route switching effects were reported (15% to 30% of users of five parallel bridges before the bridge closure used a different bridge), no robust analysis was provided.

Clegg (2007) showed that a partial bridge closure (significant capacity reduction) due to road construction generated an initial "over-reaction" effect followed by a "settling down" effect, using license plate match data from the City of York, England. Oscillation of overall traffic and individual route choice were reported.

2.1.3 Special events

Special events such as Olympic Games also significantly disrupt normal traffic by introducing a highly concentrated travel demand. However, transportation agencies usually have a greater authority in these circumstances and travelers are generally more willing to follow instructions. For example, although promoting public transit is difficult, 74% trips were carried by public transit during 2004 Athens Olympics according to Dimitriou et al. (2006). High transit ridership was also observed during the 2000 Sydney Olympics according to(Hensher and Brewer, 2002) (no detailed percentage number provided), although bus riders had to wait as long as 45 minutes. As a result, background traffic dropped 2% to 4.5% depending on the location, and travel speed doubled. These events show great potential for public transit. Although questions on how to achieve similar transit usage in day-to-day dynamics have been frequently asked, no detailed studies on decision-making mechanism under these circumstances have been provided.

2.1.4 Earthquakes

Earthquakes and similar disasters may create extensive and lasting damage to the network.

Chang and Nojima (2001) investigated the post-diaster transportation system performance after the 1995 Kobe, 1989 Loma Prieta, and 1994 Northridge earthquakes, using measures based on length of network open, total and areal accessibility. No analysis on behavioral responses were provided. Instead, Tsuchida and Wilshusen (1991) investigated the car-sharing program in Santa

Cruz County, California, which was mandated immediately after the Lima Prieta Earthquake and was removed after capacity was restored. Traffic changes, however, were not included.

Giuliano and Golob (1998) and Wesemann et al. (1996) study traffic and behavioral responses after the 1994 Northridge Earthquake in Los Angeles basin, California. Caltrans systematically documented the freeway traffic volume and Los Angeles Department of Transportation (LADOT) counted arterial traffic on a randomly chosen weekday each month. Metrolink collected all passenger counts by station and different bus operators had monthly passenger ridership by route. Vehicle occupancy was roughly estimated by the level of High Occupancy Vehicle (HOV) lane usage. Total demand (in person-trips) and shares of different modes were evaluated by the trips crossing the I-5 corridor screen line drawn between south of I-5/SR-14 junction and Balboa Boulevard. The traffic on I-5 (the bridge at Gavin Canyon and the interchange between I-5 and State Route 14 collapsed) dropped 59% immediately. However, after restoring 70% of pre-earthquake capacity by implementing a series of mitigation projects, traffic volumes increased to 88% of pre-earthquake level. After full capacity was restored in May 1994, total traffic increased quickly and went beyond the 1993 level in June by 1%. Arterials still sustained significantly higher traffic compared to the pre-earthquake levels (carrying 10.85% of all daily trips crossing the screen line on I-5 corridor compared to the 3.62% before earthquake). The rail ridership (Metrolink) surged (carrying 9.64% of all daily trips on the I-5 corridor) immediate after the earthquake, and then gradually reduced (0.83% of total trips, compared to 0.21% before the earthquake).

Bus ridership remained flat (0.29% of all trips on the same corridor) during this period. Transit trips only accounted for 1.1% of total trips once pre-earthquake capacity was restored. Meanwhile, a telephone survey was conducted to sample 1000 workers in February 1994. Significant changes were reported in all aspects of travel decisions, though with different magnitude. Changing route (31.2%) and changing schedule (21.7% of respondents left earlier while 7.9% left later) were the most dominant, while changing mode had a smaller but detectable proportion (5.8% from drive alone to carpool/vanpool and 0.3% to transit). Similar trends were revealed on I-10 where the Fairfax Avenue bridge collapsed. Systematic data collection efforts from different transportation agencies allowed this study to evaluate changes in traffic patterns over time.

However, the traffic shares of freeway, arterials, and transit one month after full capacity were restored were still significantly different from the market shares one year before. And no arguments have been provided about whether traffic patterns had re-equilibrated, which is crucial for travel demand analysis. Duration of this re-equilibration process may extend from several days (Clegg, 2007) to one year (Hunt et al., 2002) depending on context, and in models this has usually been assumed without solid justification. Robust statistics have to be introduced to evaluate the equilibration process and longitudinal observations are required.

2.2 Behavioral effects

Behavioral responses after network disruptions are the key research question in all these studies, each of which had specific focuses depending on the context and data availability. Table 3 summarizes primary findings from the literature. Instead of chronologically reviewing these studies, this section only presents important findings and unanswered questions where future research is needed.

2.2.1 Route choice and departure time

Cairnes et al. (2002) investigated 70 case studies of road capacity reduction and concluded that although people changed mode, consolidated trips for different purposes and visited alternative destinations in response to network degradation, "changing route and changing journey time seem to be the most universal". Findings in the literature generally confirm this conclusion, while the magnitude of changes varies depending on the context. However, no research efforts have been dedicated to building individual based models, using data collected from these studies. Although route switching effects were reported in these studies (Hunt et al., 2002), the details of actual routes used by respondents were ignored most of the time, preventing further theoretical studies. The survey methods used, including both telephone interview and mail-in questionnaires, cannot easily record and compare routes used, especially for car drivers. Ideally, automatic route recording devices such as GPS recorders should be employed.

Replicating travel route using questionnaires is easier for transit users. Dimitriou et al. (2006) evaluated the travel pattern during 2004 Athens Olympics , using a survey of 14,000 Olympic Games passengers. The travel chains were analyzed, showing although visitors might drive a significant portion of entire trip, the mode for final stage was predominantly public transit. However, their study focused more on public transit planning during such one-time major events, while its implications for modeling individual travel decisions are limited.

2.2.2 Preference for driving

Travelers have a strong preference for driving. According to a stated preference survey conducted after reopening of I-880 (Dahlgren, 2002), 9% of respondents stated that they would considering moving further from work and 11% reported that they would consider taking a job further from home as a result of travel time savings. A small share (7%) of respondents indicated that they would otherwise take transit if the bridge had not opened, which is surprisingly high.

Strong preference for driving alone is consistent with the difficulty of persuading travelers using public transit. In the case of I-5 in California, 88% of traffic returned with only 70% of capacity restored (Wesemann et al., 1996). Therefore, travelers must search for extra capacity available in the previously off-peak period, and thus create new congestion. However, travelers still prefer to drive, even with an 11.7 to 21.7 minutes increase in delay. In the modern metropolitan area, network redundancy is very high. A tolerance as large as 20 minutes before switching mode implies that very few travelers would switch mode because of delay. Giuliano and Golob (1998) indicated that the parking shortages, crowdedness on trains, and delays due to frequent aftershocks might drive many riders back to car. Also, accessibility provided by public transit is very low in decentralized Los Angeles. Therefore, we should be cautious in generalizing this conclusion.

2.2.3 Travel experience

Many researchers have argued travelers make travel decisions based on previous experience (Goodwin, 1977), which may introduce non-linearity and generate travel patterns in disequilibrium. van Exel and Rietveld (2001) indicated that strikes undermine the perceived reliability of public transit and encourage some transit riders to switch to driving alone or carpooling. Moreover, new patterns could become habitual once travelers consider the driving experience. Their conclusions are supported by evidence from the permanent losses in public transit ridership after major transit strikes, including 1966 New York City (2.1%-2.6%), 1977 Knoxville (7%-16%), 1981,1986 Orange County, California (15%-20%), and 1995 Netherlands (0.3%-2%).

Tsuchida and Wilshusen (1991) drew a similar conclusion after investigating the car-sharing program in Santa Cruz County, California. Commuters were required to share vehicles during the reconstruction period after the Lima Prieta Earthquake. After the damage was repaired and ride-sharing mandate removed, 57% of survey respondents continued with ride-sharing. More interestingly, the primary reason convincing them to continue was cost-savings of ride-sharing experienced during this mandate (42%), followed by the people they shared rides with (22%), enjoyment of the trip (12%), environmental preservation (12%), and finally, less stress (10%).

Hensher and Brewer (2002) noticed people were willing to change their behavior for a one-time "single largest major event" (background vehicle trips dropped and transit ridership was high) when evaluating performance of public transportation in 2000 Sydney Olympics. Priority measures during the 2004 Athens Olympics increased the average speed of buses from 15-17 km/h to 30-40 km/h, creating significant incentives for riding buses (Dimitriou et al., 2006). Both studies argued that travel experience and performance of public transportation during the Games could promote a permanent shift in travel pattern.

Evidence from these studies provides strong arguments for introducing travel experience in demand modeling, which could not only improve accuracy of demand forecasting, but also capture day-to-day traffic dynamics. More research is required to model travel experience and empirical studies after network disruptions could provide valuable guidance.

2.3 Data collection methods

High-quality data is crucial for empirical studies and it is a big challenge to design and implement data collection schemes within the limited time after network disruptions. Automatic data collection devices enable 24/7 traffic monitoring with higher accuracy, which could greatly expand the depth and extent of analysis. For example, longitudinal analyses were only implemented in the case of I-5 corridor after the Northridge Earthquake because Caltrans systematically documented freeway traffic data collected by loop-detectors, which was not available in many other studies. Data collection on arterials still depends on manual counts in all these studies, representing a major barrier for traffic analysis in the metropolitan area. This barrier could be overcome by retrieving traffic data from signal control systems, which have been widely deployed in major cities. HOV and HOT lanes provide good data resources for vehicle occupancy. However, vehicle occupancy on the entire network cannot be estimated without supplementing typically collected data. Similarly, ridership statistics from transit operators provide good estimates of total trips. However, it tells little about the boarding stops, boarding time and duration of those trips, all of which are crucial to fit a transit model.

Traffic observations alone cannot support a well-founded analysis of behavioral changes. Well-administered surveys are required. In the literature, three types of surveys, telephone survey, home interview, and mail-in questionnaires, have been employed. Home-interview and telephone survey have higher response rate ($\geq 80\%$) in studies listed), they are, however, also generally more expensive. Mail-in surveys have a much lower response rate in the literature. Moreover, concerns about self-selection biases should be addressed before using such data.

License plate matching was employed by Clegg (2007). By identifying vehicles at different survey points, trip travel time could be estimated. Based on the same approach, route choice could be systematically estimated. However, collecting license plate numbers remains labor-intensive, and cannot be implemented on a large-scale without a major new infrastructure investment. Moreover, Clegg (2007) also reported that plate-matching is error-prone and more research is required to generate convincing results.

2.4 Discussion

Although network disruptions occur from time to time and provide unique opportunities to explore travel behavior, existing studies in the literature are limited. Traffic data were limited in time and locations before loop-detectors were widely deployed, preventing continuous traffic observation. As a result, no statistical analysis have been provided to empirically measure the re-equilibration of traffic flow, a key concept in travel demand modeling. A practical measure of network equilibrium could not only advance theoretical research in travel demand modeling, but also guides the efforts in survey and behavioral study.

Although surveys based on questionnaires, telephone calls, and home interviews have been routinely conducted and generated significant findings, they are not sufficient to support the impact evaluation, the development of mitigation plans, and long-term transportation planning after major network disruptions. For example, none of the three survey tools currently used could provide a good description of route choices, which is crucial in large metropolitan areas because of the complexity in network and thus the large number of alternative routes.

Existing studies clearly showed the important role of experience in travel decisions, which has been frequently discussed in theoretical studies. However, the barriers to empirically capture its role are two-fold. First, it is difficult to observe travel decisions over time with current survey approaches (respondents describe their travel pattern either on one day, or generally during a period). Second, it is very hard to integrate survey data with traffic information (predominantly from loop-detectors), which reveals the traffic environment travelers experienced.

Considering these difficulties, this research employs advanced survey approaches such as Global Positioning System (GPS). Objective observations of travel decisions and experience such as route selected, departure time, travel speed, and on-route delay from these devices could supplement subjective evaluations collected from existing surveys, and thus allowing more sophisticated behavioral analysis. Moreover, devices such as GPS allow accurate observations of day-to-day route choices for the first time, and easily combine them with traffic information if clocks from both system are carefully synchronized.

Inspired by the data needs identified in this section, three data collections efforts have been conducted during the appropriate frame of reference. The objective is to understand how travelers' behavior and the performance of transportation networks have evolved in response to a major disruption. This includes understanding how travelers' choices (e.g. route, mode, destination, departure time, decision to telecommute) were exercised during the bridge closure and again after the reopening, and also how flows on the transportation network evolved (or did not) toward equilibrium. These efforts are discussed in the following Chapter.

Chapter 3

Data Collection

In response to the initial collapse of the I-35W Bridge, a small-scale survey was conducted in September and October 2007 to identify immediate changes in travel patterns by frequent users of the I-35W Bridge. Mail-in survey forms, together with pre-paid envelopes, were handed to drivers and transit users near major parking garages in Downtown Minneapolis and the University of Minnesota. Traffic counts and speed information on the freeway network before and after the bridge collapse were collected by a loop-detector traffic monitoring system and documented by Minnesota Department of Transportation (MnDOT). Data collected from different resources were geo-coded, merged, and analyzed on the Twin Cities planning network provided by Metropolitan Council. It took six weeks for the traffic pattern to re-stabilize. Despite the heavy losses in life and injury, as well as the psychological shock, the collapse of I-35W Bridge did not disastrously disrupt the overall traffic of Twin Cities network as initially predicted by the mass media. The total travel demand did not change significantly as a result of the bridge collapse. Increases in public transit ridership after the bridge collapse was small but detectable. Travelers exhibited great flexibility in dealing with the changed traffic pattern, although some encountered more inconvenience than others. Evidence from both traffic observations and survey results clearly indicate that changing routes and changing journey departure time are the most common responses to the bridge collapse. Findings and more detailed description of this study have been summarized in a later Chapter.

Similar to many previous studies (Giuliano and Golob, 1998; Gordon et al., 1998; Hunt et al., 2002) , the lack of individual level panel data has prevented us from further advancing our understanding of how travelers react to such disruptive events, which are crucial for evaluating the impacts of future events and developing mitigating measures. Analysis of such panel data could also provide insights for a more fundamental question of how travelers make trip choices. However, obtaining such data set is very difficult because disruptive events are mostly unpredictable. The opening of the replacement I-35W Mississippi River Bridge on September 18, 2008 caused another, but this time predicted, major disturbance to the traffic flow pattern, providing a unique opportunity to collect the needed data. A comprehensive data collection scheme was designed and implemented before the replacement bridge opened.

Data collection efforts in this study are three-fold:

1. Global Positioning System (GPS) devices were instrumented in commuters' vehicles to track travel time and routes. Participants in this study were also required to complete a series of surveys through the study period, providing information to supplement the GPS-based study.

2. Extending the paper-based survey which targeted the post-bridge collapse conditions, a second round of the survey was distributed following the opening of the replacement bridge, in order to compare travel choices in each context.

3. As a companion effort, an internet-based version of the same survey was also conducted during the same time period.

4. Aggregate data relating to freeway and arterial traffic flows were also collected to evaluate the traffic flow pattern.

These data collections efforts are described in detail in the following sections.

3.1 GPS-based Study

3.1.1 Study process

The objective of this GPS-based study is to capture commuters' travel behavior through longitudinal observations of travel choices participants made during the time periods both before and after the replacement I-35W Bridge opens. The target population of this study was commuters in the Twin Cities area who satisfy the following criteria:

1. between 25-65,

2. legal drivers,

3. have a full-time job and follow a "common" work schedule ,

4. drive alone to work,

5. are likely to be affected by the opening of the replacement I-35W Mississippi River bridge.

We were interested in those commuters who previously used the I-35W Bridge and were likely to use it again after the new bridge opens. Recruiting announcements were posted to different media, including *Craig's List* and *City Pages* online, paper version of *City Pages*, flyers at grocery stores, flyers at city libraries, postcards handed out in downtown parking ramps, and emails to more than 7000 University of Minnesota staff (students and faculty were excluded).

People interested in our study were required to complete an on-line survey form, providing background information about demographics, driving habits, job and residential locations, commute routes before and after I-35W Bridge collapse, and willingness to comply with instructions in this study. More than 1000 subjects responded to our on-line survey and subjects were randomly selected among those who satisfied the criteria previously listed. The list of selected subjects was then provided to Professor Randall Guensler of the Georgia Institute of Technology and the subcontractor Vehicle Monitoring Technologies (VMTINC), who oversaw the field study.

GPS devices were installed in the vehicles of subjects in this study two weeks before the new I-35W Bridge opened by a local sub-subcontractor (MachONE), which specializes in in-vehicle installation of electronic devices. The GPS device recorded the position of the instrumented vehicle at every second after the engine was ignited. The position log collected by the GPS was transmitted to the Atlanta-based server in real time through wireless communication systems and documented at the server. The system stops working when the engine is off. The system is not intrusive and should not have influenced subjects' driving behavior in any way aside from the trips to install and remove the device. The whole study lasted 13 weeks, during which time period subjects followed their preferred travel pattern and no instruction was given, though periodic surveys were taken.

A series of internet-based surveys were conducted to complement the GPS tracking data. The GPS data had been processed and displayed on a survey website at the end of each day during the study period. If a subject deviated from the usual commute route, a questionnaire would be sent to the subject through email to ask for reasons for route changes. The subjects could also check the routes they had followed through the web link provided in the same email in case they had forgotten their choices. Once a week, subjects were required to complete a travel diary prompted by on-screen maps and guidance, following in many ways the protocol and software originally developed for the Commute Atlanta study (Ogle et al., 2005). The travel diary provided information for trip purposes, which could not be obtained directly through GPS data (though could be inferred by matching stop locations with land use maps).

A one-time survey was conducted the day before the new I-35W Bridge opened, asking subjects questions about their prediction about the congestion level of the new bridge, planned route choices after it opened, and motivations for such choices. Answers to this survey could help us understand factors travelers considered in route decisions. At the end of the study period, all subjects completed a more comprehensive survey to evaluate the driving experience on routes using different bridges, provide demographic and social economic information, and also answer some hypothetical choice questions.

In order to expand the number of probe vehicles on the network to comprehensively evaluate changes in vehicle travel time across the network, especially on arterial roads where data collection devices such as loop detectors are not widely available, a parallel GPS-based study (funded in part by the Oregon Transportation Research and Education Consortium (OTREC), under the project Value of Reliability, referred to as OTREC2 in the text) was conducted at the same time. Subjects in this study were selected according to the same criteria, but their vehicles were equipped with logging Global Positioning System (GPS) devices (QSTARZ BT-Q1000p GPS Travel Recorder powered by DC output from in-vehicle cigarette lighter), the data from which can only be exported at the end of the study where all GPS devices are returned. The GPS devices accurately monitored the travel trajectories of each probe vehicle at a frequency of one point per 25 meters up to 13 weeks, 3 weeks before the reopening of the bridge and between 8 and 10 weeks after it.

3.1.2 Characteristics of participants

In total 43 subjects, 28 female and 15 male, participated in this study. Another 97 subjects participated in the OTREC study during the same time period and their GPS data have also been included to evaluate speed changes. Home and work locations of subjects from both studies are displayed in Figure 3.1. According to the filtering survey before the study, 88.4% claimed they used the I-35W Bridge as usual commute route before its collapse and 70% claimed that they planned to use the new I-35W bridge after its opening. However, all of them should cross the Mississippi River for commuting according to their home and work locations, and thus are likely to be affected by the opening of new I-35W Bridge even if they do not plan to use it.

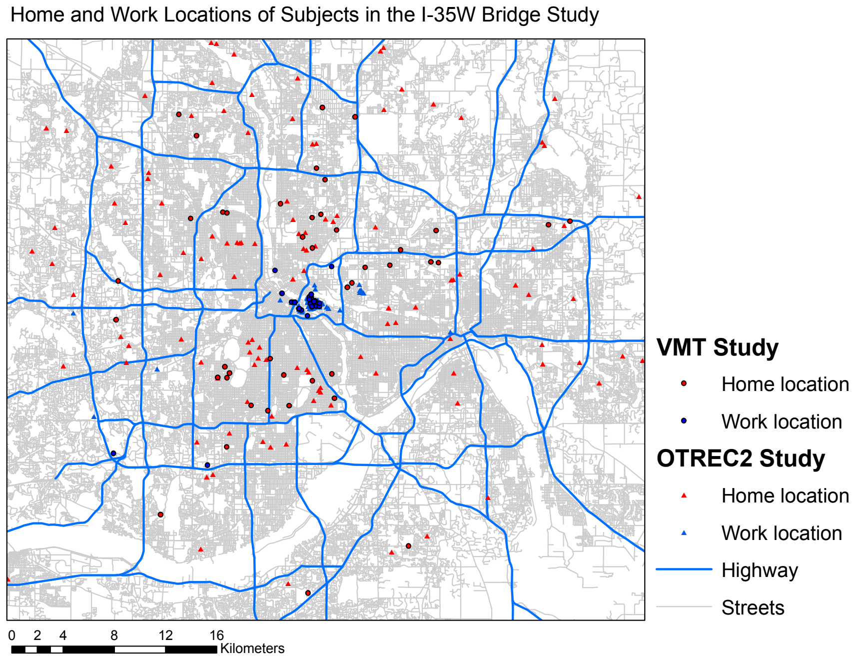

Figure 3.1: Home and work locations of subjects participating in the I-35W Bridge study

3.1.3 GPS data processing

The raw data generated by GPS devices are a list of codes, each of which contains information of one point on the trajectory of vehicles. The information available includes the record ID, latitude and longitude coordinates, date and time, and the instant speed. Ideally, movement of vehicles should be accurately captured by the GPS. However, it takes the GPS devices some time to initial after the engine is on, during which time period the records are not accurate. These points should be excluded from the dataset before further analysis. Also, original data include some long-distance travel (e.g. out-of-town trips during holidays) which could confound our analysis. These trips should also be excluded. Also, the GPS points must be merged with a GIS map in order to construct the actual routes followed by subjects and allow more sophisticated network analysis.

The TLG network (generated and maintained by Metropolitan Council and The Lawrence Group (Craig, 2005)), a detailed network conflated to the real road geometry, is used in this study. It covers the entire 7-county Twin Cities Metropolitan Area and is the most accurate GIS map to date. The original TLG network contains both two-directional and one-directional links. In order to be consistent with geo-coding conventions of planning network, all two-directional links are converted into two links in both directions. The modified TLG network contains 290231 links, providing an accurate description of the entire Twin Cities network to the street level. A 20-meter buffer was generated for all roads, which is then used to clip the GPS records. All points that are located outside of Twin Cities area as well as off-road points are excluded. The remaining points then regrouped into trips, each of which contains all points between one engine-on and engine-off events for one specific subject. Combining information from the GPS records and the GIS map, we could identify all trips each subject has made during the study period, and the characteristics of each trip, including the starting time, the ending time, the route followed, and travel speed on each link segment along the route. Figure 3.2 shows one example of commute trips.

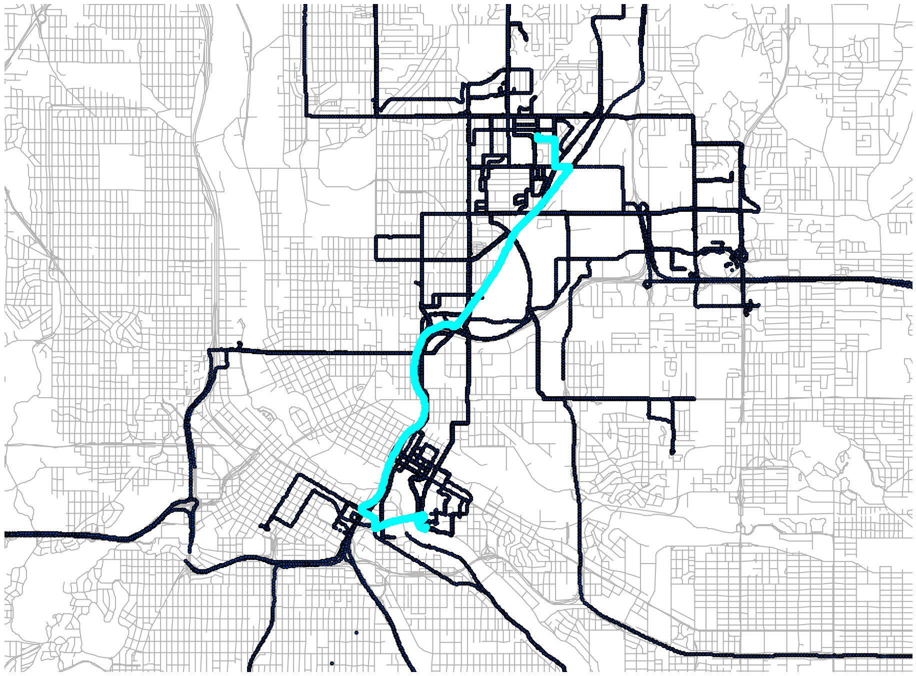

Figure 3.2: Example of one commute trip (Sep 18 Thursday 06:30:58AM to 06:43:52AM)

3.1.4 Speed map

One research question regarding the bridge opening is how congestion level and travel speed evolves after the new I-35W Bridge opens. The network speed information is also crucial for evaluating individual route decisions because it helps to identify potential alternative routes. Because GPS can accurately capture the travel speed, subjects in this study could serve as probe vehicles. Link travel speed was sampled on all the links subjects drove on. Speed samples were then pooled and speed maps was developed for the Twin Cities network for time periods both before and after the replacement I-35W Bridge opens. Figure 3.3 shows the number of speed observations obtained on each link. We obtained a very high sampling rate on the freeway system. More importantly, the number of observations are fairly high on many arterial roads, especially trunk highways and downtown streets. Detailed speed information on the arterial network, which is not available in previous studies, exhibits a major advantage of this study.

Figure 3.4 compares the estimated speed before and after the I-35W bridge opens. Only links with more than 5 observations during the periods both before and after the bridge opens are included here. According to the map, speed on I-94, TH280, and non-freeway bridges crossing the Mississippi River improved after the replacement I-35W Bridge had opened. However, the speed on I-35W deteriorated, showing that commuters who use the I-35W but do not cross the Mississippi River were worse off as a result of the replacement bridge opening.

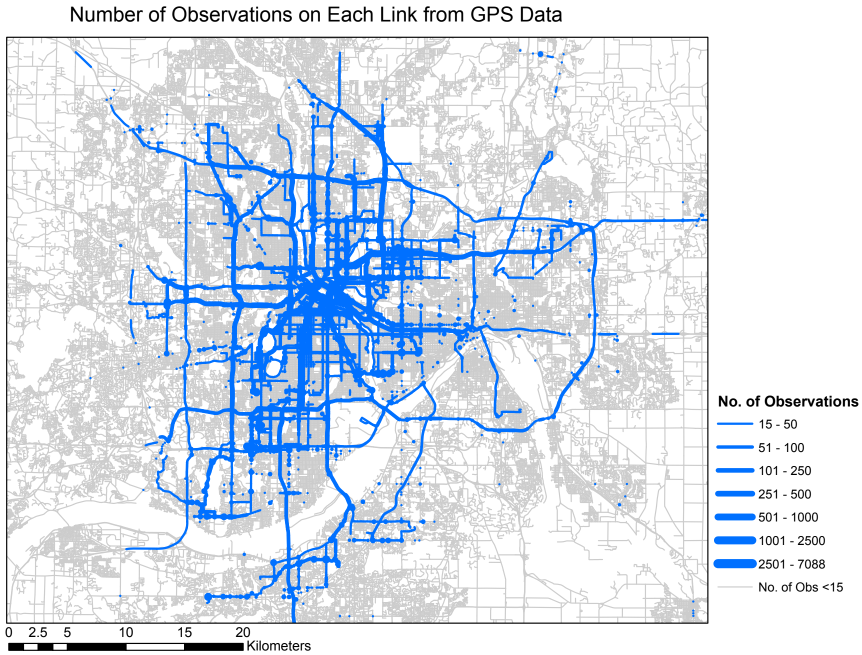

Figure 3.3: Number of speed observations on each link during the study period

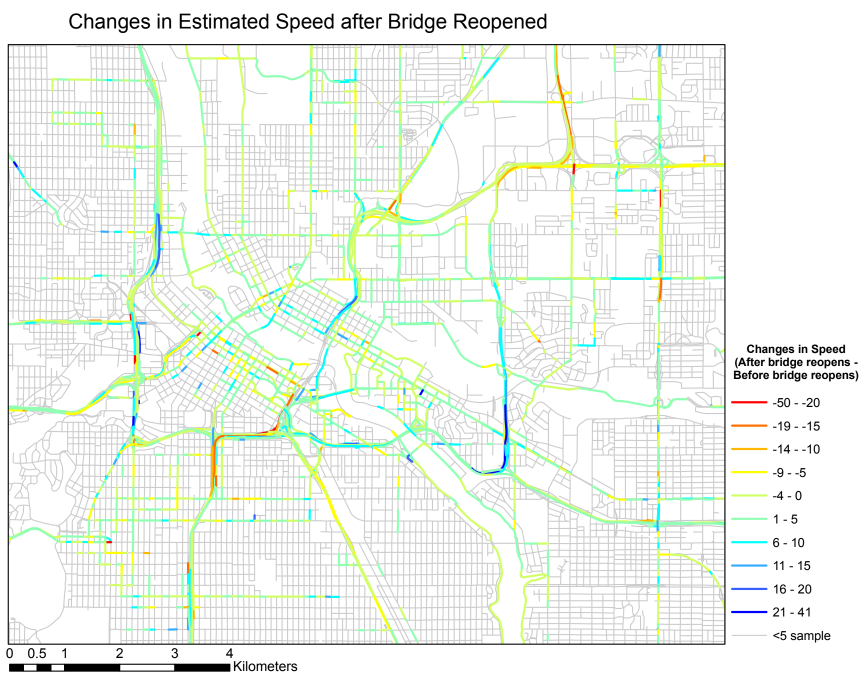

Figure 3.4: Comparison of travel speed before and after the replacement I-35W Bridge opened

3.2 Paper and web-based surveys

Extending the paper-based survey which targeted the post-bridge collapse conditions, a similar mail-in survey was conducted. Questions in the survey were separated into three parts:

1. Travel choices of the morning commute;
2. Self-evaluation of the impacts from the bridge collapse and the replacement bridge opening; and
3. Demographic information.

In the first part, respondents answered questions associated with their morning commute in five different time periods. These periods are:

1. Before the bridge collapse,
2. Before the replacement bridge opening,
3. On the day of the replacement bridge opening,
4. Weeks following the bridge opening, and
5. On the day the survey was completed.

Travelers' trip-making characteristics are revealed by comparing their travel behaviors before and after network topology changes. Traveler's morning commute choices asked in this part include departure time, arrival time, travel mode, route choice, route familiarity, and motivation for changes. The survey provided five maps, with respect to five time periods, on which participants were asked to draw their morning commute routes. In the second part, participants were asked on the impact of their morning commutes by the bridge collapse and opening, such as whether participants had to cancel trips or avoid certain destinations. Participants were also asked to provide the information sources of the replacement bridge opening. Finally, respondents were asked to answer questions related to their demographic backgrounds, which include gender, work schedule flexibility, residential and work locations, household size, number of children, age, and annual household income. The attached questionnaire shows details of the questions asked in the survey.

In total, 840 survey forms were handed out in Downtown Minneapolis and the University of Minnesota on October 30th, 2008, six weeks after the replacement bridge opened. 137 respondents were received. The answers are then digitized and documented for further analysis.

Questions similar to the paper-based survey were incorporated in the survey website, hosted on a personal computer stationed in the Minnesota Traffic Observatory at the University of Minnesota. 5,000 people are randomly selected around the seven-county Twin Cities area from a mailing-list purchased from a survey company and a cover letter, which described the purpose of the survey, the website link, and the incentives involved, was sent out to invite people to visit the website and participate in the survey. To encourage responses, the first 500 participants received a $5.00 coffee card from one of three coffee shops of their choosing (Starbucks, Dunn Brothers, or Caribou Coffee). Additionally, two participants of all survey takers would be selected from a drawing for either a Nintendo Wii or a $250 gift card from a store of their choosing (Best Buy, Wal-Mart, Target, etc.).

The cover letters were mailed on Monday, November 24, 2008 and the survey was kept online between November 24, 2008 and January 15, 2009. Approximately 350 individuals responded to the survey. An example of the survey form is included in the appendix H.

3.3 Traffic data

Traffic data have also been collected to complement individual data. Traffic counts and speed estimates for each 15-minute time period are documented by MnDOT. Arterial traffic counts are provided by the City of Minneapolis. Table 7.3 summarizes the number of crossing river trips before and after the replacement I-35W Bridge opens. The usage of arterial bridges reduced significantly as a result of the replacement I-35W Bridge opening while the overall crossing river demand increased 3.1%. The change in overall crossing river demand is smaller compared to that has been observed after the bridge collapse.

Table 3.1: Daily trips on all bridge crossing the Mississippi River before and after the bridge collapse as well as replacement bridge opening

	Bridge Collapse				Replacement Bridge Open			
Bridge	Before	After	Increase	Percentage	Before Open	After Open	Change	Percentage
Camden Bridge	8748	N/A			N/A	N/A		
Broadway Str	20931	N/A			N/A	N/A		
Lowry Str	16296	N/A			N/A	N/A		
Plymouth Str	11226	13842	2616	23.30%	13842	10738	-3104	-22.40%
Hennepin Ave	33559	45936	12377	36.90%	35799	34004	-1795	-5.00%
3rd Ave	31303	39423	8120	25.90%	38746	15067	-23679	-61.10%
10th Street	27356	33937	6581	24.10%	39242	9878	-29364	-74.80%
Washington Str	20713	31941	11228	54.20%	31941	16134	-15807	-49.50%
Franklin Ave	9800	13061	3261	33.30%	10413	10074	-339	-3.30%
Ford Pkwy Bridge	18354	19426	1072	5.80%	N/A	N/A	N/A	N/A
I-694	160426	168645	8219	5.10%	164910	160177	-4732	-2.90%
I-94	155771	196829	41058	26.40%	172629	153917	-18712	-10.80%
I-35E	87251	88032	781	0.90%	96955	96160	-795	-0.80%
TH-55	28826	27534	-1292	-4.50%	54223	52523	-1699	-3.10%
I-35W	140000	0	-140000	-100.00%	0	120349	120349	
Arterial total	152311	197566	45255	29.70%	169983	95895	-74088	-43.60%
Freeway total	572274	481040	-91234	-15.90%	488717	583127	94410	19.30%
Total	724585	678606	-45979	-6.30%	658700	679022	20322	3.10%

Figure 3.5 summarized the daily trips on the new I-35W Mississippi River Bridge. A one-time jump in bridge usage was observed during the first week and no oscillation has followed. The Root Mean Square Error measure (Figure 3.6) developed based on daily traffic counts at 34 loop detector stations at the vicinity of the I-35W Bridge also suggested that the traffic flow stabilized one week after the replacement bridge opened.

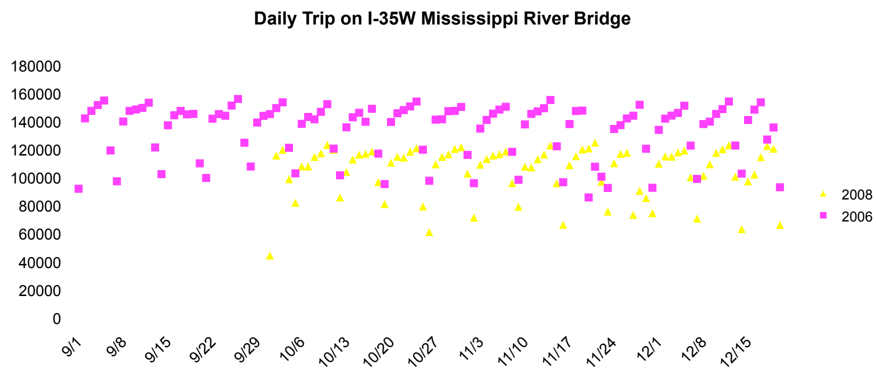

Figure 3.5: Daily trips on the I-35W Mississippi River Bridge

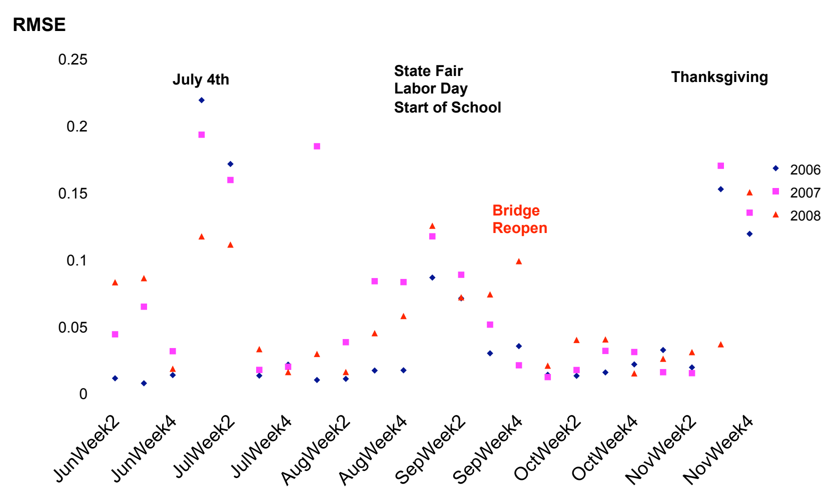

Figure 3.6: RMSE of traffic data

3.4 Transit data

Travelers show great resistance to changing mode (Giuliano and Golob, 1998; Hunt et al., 2002). As part of the traffic mitigation plan, Metro Transit, the primary public transit service provider at the Twin Cities, enhanced their service by adding new buses and expanding capacity in park-and-ride lots. The monthly bus ridership was collected at the fare box and documented by Metro Transit. Figure 3.7 summarizes the monthly total trips during 2006 and 2007, on all routes and on those routes crossing the Mississippi River, respectively. In order to detect the effects of the bridge collapse, a regression is built as follows:

$$y_t = \beta_0 + \beta_1 D_t + \beta_2 I_y + \beta_3 VKT_t + \beta I_{I-35} + \varepsilon$$

where y_t is the monthly ridership, which is a function of the number of work days of the month (D_t), dummy variables for the year (I_y), total Vehicle Kilometers Travel of the month (VKT_t) and a dummy variable indicating the time period after the bridge collapse (I_{I-35}). Table 3.2 summarizes the results and a R^2 value of 0.57 was obtained. The number of work days is statistically significant and positively correlated with the monthly ridership. This is consistent with the fact that 48.3% of total public transit trips are commute trips (home based work, home based work-related, home based school and non-home based work) at the Twin Cities (seven county area) according to the 2000 Travel Behavior Inventory (TBI) conducted by the Metropolitan Council. The impact of bridge collapse is statistically significant, which has led to a 6.6% increase in monthly ridership according to the regression model. The year-to-year effect is positive, but not statistically significant. The freeway VKT did not play a significant role either, suggesting different patterns exist for transit usage and freeway traffic, and transit is more of a substitute for arterial travel than freeway travel. Similar results are obtained by regressing the total number of trips on all crossing-river routes, although the magnitude of impacts due to bridge collapse is larger (7.4%) according to the coefficients. However, bus riders on these routes do not necessarily cross the river. Moreover, public transit trips only represent only 2.3% of total trips in the seven county area according to the 2000 TBI. Therefore, the effects of such increases in transit ridership are limited and probably undetectable from traffic counts (as shown in the survey results).

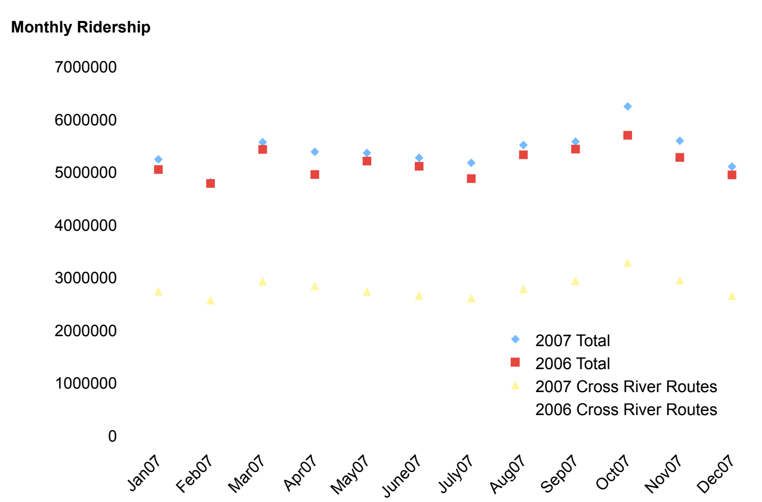

Figure 3.7: Transit Ridership before and after the Bridge Collapse

3.5 Conclusions

Three different data collections efforts have been designed and implemented before and after the opening of the new I-35W Bridge. Both the aggregate and individual travel data were collected and

Table 3.2: Regression on monthly transit ridership

Independent Variables	*Coefficients*	*t Stat*	
Intercept	1759581	1.85	*
WorkDays	122085	2.44	**
2007/2006	27159	0.22	
VKT	0.00084438	0.92	
After collaspe	349697	2.50	**

* Statistically significant at 10% level

* Statistically significant at 5% level

documented for further analysis. GPS tracking data provided not only the detail information for all trips made by each subject, but also speed information on links they passed on. The speed map developed based such information covers both freeways and arterials with fairly high sampling rate. Speed estimates on arterial roads allow researchers to compare network performance and construct alternative routes for network analysis based on real observations instead of assignment results. Accuracy and comprehensiveness provided by the GPS technques in this study exhibited significant advantage over previous studies.

Chapter 4

Unexpected Cause, Unexpected Effect: Empirical Observations of Twin Cities Traffic Behavior after the I-35W Bridge Collapse and Reconstruction

This chapter discusses the observed evolution of traffic following both the collapse and reopening of the I-35W Bridge. It analyzes the traffic dynamics of two network topology change scenarios: 1.) Unexpected Long-Term Disruption versus Expected Long-Term Disruption, and 2.) Reopening of a Previously Severed Link versus Pre-Disruption Equilibrium. In both cases, it is found that traffic behaves different when an unexpected long-term disruption has occurred. This work contributes by identifying two unique trends witnessed following prolonged, unexpected disruptions: an avoidance phenomenon after the disruption and a stunted link demand restoration following reopening. As illustrated in this study, neither of these trends is observed in preplanned closures. As such, traffic models proposing to predict evolutionary dynamics following a network disruption will need to account for these differences, depending on the type of disruption.

This work bridges a gap in existing research by providing observational data for a prolonged, unexpected disruption on a day-to-day basis. It provides an opportunity for additional research questions into the motivations and perceptions of drivers following such disruptions and offers guidance to the development of theoretical day-to-day models designed specifically for post-disruption scenarios. With knowledge how traffic evolves in the short term following a disruption, network operators can better allocate traffic management resources, such as infrastructure enhancements, law enforcement presence, or incident management vehicles, to improve operational efficiency and commuter safety.

This chapter begins by investigating current research on day-to-day traffic dynamics and network disruption. It then discusses the I-35W Bridge collapse event and illustrates the traffic dynamics following the tragedy. Given behaviors that starkly contrast trends observed at preplanned closures, it is shown that the effects of unexpected disruption are not unique to just the I-35W Bridge scenario. Lastly, it explores the behavior of traffic following the reopening of the bridge and reveals a unique disparity in traffic demand despite the identical network topology to the pre-collapse environment.

4.1 Literature Review

Traditionally, travelers route choice behavior has been modeled using the user equilibrium concept, in which travelers make their route choice decision by selecting the path with the lowest travel cost ((Wardrop, 1952)). Using this concept, Beckmann et al. (1955) formulated a mathematical model to solve deterministic user equilibrium, assuming that drivers had perfect network knowledge, were rational, and were homogeneous. However, given the improbability of these assumptions, stochastic user equilibrium models were proposed, where route costs were based on travel times with an inherent error due to driver perception ((Daganzo and Sheffi, 1977; Sheffi and Powell, 1982)). The conventional approach has been to solve route choice by assuming the network achieves equilibrium, but some work has revealed a network to be a constantly evolving entity based on drivers daily experiences and perceptions. Horowitz (1984) showed that a two-link network, given a set of learning mechanism assumptions, may never achieve stability under stochastic user equilibrium.

To understand the evolution of traffic dynamics on a day-to-day basis, dynamical systems have been proposed (e.g. (Friesz et al., 1994; Smith, 1984)). Experimental models have been proposed and tested in simulation (Mahmassani and Chang, 1986, Jotisankasa and Polakm, 2005), but work done by Cascetta (1989) has been tested against empirical data. These models, however, only focus on the evolution of traffic dynamics on a network with unchanging infrastructure.

Given the infrequent occurrence of prolonged, large-scale network disruptions and the scarcity of data collection devices near these disruptions, most work regarding network disruptions has been on the long-term impacts. The disruption of a transportation network can have substantial consequences on an economy, either at a local, regional, or national level ((Ham et al., 2005a,b; Kim et al., 2002; Sohn et al., 2003)). Given these impacts, research has been conducted to aid engineers and planners in finding optimized reconstruction schedules following such disruptions ((Chen and Tzeng, 1999; Kiyota et al., 1999; Lee and Kim, 2007)) or identify network vulnerabilities ((Ball et al., 1989; Matisziw and Murray, 2009)). While useful for long-term planning, this research fails to address transient traffic dynamics in the short term as a network seeks a new equilibrium. The collapse of the Tasman Bridge in Hobart, Australia, prompted an investigation into traffic change, but the work provides only long-term results ((Hunt et al., 2002)). Some research has looked into the consequences on a network following an earthquake, but the focus of this work is either on transportation system performance ((Chang and Nojima, 2001)), the success of a car-sharing program to reduce commuting traffic following a disaster ((Tsuchida and Wilshusen, 1991)), or single-point medium and long-term results ((Giuliano and Golob, 1998; Wesemann et al., 1996)). To date, the evolution of traffic following an unexpected disruption in network infrastructure remains largely unexplored.

4.2 I-35W Bridge Collapse

On August 1, 2007, at approximately 6:05 PM, the I-35W Bridge over the Mississippi River in Minneapolis, Minnesota, unexpectedly collapsed. The sudden tragedy resulted in the deaths of thirteen commuters and the injury of hundreds. In quick response to the disaster, the Minnesota Department of Transportation converted a former arterial, Minnesota Trunk Mn 280 (Mn 280), into a freeway on August 2nd and designated I-94/Mn 280 as the alternative route to reopen the I-35W corridor.

Despite the tragedy, the vast majority of loop detector infrastructure around the Twin Cities remained fully operational. Using loop detectors on all Twin Cities on-ramps to capture traffic counts, the total traffic demand to the freeway was assessed on a daily basis during a three-hour period in the AM Peak. Data was collected between July 23, 2007, and August 31, 2007, to determine if the bridge collapse caused a significant change in freeway demand. These daily total counts are provided in Figure 4.1.

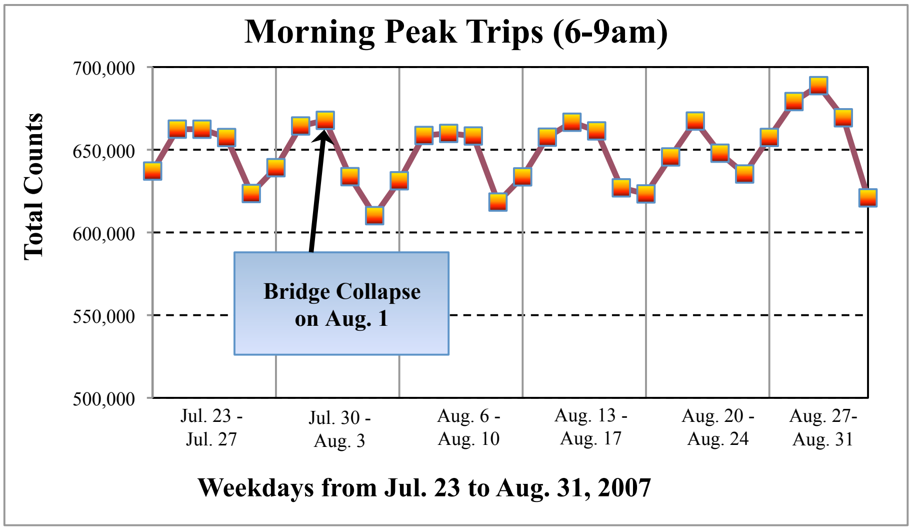

Figure 4.1: Daily trips entering the Twin Cities freeway network via on-ramps

As revealed by the on-ramp data, freeway traffic demand in the days and weeks following the bridge collapse does not experience any drastic changes, fluctuating within the bounds of weekly variation. The lone exception is on Thursday, August 2, 2007 where a noticeable decrease occurs when compared to other Thursdays, but otherwise demand remains consistent with previous weeks. This shows that the bridge collapse did not influence freeway demand during the AM Peak on the system as a whole. Given this, the next question is how, if at all, the bridge collapse influenced traffic within the network.

The focus of this work will be on the evolution of traffic patterns on freeway routes heading toward the bridge. To do this, several zonal regions will be defined around the bridge collapse site. These zonal regions do not necessarily have a Euclidean radius, as such a radius would collect biased infrastructure features (e.g. accounting for a major interchange on one side of the zone, but not the other). Instead, the boundaries of these zones are defined by cordon lines, which are drawn to capture similar network topology. For example, a cordon may be drawn to cross all routes to downtown Minneapolis, as to study if traffic avoided the central business district after the collapse. These lines serve as counting points, where all traffic entering the cordon is tallied and aggregated over the analysis period.

Five cordons are proposed, shown in Figure 4.2. The network topologic features intended to be captured are discussed in Table 4.1. For reference, Cordon 1 refers to the smallest cordoned area near bridge while Cordon 5 refers to the largest cordoned area around the metropolitan area.

The aggregated freeway counts entering these cordons will be analyzed for each non-holiday weekday between Monday, July 9, 2007, and Friday, November 16, 2007. The period in which traffic is counted will be during the AM peak, as the vast majority of trips in this time period his-

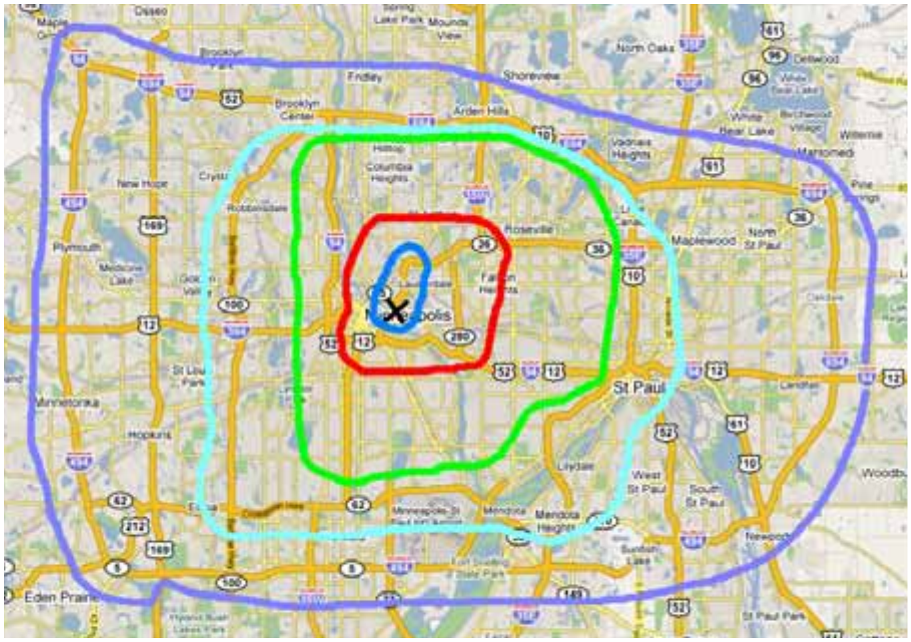

Figure 4.2: Five cordon circles around the Twin Cities for the I-35W Bridge, where the closed bridge is marked with an "x"

Table 4.1: Network topologic features of cordoned areas in Twin Cities

Cordon Number	Region within Cordon	Network Topology Features	Approximated Cordon Radius (miles)
1	Immediate Area of I-35W Bridge	No alternative routes within cordon. No Freeway connectivity within cordon. Traffic approaching bridge inforced to exit	0.5
2	I-35W/I-94 Corridor Interchange	Includes I-94 corridor and I-35W (using Mn 280 detour) corridor. No freeway based alternative routes	2.5
3	City of Minneapolis and Minneapolis Central Business District	Includes all routes bound for Minneapolis. Some freeway based alternative routes.	5.5
4	Minneapolis and St. Paul Central Business District	Includes all routes heading toward central business district in either city. Many freeway-based alternative routes.	8.5
5	Twin Cities Metropolitan Area	Includes all routes approaching the I-494/I-694 beltway. Many freeway-based alternative routes.	15

torically are inflexible ones, such as journeys to work or school. To avoid issues of peak spreading, the AM peak period is designated between 6 a.m. and 10 a.m. local time. Thus, the aggregated total for each day consists of four hours of traffic counts.

Figure 4.3 illustrates the evolution of daily four-hour traffic counts over the analysis time frame. Prior to the bridge collapse, traffic counts are mostly stable for all five cordons. However, after the collapse, these counts dramatically change. The traffic demand at Cordon 1 drops to nearly zero while demand at Cordon 2 and Cordon 3 decreases as well. In the weeks following the collapse, the demand at these three cordons undergoes a recovery process to a certain stabilizing point in the long term. These demand changes are not observed at Cordon 4 or Cordon 5, where total demand stays relatively stable across the entire time period.

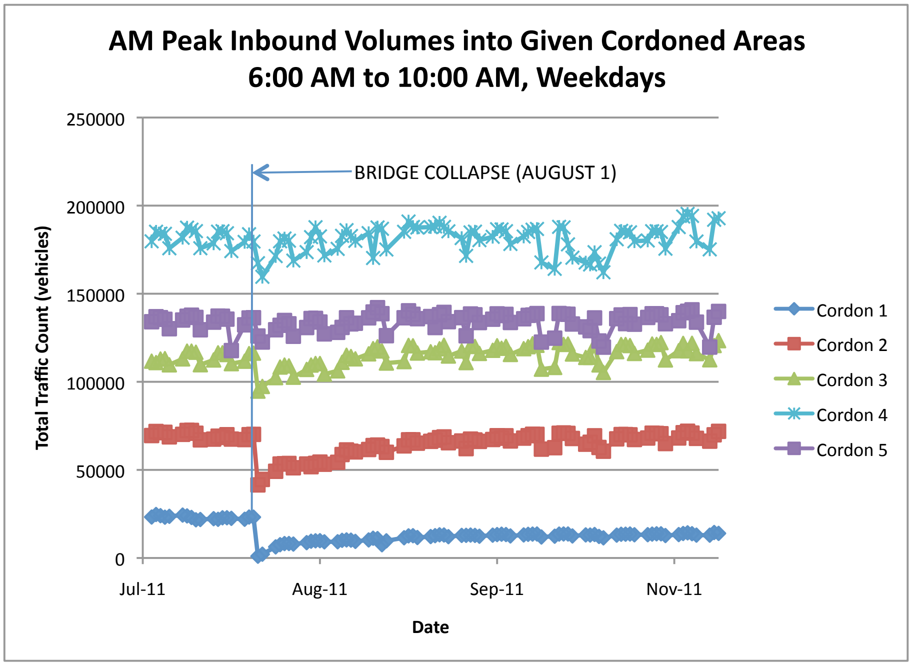

Figure 4.3: Total traffic counts for each cordon circle for Twin Cities network in 2007

Taking a closer look at the cordons, it is seen that these dramatic demand decreases, or shocks, diminish in intensity as alternatives become available, generally corresponding to the distance from the bridge increasing. Between pre-collapse demands and demands observed a week following the collapse, Cordon 1, Cordon 2, and Cordon 3 experience shocks of 67 percent, 25 percent, and 6.5 percent, respectively, while Cordon 4 and Cordon 5 experience no notable shocks. Similarly, aside from Cordon 1, the recovery rate to pre-collapse demand is faster with more alternatives, as Cordon 2 and Cordon 3 recover by September 28 and August 24, respectively, and Cordon 4 and Cordon 5 recover seemingly instantaneously. Cordon 1 can be considered a unique case as, given a severed corridor and no alternative routes within the cordon, the long-term post-collapse demand is more than 40 percent lower than pre-collapse demand. Thus, recovery to this substandard demand occurs in a relatively short time, achieving stability on around August 24. Stability, for this work, was considered present for a given cordon when week-by-week demands vary by less than five percentage points.

When analyzing Year 2006 data for the same time period, these shocks and recoveries are not observed, revealing that they are a consequence of the bridge collapse. Traffic counts entering the cordons during the same seasonal time period in Year 2006 are shown in Figure 4.4 to reveal these absences.

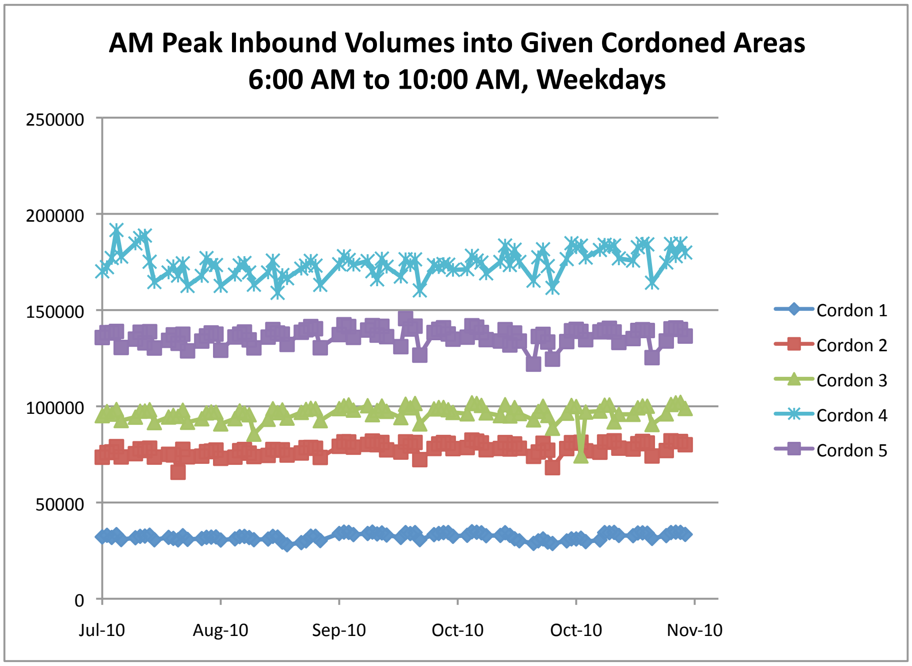

Figure 4.4: Total traffic counts for each cordon circle for Twin Cities network in 2006

Moreover, as shown by the daily demand for the freeway in Figure 4.1, the magnitude of AM commuters over this time period remains largely unchanged, suggesting that the decreases in demand corresponds with a desire of avoidance for these cordons. This is particularly interesting because this avoidance results in spare capacity within the cordoned areas. Traditional deterministic route choice models would favor these underutilized areas, but evidence in Figure 4.3 reveals such changes require an extended period of time. Thus, a perceived travel cost or risk is likely present to discourage usage. The modeling of such perceived costs is left to future research.

Is this avoidance phenomenon a characteristic of unexpected network disruptions or is it unique only to the Twin Cities network? To answer this question, another network with an unexpected disruption event will be analyzed to observe the presence of this phenomenon.

4.3 MacArthur Interchange Collapse

In the early morning hours of Sunday, April 29, 2007, a tanker truck carrying flammable fuel overturned on the MacArthur Interchange near Oakland, California, which is a busy interchange serving major routes including Interstate 80, Interstate 580, Interstate 880, and the Bay Bridge into San Francisco. The resulting fire from the tanker truck structurally weakened a ramp overpass, causing it to collapse and effectively close two freeway-to-freeway ramps. The extent of the damage required a construction effort that, as initially stated to the public, would likely take several months. While not a full closure for the interchange, the absence of the ramps significantly reduced accessibility for certain highways.

The same cordon-line methodology will be applied to the Bay Area network, using California Department of Transportation Freeway Performance Measurement System (PeMS) data to provide traffic counts. Four cordons are proposed, shown in Figure 4.5. The network topologic features intended to be captured are discussed in Table 4.2. For reference, Cordon 1 refers to the smallest cordoned area near bridge while Cordon 4 refers to the largest cordoned area around the metropolitan area.

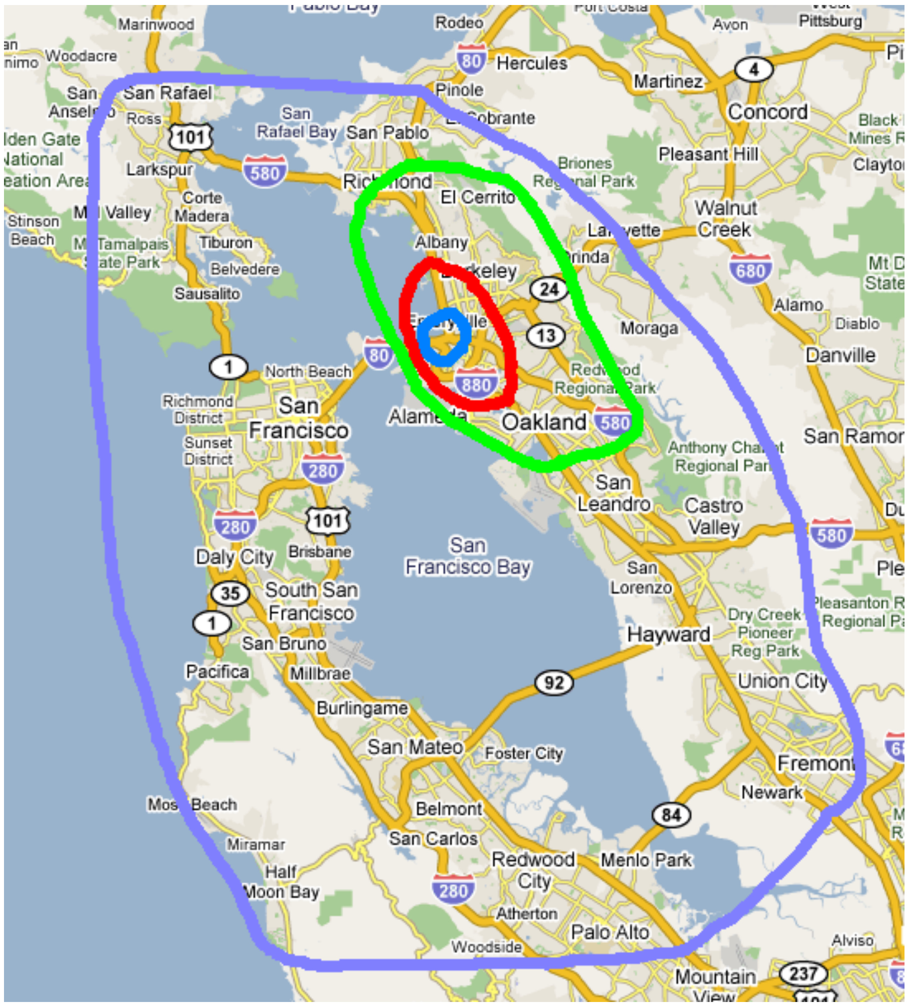

Figure 4.5: Four cordons around the MacArthur Interchange in the Bay Area, where the closed ramps are located within the innermost cordon

The aggregated counts entering these cordons will be analyzed for each non-holiday weekday between Monday, April 2, 2007, and Friday, June 29, 2007. Like for the Twin Cities, the AM Peak period is the analysis time frame, but instead using four-hour counts between 5 a.m. and 9 a.m. local time.

Figure 4.6 illustrates the evolution of daily four-hour traffic counts from before to after the interchange disaster. Prior to the ramp collapse, traffic counts are fluctuating at gradual rates. However, after the collapse, the counts in the three innermost cordons experience sudden decreases and a recovery period. While not nearly as dramatic as seen in the Twin Cities, their presence is still notable. At Cordon 4, demand remains relatively stable.

Table 4.2: Network topologic features of cordoned areas in Bay Area

Cordon Number	Region within Cordon	Network Topology Features	Approximated Cordon Radius (miles)
1	Immediate Area of MacArthur Interchange	No alternative routes within cordon. No Freeway connectivity within cordon for corridors with severed connections. Unsevered routes at full capacity.	0.5
2	I-80/I-480/I-880/I-980 Corridor	Includes interchange-bound corridors. Some freeway-based alternative routes available within cordon.	2
3	Greater Oakland/Berkeley Area	Includes freeway routes to the Oakland/Berkeley Areas. Some freeway-based alternative routes available within cordon.	5
4	Bay Area Metropolitan Area	Includes all freeway routes to San Francisco/Oakland Area. Many alternative routes within cordon.	8-24

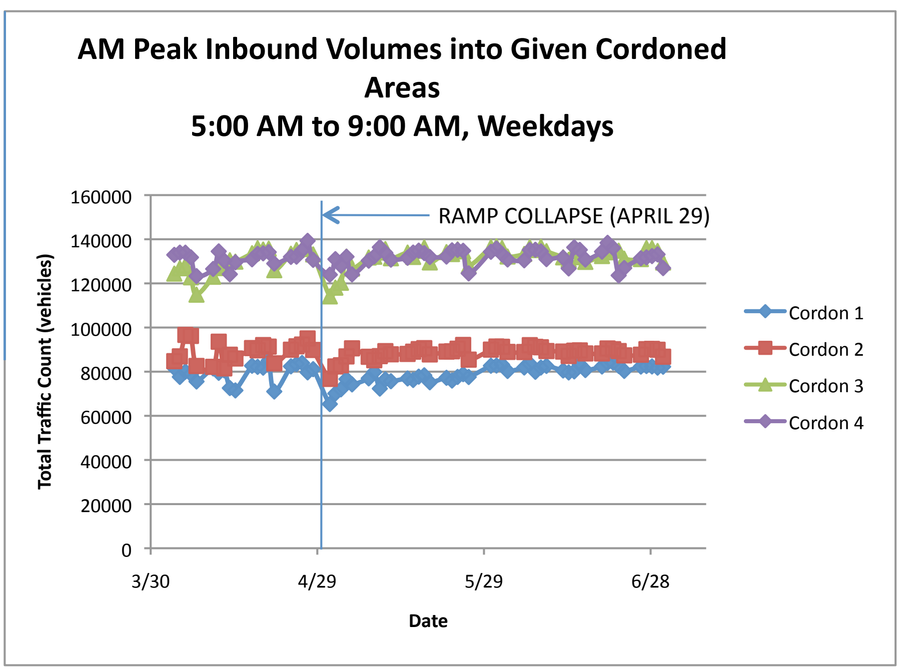

Figure 4.6: Total traffic counts for each cordon circle for Bay Area network

It is important to note that the Bay Area freeway network has some differences compared with the Twin Cities network. First and foremost, the MacArthur Interchange collapse was only a partial closure. Additionally, the Bay Area transportation network is generally closer to capacity and the availability of alternatives overall is much more limited due to the proximity of the San Francisco Bay. Nonetheless, the avoidance phenomenon, while not nearly as pronounced, is still observed with this event.

Two cases of long-term unexpected network disruption have revealed the presence of this avoidance phenomenon. Now, the question becomes whether this phenomenon is something unique to unexpected disruptions or if it is applicable to all long-term disruptions, including planned closures.

4.4 Trunk Highway 36 Construction Closure

On May 1, 2007, a two-mile length of Trunk Highway 36 (Mn 36) in the Twin Cities, Minnesota, was fully closed for a construction project intended to upgrade the road to freeway standards. Mn 36 was originally a suburban arterial that served as a major thoroughfare for suburban commuters in the northeastern metropolitan area that were heading to the urban center. This construction project was slated to keep the Mn 36 corridor closed for several months. In the preceding months, the Minnesota Department of Transportation informed the general public of the closure and suggested detour routes on the adjacent Interstate 694 (I-694).

Keeping with the previous cases, the cordon-line methodology will be applied around the Mn 36 construction site, analyzing the time periods before and after the closure. Four cordons are proposed, shown in Figure 4.7. The network topologic features intended to be captured are discussed in Table 4.3. For reference, Cordon 1 refers to the smallest cordoned area near bridge while Cordon 4 refers to the largest cordoned area around the metropolitan area.

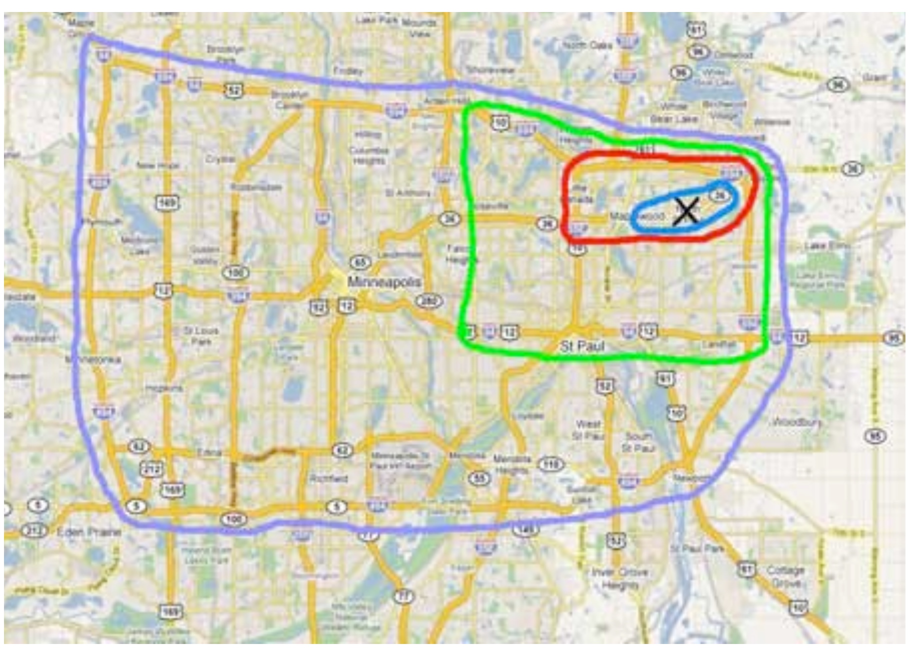

Figure 4.7: Four cordon lines around the Mn 36 construction site, where the preplanned construction closure is marked with an “x”

Table 4.3: Network topologic features of cordoned areas in Twin Cities for Mn 36 closure

Cordon Number	Region within Cordon	Network Topology Features	Approximated Cordon Radius (miles)
1	Immediate Area of Mn 36 Construction Area	No freeway or arterial-based alternative routes within cordon. No corridor connectivity within cordon	0.5
2	I-694 Detour	Includes I-694 alternative route, the defined detour suggested by Mn/DOT. No freeway-based alternative routes within cordon.	3.5
3	I-94 corridor, I-694 corridor, and St. Paul Central Business District	Includes all routes bound for downtown St. Paul, as well as I-94 and I-694 corridors. Some freeway-based alternative routes.	5.5
4	Twin Cities Metropolitan Area	Includes all routes approaching the I-494/I-694 beltway. Many freeway-based alternative routes.	15

The aggregated counts entering these cordons will be analyzed for each non-holiday weekday between Monday, March 26, 2007, and Tuesday, July 31, 2007. The period in which traffic is counted will be the AM peak period, keeping a four-hour count between 6 a.m. and 10 a.m. local time.

Figure 4.8 illustrates the evolution of traffic over the four-month time frame. Prior to the road closure, traffic counts are mostly stable at all four cordons. However, when the closure occurs, a different pattern emerges than seen in the unexpected disruption cases. Rather than experiencing a sudden shock and prolonged recovery, the traffic demand does not change. The lone exception is Cordon 1, where the absence of an open corridor or alternative routes causes a reduction. For all cordons, traffic seems to instantaneously adapt to the new network.

This observation starkly contrasts the avoidance phenomenon observed after the unexpected disruptions. It is not the only case, as the absence of a shock and prolonged recovery can be found in other examples of preplanned disruptions. In the literature, Hunt et al. (2002) studied traffic equilibration following the planned construction closure of a bridge in Calgary, stating equilibrium was reached quickly.

This evidence reveals that traffic equilibration is different when long-term disruptions are expected versus unexpected. It appears that awareness of an upcoming closure gives drivers a different perception of how the network will be than when a closure abruptly occurs. The exact causes and influential forces are left for future research, but the awareness of these differences is useful for practitioners seeking to better cope with future disruptions.

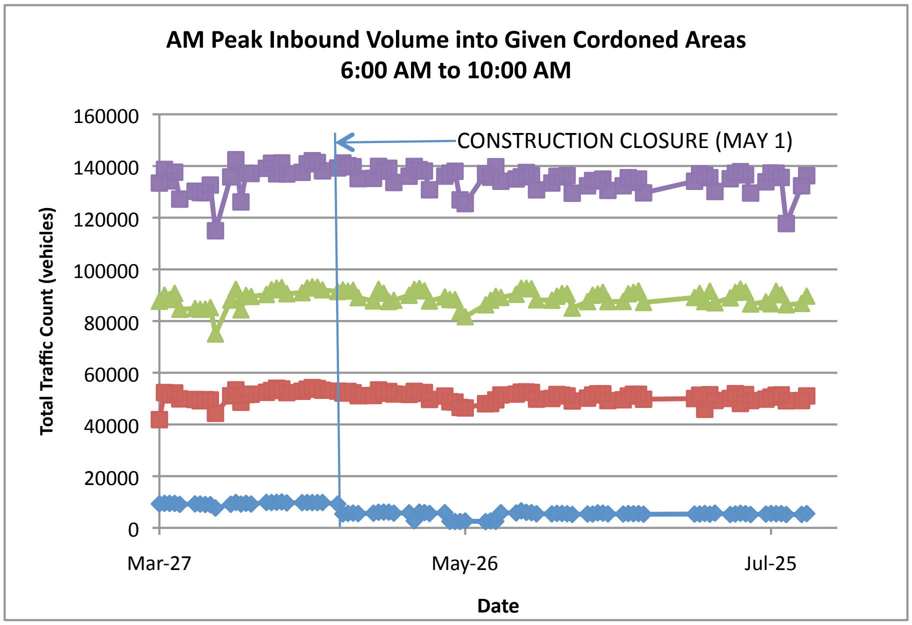

Figure 4.8: Total traffic counts for each cordon circle for Twin Cities network for Mn 36 closure

4.5 I-35W Bridge Reopening

Opportunities have been available in the past to study the evolution of traffic dynamics following the opening of a new link, as new roads are being built daily. However, no study to date has investigated the adjustments of traffic dynamics following the reopening of a link that had been unexpectedly severed in the past. Intuition would suggest that, given two nearly identical network topologies, the traffic dynamics after reopening would roughly match pre-collapse traffic dynamics. But, after seeing the avoidance phenomenon following the collapse, is this intuition necessarily correct for reopened links that were unexpectedly closed?

On Thursday, September 18, 2008, the replacement I-35W Bridge over the Mississippi River was opened to the public. The infrastructure itself was very similar to the first bridge, the lone exception being an additional lane used as an exit only ramp. Initially slated to be returned to an arterial, Mn 280 was maintained as a freeway for many months after the new I-35W Bridge opened. With minor exceptions, the Twin Cities network was effectively restored to the way it had been prior to the bridge collapse.

To begin analysis of traffic dynamics following the opening, the cordon-line methodology will be applied, using a time frame from Monday, August 18, 2008, to Friday, October 31, 2008. The five cordon lines described in Figure 2 will be used and the four-hour analysis period will be between 6 a.m. and 10 a.m.

As shown in Figure 4.9, the reopening of the bridge has immediate consequences. Prior to the reopening, traffic demand across the cordons is relatively stable, changing gradually due to seasonal variation. However, immediately after opening, the demand at some cordons experiences a sudden, drastic change. At Cordon 1, it doubles in value. At Cordon 2 and Cordon 3, it increases by 12 percent and 2 percent, respectively. At Cordon 4 and Cordon 5, there is no notable change. This sudden recovery starkly contrasts the behavior at the unexpected closure, as new demands are reached almost instantaneously rather than over a prolonged recovery period. After these changes, the demand remains relatively stable, changing gradually due to seasonal variation.

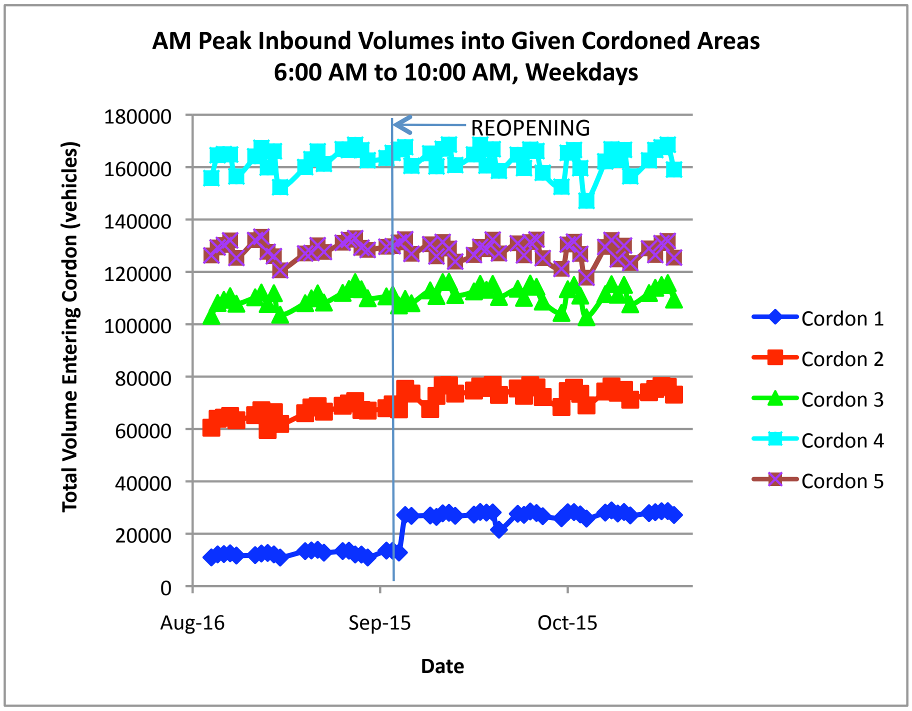

Figure 4.9: Total traffic counts for each cordon circle for Twin Cities Network around time of Bridge Reopening

At first glance, it would appear that traffic fully recovered to pre-collapse levels. However, when comparing cordon crossings between October 2006 and October 2008, traffic demand has decreased overall. The change is notable, though not drastic, typically ranging between 5 and 7 percent, but it suggests that the new traffic dynamics may not be the same. To investigate further, traffic demands near the bridge are studied between 2006 and 2008, utilizing functioning loop detectors near the University Avenue ramp (north of bridge) and the Washington Avenue ramp (south of bridge). The locations of these detectors relative to the bridge are shown in Figure 4.10. Four-hour counts for the northbound and southbound directions between 6 a.m. and 10 a.m. are compared over the two years. The results are shown in Figure 4.11 and Figure 4.12.

Following the reopening of the I-35W Bridge, traffic demand immediately jumps to a stabilized value on both northbound and southbound directions. This observation is made from the second-closest loop detector counts upstream and downstream of the bridge, as the post-collapse detectors nearest the bridge (used in Figure 4.11 and Figure 4.12) were not turned on until October 2, 2008. Nonetheless, when data is available for detectors nearest the bridge, it is clear that the new demands are less than the 2006 traffic demands at the same locations. The 2008 demands remain lower in the months following the opening, suggesting that traffic does not recover in the medium-term. Even when looking eight months after reopening (May 2009), the new demand is still 14 percent, on average, below the demand found two years prior (May 2007). (A greater drop than is seen network-wide due to gas prices, economic conditions, and other secular conditions).

This is quite surprising, given the available capacity on the bridge. Are commuters intentionally avoiding the bridge? Or, has traffic demand around the Twin Cities simply decreased between 2006

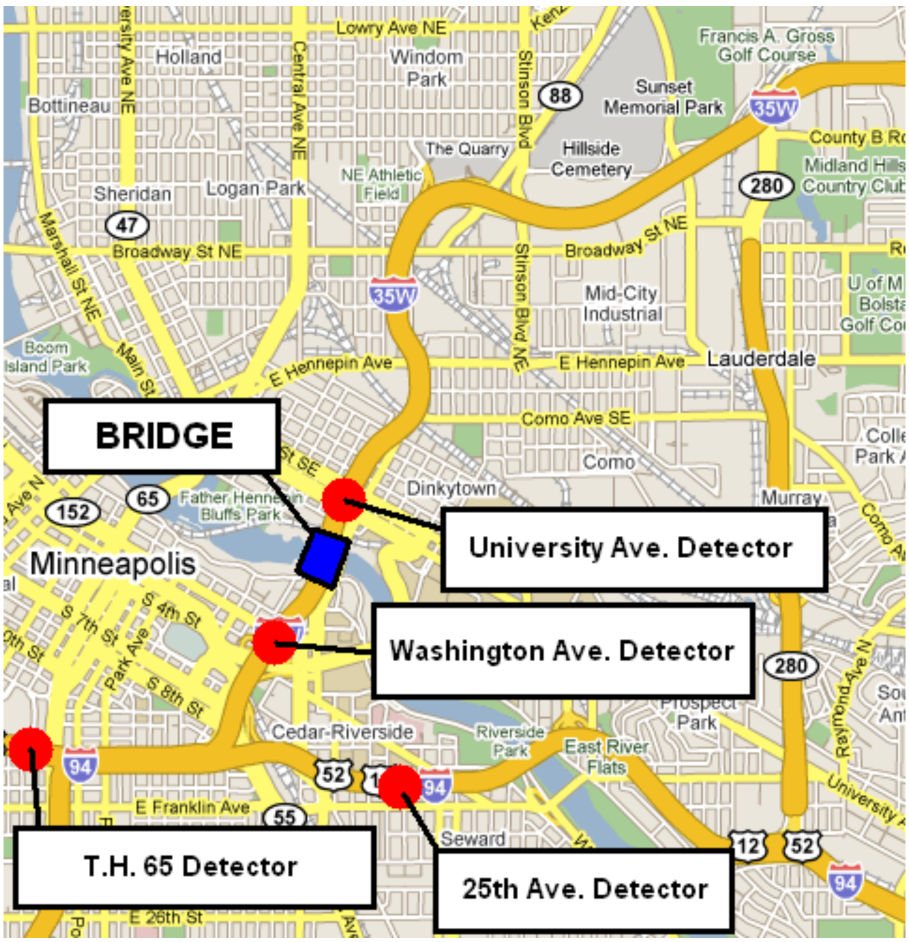

Figure 4.10: Locations of I-35W and I-94 loop detectors in post-reopening count analysis, with the I-35W Bridge identified

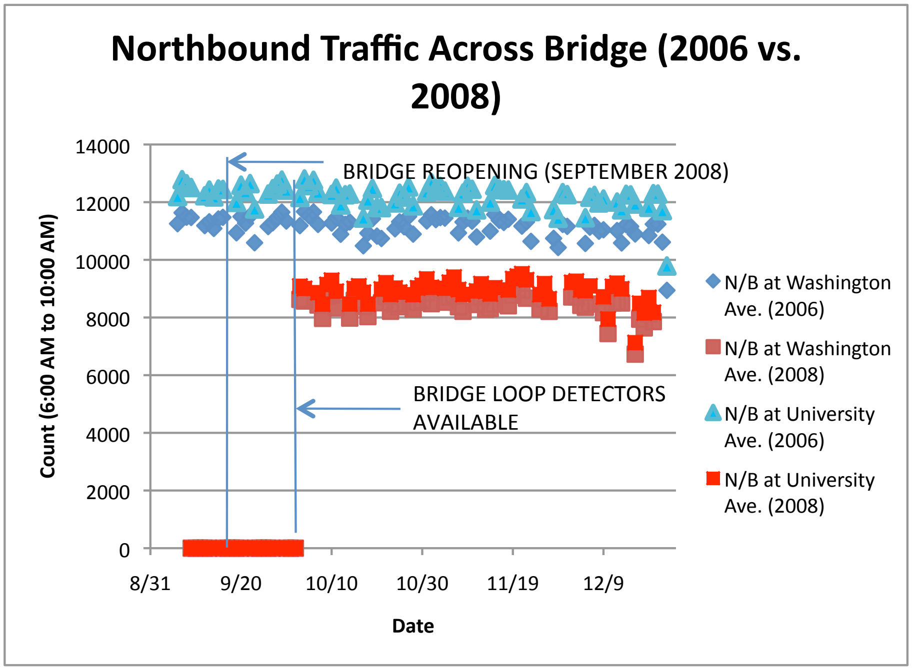

Figure 4.11: Northbound traffic across I-35W Bridge (2006 versus 2008)

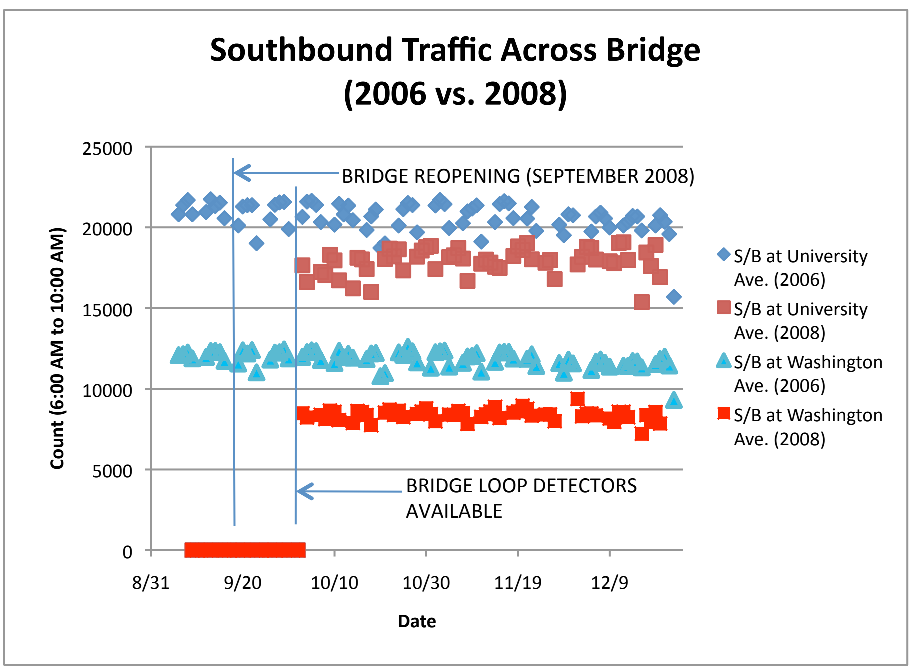

Figure 4.12: Southbound traffic across I-35W Bridge (2006 versus 2008)

and 2008? To answer this, traffic counts on the nearby I-94 will be assessed for the same time period using loop detectors near Mn 65 and 25th Avenue, as shown in Figure 4.10. The results are shown in Figure 4.13 and Figure 4.14.

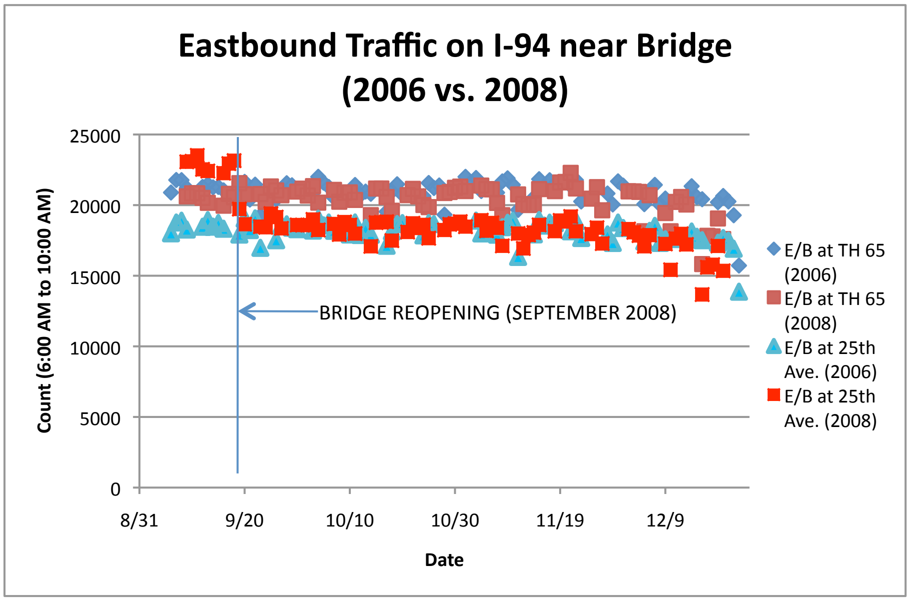

Figure 4.13: Eastbound traffic along I-94 near I-35W (2006 versus 2008)

Following the I-35W Bridge reopening, I-94 traffic in 2006 and 2008 for both westbound and eastbound directions is approximately the same. Prior to reopening, the 25th Avenue detectors reported higher demands in 2008 due to that portion of I-94 serving as the I-35W detour to Mn 280, but this is not particularly important. Nonetheless, it is clear that post-reopening I-94 demands are very similar to 2006 demands, suggesting that traffic in the area has remained relatively constant.

Given these observations, why has demand across the I-35W Bridge decreased, despite nearly identical network topologies? In cases of a route reopening from a planned closure, traffic demand returned to pre-closure levels shortly after reopening. For example, looking at a section of Mn 36 that experienced over a 20 percent traffic reduction during the construction closure as reported by operating loop detectors, demand at that site returned to within 6 percent of the previous years demand immediately after a full reopening. This is vastly more than the 15 to 30 percent loss at the I-35W Bridge between 2006 and 2008.

This data reflects that, all things being equal, demand restoration for a reopened link is different if the link experiences an expected closure versus an unexpected closure. For this data set alone, the differences in demand restoration may be in part due to three facts:

1. The unexpectedness of the I-35W Bridge collapse and the mandatory route changes some commuters were forced to make created inherent resistance to return to the bridge following reopening.

2. The prolonged closure was lengthy enough for the benefits of route familiarity in the disrupted network to outweigh the low travel times found on the new bridge.

3. The tragedy itself discouraged some commuters from returning to the site.

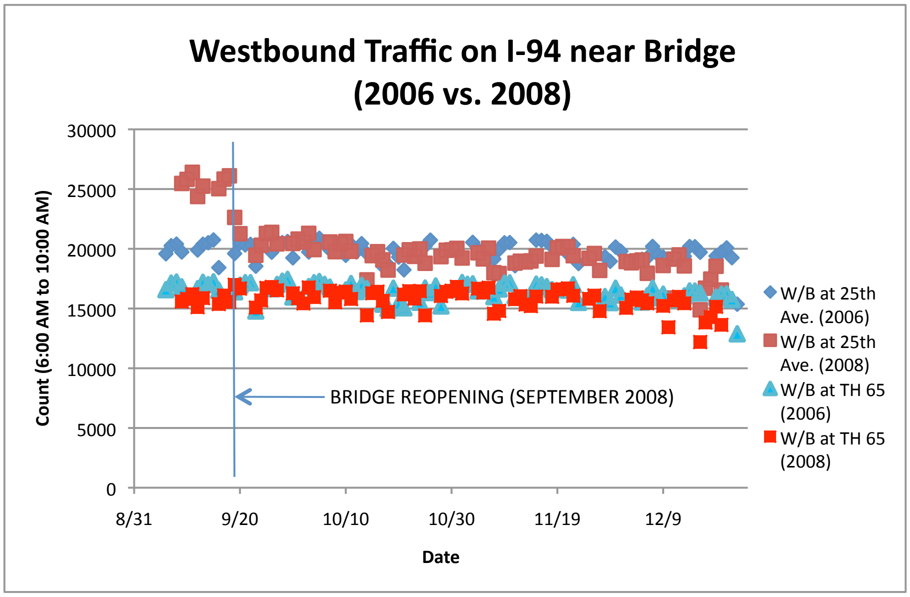

Figure 4.14: Westbound traffic along I-94 near I-35W (2006 versus 2008)

Future research is most definitely warranted, but the takeaway point from this analysis is that, despite similar topologies, demand restoration along a link that has previously endured a long-term closure due to an unexpected incident may not fully occur.

4.6 Discussion

To date, little is known about the transient traffic dynamics following a prolonged, unexpected network disruption, mostly due to the fortunate fact that these events seldom occur. Nonetheless, it is extremely important for practitioners and researchers to understand driver behavior after the occurrence of such events so that the resulting traffic demand can be better dealt with. This study has explored the observed traffic dynamics on the Twin Cities network following the collapse and reopening of the I-35W Bridge. The data has shown that driver route choice behavior is different for unexpected disruptions than for the common, preplanned disruptions.

Following an unexpected disruption, an avoidance phenomenon is observed, where drivers initially avoid the disruption site until the perceived risk of the area gradually diminishes. This avoidance phenomenon is witnessed in the Twin Cities network after the bridge collapse, as well as in the San Francisco Bay Area network after a similar disaster. Following the reopening of the disrupted link, the data reflects an absence of full demand restoration, where fewer drivers opt to utilize the new link. This suggests that commuters feel less of an incentive to reestablish pre-collapse routes, either out of memory of the tragedy, the influence of their potentially involuntary route changing experiences, or the familiarity of the disrupted network over a prolonged period.

This work helps answer theoretical questions of traveler behavior following unexpected network disruption. With these observations, future research can be conducted to develop models that describe the perceived network risks of unexpected disruptions and the influence of familiarity and personal fear on route choice following network restoration. The observations provided in this work are beneficial to transportation engineers, researchers, and planners alike. From a policy perspective, this knowledge could aid in better identifying the risks and rewards of network restoration following an unexpected tragedy. From an operations perspective, this knowledge could help traffic managers understand how traffic is evolving in the long-term and the dynamics of how it will get there. Lastly, from a safety perspective, this knowledge could provide insight of where network congestion may appear, allowing a more effective deployment of incident management resources and infrastructure improvements.

Chapter 5

Planned Versus Unplanned: Travel Impacts and Adjustment Strategies of the Collapse and the Reopening of I-35W Bridge

The previous section investigates traffic responses to planned and unplanned network disruptions and concludes that travel demand after this unplanned network disruption experiences a sudden shock and prolonged recovery, while it remains almost unchanged after planned road closures. This section complements the previous section from the microscopic perspective by investigating how travelers responded to the I-35W Bridge collapse and opening based on survey data collected in the aftermath of both events.

Paper-based hand-out/mail-back surveys were conducted both after the bridge collapse (some results of this survey have been reported in Zhu et al. (2009)) and the bridge reopening. This study also used a web-based survey after the bridge collapse to supplement paper-based surveys, which could cover a more geographically diverse population with lower cost.

Web-based surveys have been used in collecting public responses (e.g. Kockelman and Kalmanje (2005)) and exhibits significant advantages in reaching a wider population within reasonable budget compared to conventional survey techniques such as mail-in questionnaires, phone calls, and personal visits. This study compares the results of the web-based and paper-based surveys.

Results from all three surveys are reported and discussed. Findings from this research could advance our understanding of the behavioral changes and decision-making mechanism, thus assisting future traffic management and mitigation plan development in response of network disruptions. A detailed description of surveys conducted is given in the next section.

5.1 Surveys

A hand-out/mail-back survey was conducted by the University of Minnesota, during September 2007, in order to capture individual responses to the bridge collapse. The survey questionnaire included questions about demographics, self-evaluation of the impacts of general travel patterns, travel choices during the morning commute, and four maps on which respondents were asked to draw their commute routes during four time periods: before the bridge collapse, the second day, two weeks later, and six weeks later when traffic stabilized, respectively. Questions about morning commute included the departure time, arrival time, travel mode, route choice, route familiarity, and motivation for any changes during each time period. Questions targeting general travel patterns included whether travelers canceled trips or avoided destinations. The survey was distributed in both the downtown area of the City of Minneapolis and the nearby Minneapolis campus of the University of Minnesota (Figure 5.1 shows their relative locations to the I-35W Bridge), two communities significantly affected by the bridge collapse. Survey questionnaires were randomly handed out on streets, at bus stops, and at the exits of structured parking ramps during workday afternoons of the last two weeks in September, 2007. A total of 1000 survey forms were distributed, and responses arrived through September and October. In all, 141 usable responses were received.

Extending the paper-based survey which targeted the post-bridge collapse conditions, a similar mail-back survey was conducted after the replacement bridge opened. The same questions were asked and five maps were provided, targeting route choice before the bridge collapse, before the bridge reopening, on the day of the bridge reopening, and on the day of survey completion. In total, 840 survey forms were handed out in Downtown Minneapolis and the University of Minnesota on October 30th, 2008, six weeks after the bridge reopened, of which 137 responses were received. The answers were then digitized and documented for further analysis.

Both paper-based surveys targeted a population selected by their work locations. In contrast, the web-based survey was adopted to reach out to a wider spectrum of residents at the Twin Cities area. A set of eight Zip codes in the Twin Cities area, differing in their distance to downtown Minneapolis, were selected. Postcards that carried an invitation message for the web-based survey and the web address were sent to a pool of 5000 individuals who reside in the selected areas. Reminder post cards were sent a week after the initial mailing was sent out, and 192 cards were returned due to wrong mailing address. Of 269 respondents, 54 dropped out before completing the questionnaire. In this study we use the 215 respondents that completed the survey. This survey piggybacked on a broader survey about travel behavior, only the results related to the I-35W Bridge are presented here (Tilahun, 2009).

5.2 Demographics

Figure 5.1 shows the geographical distribution of residential and work locations of subjects in all three surveys. While most subjects in paper-based surveys work in downtown Minneapolis and at the University of Minnesota campus, their residential locations are well-dispersed across the Twin Cities area. In contrast, the web-based survey captured a population whose workplaces are widely spread out in the region, supplementing the subject list from paper-based surveys.

Table 5.1 summarizes demographic information in all three surveys. The number of female respondents were consistently larger than their male counterpart in all three surveys (to compare, females represent 49.8% of total population according to 2000 Census). The age and household size distributions are also similar. However, more subjects (74%) in the web-based survey chose personal vehicle as primary commute mode than the paper-based survey (63.1% after the bridge collapse and 47.4% after the bridge reopening). This difference in mode shares is due to the different sample population targeted by two survey techniques. According to the 2000 Travel Behavior Inventory (TBI) data (Metropolitan Council, 2009), 77.6% commuters in the Twin Cities area drive alone and 4.4% drive with passenger, while public transit only carries 4.8% of work trips. However, public transit has a share of 25% (Levinson and Krizek, 2008) and 24% (Zhu et al., 2009)

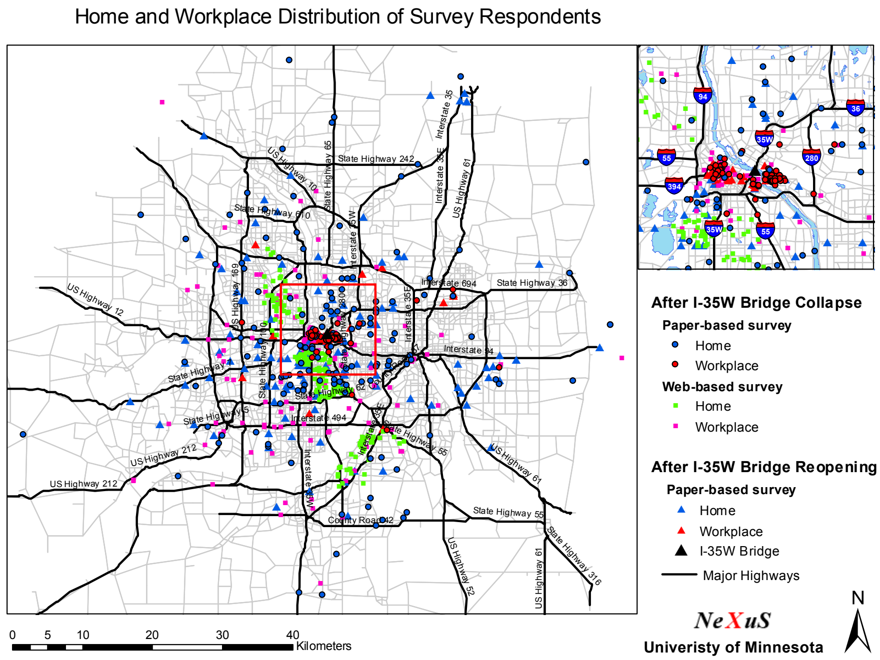

Figure 5.1: Home and workplace of subjects in both paper-based and web-based surveys

when we consider work trips to downtown Minneapolis and the University of Minnesota campus, respectively. The share of public transit becomes even higher when we evaluate peak hour work trips alone (up to 44% for downtown Minneapolis). Therefore, mode shares in our survey are roughly consistent with TBI data and the web-based survey helped to cover a larger population in the metropolitan area which the paper-based survey failed to reach.

5.3 Information acquisition

Respondents were asked to report how they found out about the bridge collapse and its reopening and the results are summarized in Table 5.2. The percentage of respondents who first learned of the bridge collapse from family members and friends were much higher than that in the new bridge opening case, possibly because many people called their family and friends to check their safety immediately after knowing the tragedy, helping to spread information. This differed from the opening of the replacement bridge, which while well-covered by the media, received a much lower profile and was likely not as significant point of personal conversation. This difference in level of psychological shock between the surprise bridge collapse and the well predicted opening, combined with the reluctance to change travel habits, may help to explain why traffic in the impacted area saw a steep drop and prolonged oscillation after bridge collapse, while traffic on the new I-35W Bridge stabilized within a week and only represented 86% of what was observed before bridge collapse, even with higher capacity.

Consistently, people whose travel pattern was affected by these incidents are most likely to get information through personal networks. This finding shows that personal communication is an important resource for spatial and travel information, which has not been sufficiently addressed by

Table 5.1: Description of the respondents

Description	Categories	Bridge Collapse		Bridge Reopening	Metropolitan *
		Web-based N=215	Paper-based N=141	Paper-based N=137	Control
Sex	Male	40.9%	34.0%	36.5%	50.2%
	Female	59.1%	61.7%	48.9%	49.8%
	N/A		4.3%	14.6%	
age	18-34	45.1%	N/A	41.1%	34.0%
	35-49	34.4%		29.9%	37.1%
	50 and over	20.5%		29.1%	28.8%
Household income	Less than $50,000	25.6%			36.9%
	$50,000-$99,999	50.2%			34.8%
	$100,000 and over	20.5%			28.3%
	Not reported	3.7%			
Household Size	One	28.4%	12.1%	20.4%	Avg = 2.51
	Two	36.3%	35.5%	39.4%	
	Three or more	34.9%	48.2%	36.5%	
	Not reported	0.5%	4.2%	3.6%	
Usual mode	Car	74.0%	63.1%	47.4%	86.9%
	Other	23.7%	34.1%	40.9%	13.1%
	Not reported	2.3%	2.8%	11.7%	
Home distance to 35W bridge	0-4 km (0-2.5 mi)	3.3%	9.9%	11.3%	
	4-8 km (2.5-5.0 mi)	39.5%	20.6%	16.3%	
	8-16 km (5.0-9.9 mi)	30.7%	30.5%	27.7%	
	16 km (9.9 mi) and over	24.7%	36.2%	32.6%	
	Home location unknown	1.9%	2.8%	9.5%	
Work distance to 35W bridge	0-4 km (0-2.5 mi)	19.5%	91.5%	80.1%	
	4-8 km (2.5-5.0 mi)	10.7%	1.4%	0.7%	
	8-16 km (5.0-9.9 mi)	19.1%	2.1%	4.3%	
	16 km (9.9 mi) and over	33.0%	2.1%	2.8	
	Work location unknown	17.7%	2.8%	9.5%	

* Data are estimated by the US Census Bureau for the Minneapolis-St. Paul-Bloomington, MN-WI Metropolitan Statistical Area based on the 2008 American Community Survey (Bureau, 2008).

Table 5.2: First heard about bridge collapse and reopening

Description	Bridge Collapse All respondents	Bridge Collapse Impacted	Bridge Reopening All respondents	Bridge Reopening Impacted
Media (TV, Radio, Internet etc.)	54.4%	33.3%	84.7%	78.2%
Family and Friends	39.1%	58.3%	10.9%	18.2%
Other	5.6%	8.3%	4.4%	3.6%

existing travel demand models.

5.4 Travel impacts

Impacts of the bridge failure are likely to be felt the most by people in the in the immediate vicinity of the bridge. In addition, those individuals who do not reside in the vicinity but have destinations such as work and leisure or social activities in the area are also likely to have their travel impacted. This section examines the location and demographic characteristics of those individuals whose travels were impacted by the bridge collapse.

Over 28% respondents from the web-based survey and 54.6% respondents from the paper-based survey reported that their travels had been affected by the I-35W Bridge collapse. The higher percentage from paper-based survey is consistent with the fact that most respondents in paper-based survey work near the bridge (see Figure 5.1). We further hypothesize that, in addition to home and work location proximity to the bridge, the respondents' household structure, the presence of children, and the number of contacts that people have in close proximity to their residence, would be important descriptors of the likelihood their travels would be impacted by the collapse.

A logit model is used to investigate which respondents were more likely to be impacted by the bridge failure. Specifically we test:

$log[p/(1-p)] = \beta_0 + \beta_1 * H_d + \beta_2 * W_d + \beta_3 * S + \beta_4 * M + \beta_5 * C + \beta_6 * Z + \beta_7 * K$

where

- p: The probability of a respondents travel being impacted by bridge failure
- H_d: Distance from respondents home to bridge
- W_d: Distance from respondents work to bridge
- S: Sex
- M: Usual mode to work
- C: Number of contacts with in 16 km of home with whom the respondent communicates with at least twice a week
- Z: Household Size
- K: Are there children 17 or under in the household?

Results are summarized in Table 5.3. Respondents in the web-based survey who lived within a 4 km radius of the bridge were much more likely to have their travels impacted by the bridge failure than those outside. The estimated coefficients to the successive categories are positive and decreasing with 4-8 km radius higher than that for 8-16 km, which is higher than greater than 16 km radius. The same is true of where people worked. Those within 0-4 km of the bridge reported their travels were impacted, similarly those in the 4-8 km radius were also impacted but to a lesser magnitude. While there was not a significantly different rate of impact among those in the 8-16 km radius as compared to those over 16 km out, the trend is still positive. In both work proximity and home proximity we find a decreasing impact as the home and work locations extend from the center. Proximity of work location to the bridge was dropped for paper-based survey respondents since most of them worked within a 4 km radius. The role of home locations was not significant either.

Table 5.3: Modeling bridge failure impacts, location and demography

		Web-based Survey		Paper-based Survey	
		Estimate	Pr(>|z|)	Estimate	Pr(>|z|)
	(Intercept)	−3.8440	0.0001 ***	0.34	0.616
Home to bridge distance	8-16 km	0.4583	0.4288	-0.41	0.412
	4-8 km	0.8870	0.1058	-0.69	0.220
	0-4 km	3.3130	0.0131 **	0.078	0.909
Work to bridge distance	8-16 km	0.3467	0.5198		
	4-8 km	1.0410	0.0840 *		
	0-4 km	1.2939	0.0280 *		
Sex	Male	−0.4756	0.2467	-1.27	0.004 ***
Mode	Car	0.9350	0.0912 *	1.18	0.005 ***
Contacts in 16 km	1-4	0.6287	0.3541		
of home (base=0)	5-9	0.0485	0.9490		
	10 or more	1.0209	0.1204		
Household	two	1.1423	0.0316 **	-0.88	0.15
size (base=1)	three	1.4209	0.0375 **	-0.49	0.474
Children in household	(Yes=1)	−1.1701	0.0721 *	1.37	0.016**
LR:	169.14 on 156 degrees of freedom			31.59 on 126 degree of freedom	
psuedo-R^2		0.161		0.170	
		* Statistically significant at 10% level			
		** Statistically significant at 5% level			
		*** Statistically significant at 1% level			

Social networks play an important role in forming travel patterns. We anticipate that those respondents who have more close social contacts tend to make more discretionary trips to connect with friends and family, thus a higher chance to be affected by the bridge collapse. A "close contact" in this case is defined as those contacts that the respondent communicates with at least twice a month either face-to-face or through other communication technologies and who don't reside in the same household as the respondent. The trend from the model weakly suggests that those with 10 contacts or higher were more impacted as compared to those with fewer contacts ($p - value = 0.12$). Constrained by survey length, social network questions were not included in the paper-based survey.

Car users are consistently more likely to be affected in both surveys. This is not surprising since there had been few transit using I-35W Bridge before its collapse. Although the bus-only shoulder on the parallel I-94 Bridge was opened to all traffic in the aftermath of the I-35W Bridge collapse, other transit routes were almost intact.

Larger household size implies more trips and higher chance to feel the impacts of bridge collapse. And the presence of children in the household could further impose constraints on trip schedule, thus less flexibility in travel pattern and larger chance to feel the inconvenience caused by the bridge failure. The result for children in household is significant in both surveys, but with opposite signs, pointing to the difficulty in drawing conclusions about their effect.

5.5 Adjustment strategies

Table 5.4 summarizes how travelers who felt impacted by either the bridge collapse or the new bridge opening adapted to new traffic conditions. Among them, changing route and changing departure time are the most prominent reactions, which is consistent with previous studies. People are loyal to their travel mode, potentially due to various constraints such as fixed schedules, car availability and parking policies which cannot be easily changed. Because respondents from the web-based survey generally work at locations further from the I-35W Bridge, they have more flexibility in arranging their travel schedule. Therefore, they react to the bridge collapse more moderately than respondents in the paper-based surveys.

Table 5.4: Adjustment strategy by subjects in three surveys

Categories	Bridge Collapse		Bridge Reopening
	Web-based N=215	Paper-based N=141	Paper-based N=137
Felt impacted	N=60 (27.9%)	N=77 (54.6%)	N=49 (35.8%)
Strategy	Percentage among impacted		
Route change	45%	72.7%	46.9%
Changed departure time	8.3%	75.32%	36.7%
Change Destination	N/A	61.04%	4.1%
Mode change	0	6.49%	4.1%

The sixty people who reported being impacted by the bridge collapse in the web-based survey were further asked about the frequency of bridge usage. According to Table 5.5, the use of the collapsed bridge was relatively low for most respondents self-claimed as impacted. The usage for non-work trip is higher, though. By further comparing this result with self-adaptation strategies summarized in Table 5.4, we found that five individuals that used the bridge a few times a week as well as 13 people who used it rarely or never on their commutes have also changed their routes to work. Moreover, travelers have foregone trips for social networking and shopping according to Table 5.6. This evidence suggests that dimensions beyond route choice should be considered when evaluating the impacts of infrastructure disruption.

Table 5.5: Use frequency of I-35W Bridge among those affected in web-based survey

Frequency	Work trips	Non work trips
At least once a week	10	16
At least once a month	7	33
Rarely/Never	43	10

Table 5.6: Reported effect of bridge collapse on different activities from web-based survey respondents

Description	Impact	All respondents	Impacted respondents
Effect on Visiting friends	Increased it	1.4%	1.7%
	Not affected	94.4%	90.0%
	Decreased it	3.3%	8.3%
Effect on Shopping	Increased it	0%	0%
	Not affected	91.6%	85.0%
	Decreased it	5.6%	11.7%
Effect on Internet Shopping	Increased it	0%	0%
	Not affected	99.1%	96.7%
	Decreased it	0.50%	1.7%

The opening of new I-35W Bridge, with 5 lanes in each direction compared to 4 lanes before it collapsed, might be expected to significantly improve the traffic conditions. However, according to the commute time changes derived from self-reported departure time from home and arrival time at work collected in the survey after the replacement bridge opened (see Figure 5.2), a few travelers reported a longer travel time, comparing to both cases before the bridge reopening and the bridge collapse. This result echoes findings from a parallel study targeted on travel cost evolution after the bridge reopening: travel conditions are not improved for everyone with a faster bridge.

5.6 Discussion

People who work or reside near the I-35W Mississippi River Bridge are more likely to feel the impacts of the bridge failure. However, its impacts reached further than the frequent bridge users. Although changing route and changing departure time are the most common reactions, people did forego some trips. Therefore, simply re-assigning travel demand on the degraded network cannot capture the full effects of the bridge collapse.

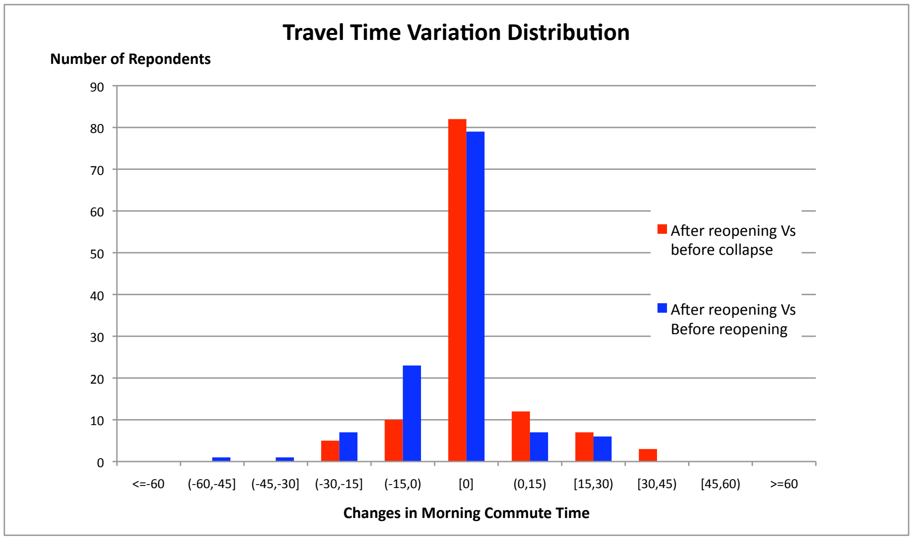

Figure 5.2: Changes in morning commute duration after the bridge reopening compared with before the bridge collapse and before the bridge reopening

Traffic impacts generated by the bridge reopening are less significant compared to what happened after the bridge collapse. Information resources also differ according to our survey, highlighting the role of social networking which has not been widely considered in current demand models. Moreover, travel cost has not been consistently reduced for all travelers by adding a faster link with high capacity to the network. Losers from the restoration of bridge service have been observed according to the post-bridge reopening survey.

Although the response rate for the web-based survey is still low (215 out of 5000), the low marginal cost after setting up the survey website and time savings in digitizing make it a good complement to, and perhaps surrogate for, conventional paper-based surveys. Flexibility in web design allows researchers to ask questions adaptive to previous answers and can generally accommodate more questions (intimidating long questionnaires could be divided and hidden before popping up). It could reach out to a wider public and no obvious biases have been found when compared with the population in similar geographical regions.

Chapter 6

Bridge Fear? Psychological Impact of I-35W Bridge Collapse on Driving Behavior

Analysis based on traffic data suggested that travelers exhibited an avoidance phenomenon following an unexpected disruption, where drivers initially avoid the disruption site until the perceived risk of the area gradually diminishes. Table 7.3 also indicated that the total number of crossing river trips dropped 6.3% and only 3.1% have been restored after the replacement bridge opened. Researchers such as Goodwin (1977) argued that previous experience is crucial for travel decisions. Therefore, the dramatic incidents such as I-35W Bridge collapse could have s stronger psychological impact and changed people's travel behavior more significantly, which could have contributed to the drop in crossing-river travel demand.

In order to understand the role of psychological impacts in shaping travel decision, surveys have been conducted among all participants of GPS-based studies. Questions have been asked about worries while driving on or under a bridge (or overpass) before and after the bridge collapse, respectively. (In addition to the I-35W Collapse, concrete from the Maryland Avenue overpass over I-35E in St. Paul fell onto the roadway and hit two vehicles on July 26, 2008, garnering media attention.) Answers to these questions have been merged with demographic data and results are summarized in Table 6.1. In total, 181 effective respondents have been received (43 from VMT study, 112 from the parallel OTREC2 study and and 26 from the parallel OTREC1 Value of Reliability study). Consistent with other surveys, the percentage of female participants is higher than found in the general population.

Table 6.1: Attitude towards driving on or under bridges among respondents (*ex post* self-evaluation for attitudes both before and after the I-35W Bridge collapse)

Questions	Total	Otrec1	Otrec2	VMT	Non-frequently Users	Frequently I-35W Users	Female	Male
Total Subjects	181	26	112	43	78	100	112	66
Worry about driving ON bridges or overpasses?								
After the I-35W Bridge collapse	44.2%	46.2%	42.9%	46.5%	42.3%	45.0%	49.1%	36.4%
Before the I-35W Bridge collapse	20.3%	19.2%	19.5%	23.3%	20.3%	21.0%	21.2%	18.2%
Worry about driving UNDER bridges or overpasses?								
After the I-35W Bridge collapse	39.1%	32.0%	39.6%	41.9%	35.1%	41.4%	44.1%	30.8%
Before the I-35W Bridge collapse	18.2%	11.5%	19.6%	18.6%	19.2%	18.0%	22.1%	12.1%
Worry about a bridges or overpasses might collapse while driving ON it?								
After the I-35W Bridge collapse	42.9%	53.8%	40.7%	41.9%	39.2%	45.0%	46.0%	37.9%
Worry about a bridges or overpasses might collapse while driving UNDER it?								
After the I-35W Bridge collapse	35.0%	36.0%	34.8%	34.9%	30.8%	37.4%	41.1%	24.6%
Does this worry affect your driving?								
After the I-35W Bridge collapse	14.4%	8.0%	11.2%	26.2%	8.3%	19.2%	16.7%	10.9%
Among those who worried (N=78)	26.9%	16.7%	19.6%	30.3%	12.9%	36.2%	27.8%	25.0%

Figure 6.1 illustrates the changes in attitude towards driving on bridges or overpasses among different population groups according to their *ex post* self-evaluation to the questions. About 45% of respondents indicated that they sometimes worried about driving on bridges or overpasses after the I-35W Bridge collapse, while only about 20% respondents felt so before the incident. The increase in percentage of people who worry about driving on bridge is consistent across all population groups, which clearly shows the psychological impacts generated by this dramatic incident. Similarly, people who worry about driving under a bridge or overpass also increased after the bridge collapse, and the magnitude is similar (see Figure 6.2). Although the trend is very clear, it has to be pointed out that the survey may have exaggerated the percentage of people who worried about driving on the bridge because questions were asked after the events. It is difficult to evaluate people's true attitude towards driving on bridge before the bridge collapse while excluding the impacts of that incident.

The percentage of respondents who worried about driving on bridges are slightly larger among frequent I-35W Bridge users compared with those who did not often use it, which is intuitive because of the immediacy of bridge collapse to frequently I-35W Bridge users. However, the increase in percentage of people who worried about driving on bridge is also significant among travelers who did not often use it, which implies that the impacts of I-35W bridge collapse are regional instead of local, possibly due to wide media coverage and discussions among residents at the Twin Cities. Females seem to worry more (about 15% higher in percentage) than their male counterparts. About 27% of those who felt worried indicate that this internal anxiety has affected their travel decisions. Therefore, the difference in gender effects on worry of driving on bridge could have significant impacts on travel patterns of different trips where participation of males and females are disproportionate.

Questions were asked to distinguish the worry about driving on bridge from the worry about possible bridge collapse. However, respondents either ignored the differences in the way questions were asked or were indifferent about these worries. The answers to both sets of questions are quite similar.

To conclude, the surveys show clearly that the bridge collapse arouses concerns about safety of driving either on or under bridges and overpasses and such concerns affect travel decisions. The effects of bridge collapse differ by gender, thus could affect different trips disproportionately. However, more modeling work is required to accurately quantify such impacts.

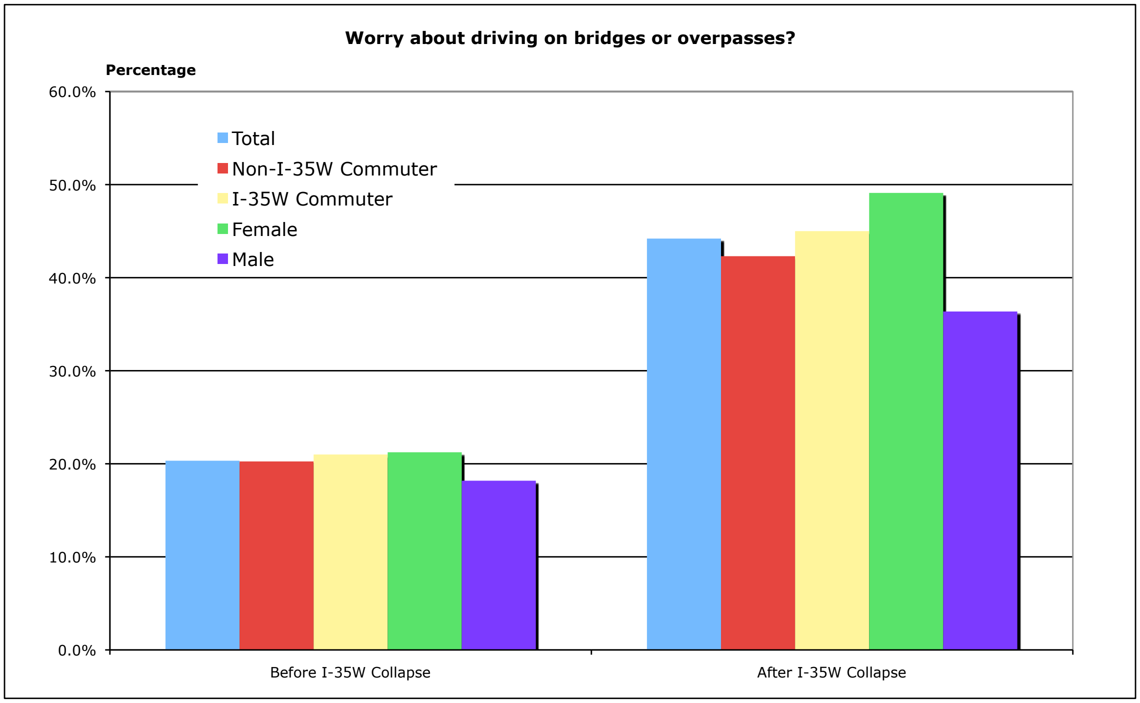

Figure 6.1: Percentage of respondents who worry about driving on bridges or overpasses

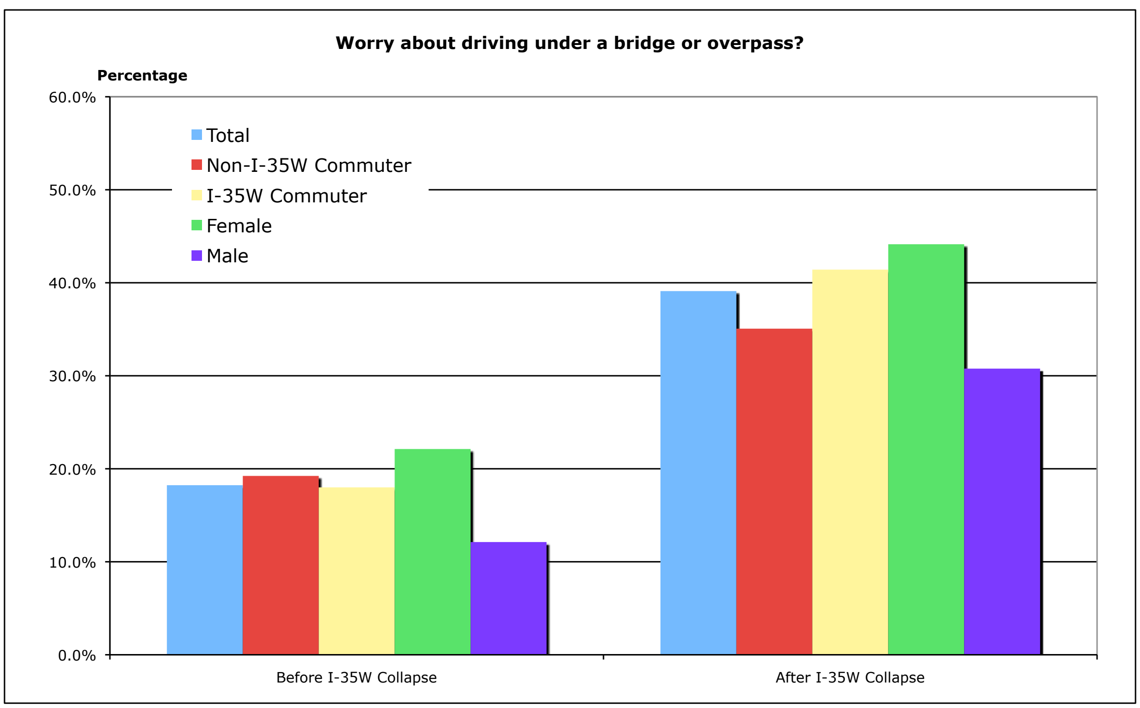

Figure 6.2: Percentage of respondents who worry about driving under bridges or overpasses

Chapter 7

Measuring Winners and Losers from the new I-35W Mississippi River Bridge

Adding capacity to a transportation network does not guarantee that individual travelers will enjoy shorter travel times. One famous example demonstrating this paradox was introduced by Braess (1968) in 1968, which shows that one additional link to the network may cause longer travel times for every traveler if all travelers choose to minimize their own travel times. In this case, each traveler's decision to act selfishly may achieve a user equilibrium that makes everyone worse off, and thus increase total travel cost. Ever since this phenomenon was first described in the literature it has been widely studied due to its significance for network design.

The Braess Paradox assumes fixed travel demand and attributes the increased travel cost to the redistributive effects (route choice) caused by the new capacity. However, the added capacity could also encourage people to make more trips, longer trips, and more private-vehicle trips, increasing travel cost by inducing new demand. For example, Noland and Lem (2002) investigating cases in both the US and UK, conclude that a 10% increase in lane miles could cause a 3% to 11% increase in Vehicle Miles Traveled (VMT). Although the concept of "induced demand" has been widely accepted, its magnitude remains the subject of study (Parthasarathi and Levinson, 2003). Cervero (2003) modeled 24 California highway projects across 15 years and found an much smaller elasticity of 0.24. Mokhtarian et al. (2002) investigated 18 cases of capacity expansion in California and found no evidence of induced demand. Handy (2005) provided a comprehensive review on this topic and concluded that new capacity "might increase travel a little". While empirical studies on induced demand have been relatively abundant (if inconclusive), studies on Braess Paradox are predominantly theoretical.

Braess Paradox occurs because on transportation systems the Wardropian User Equilibrium (analogous to the Nash Equilibrium in game theory): "The journey times in all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route," is not system optimal: "At equilibrium the average journey time is minimum" (Wardrop, 1952). Thus road users pursuing a selfish strategy may overload the added link or capacity, generating detrimental congestion effects (Helbing and Huberman (1998); Helbing and Treiber (1998) illustrated how moderate increase in flow density near its critical value could trigger traffic clusters and severe jams) that lead to longer travel times for everyone. This phenomenon was first illustrated by Braess (1968) (which was originally written in German, and later introduced to English-speaking community by Murchland (1970), while the full translation was provided by Braess et al. (2005)

) on a very simple network containing four links and one origin-destination (OD) pair, under the assumptions of fixed demand and affine link performance functions.

Results from two widely cited cases present counterintuitive consequences of either expanding the network (Stuttgart, (Knödel, 1969)) or removing links from the network (New York City, Kolata (1990)). In both instances, the Braess Paradox may explain the unexpected results. Still, research in this field is largely conceptual and usually based on small networks with simplified link performance functions.

Steinberg and Zangwill (1983) explored this problem on a more general network and concluded that "Braess paradox is about as likely to occur as not occur". Pas and Principio (1997) indicated that the occurrence of Braess Paradox depends on link congestion function parameters and the demand for travel. Researchers have also captured new paradoxes under different assumptions of network conditions (Arnott et al., 1993; Cohen and Kelly, 1990; Dafermos and Nagurney, 1984; Fisk, 1979; Lin and Lo, 2009; Nagurney, 2000; Nagurney et al., 2007; Yang and Bell, 1998). Roughgarden and Tardos (2002) quantified the travel time losses caused by the selfish routing strategy, which he dubbed the "Price of Anarchy" and obtained its upper bound under certain conditions. Youn et al. (2008) further explored this concept and identified links that might trigger Braess Paradox on sketch networks of Boston, New York, and London. Although this research was based on maps of real networks, it still assumed link performance functions (which map traffic flow onto travel time) and unique origin-destination pairs. The lack of field evidence (excepting the two previously mentioned examples) inspired the arguments that the Braess Paradox is only a theoretical curiosity and is too extreme to be a real-world phenomenon due to complexity in travel behavior and network conditions. Rapoport et al. (2009) observed a series of independent and repeated route choice decisions of participants when facing a Braess Paradox type network in two laboratory experiments and concluded that the paradox was likely. However, it is apparent that more field evidence is needed to ascertain the likelihood of Braess Paradox on real network.

To date, no studies that demonstrate the Braess Paradox on real large-scale networks. This may be due to

1. the difficulties in accurately measuring network flow and travel time;
2. confounding factors contributing to long-term changes in travel demand and pattern;
3. the lack of a clearly defined impact zone isolated from the rest of the network; and
4. the relative rarity of such paradoxes.

The research presented here closes this gap in the literature by testing the existence of Braess Paradox on the Minneapolis - St. Paul (Twin Cities) regional network based on field data, thus avoiding strong assumptions about link performance functions and travel behavior inherent in previous analyses. It has to be pointed out that given the large number of OD pairs on the real network, some travelers, most likely those who were directly connected by the new fast link, must be better off. Thus it is impractical to find the ideal case where everyone suffers a longer travel time due to one additional link added to the network, as illustrated in most theoretical research. Instead, this research examines the overall effects to all travelers and how they are distributed among different groups.

The I-35W Mississippi River Bridge famously collapsed on August 1, 2007. The opening of the replacement bridge on September 18, 2008 restored a major (10 lane) connection on the Twin

Cities network, providing a unique opportunity to evaluate the impacts generated by this additional link on network performance, and thus empirically test whether a Braess Paradox occurred. Casual observation and anecdotal evidence suggested the bridge reopening was not universally appreciated by commuters, but more rigorous analysis is required. To overcome the difficulties in measuring real travel time, GPS devices were installed in vehicles of a randomly selected sample of 187 travelers. The 8 weeks of GPS data from these probe vehicles (2 weeks before the reopening of the bridge and 6 weeks after it), allows us to estimate travel time on the network during different time periods. The system-wide travel time was then evaluated during different time periods and for different travel demands. This research presents a methodology for testing for the Braess paradox using real data. The spatial and temporal patterns in travel cost changes due to the additional link could also provide insights for theoretical analysis and have importance implications for future network expansion decision-making.

This section describes the data used in this study. The travel cost are then evaluated under different travel demands and the results are further analyzed. This section concludes with a discussion of findings from this study and their implications for future research.

7.1 Network speeds

The average link speed has been estimated from GPS data collected from all probe vehicles passing this link during a defined time period. There has been a large body of literature discussing the minimal number of observations required to ensure reliable speed estimate. For example, Long Cheu et al. (2002) concluded that ten probe vehicles must pass though a link within the sampling period to achieve a accuracy within a 95% confidence interval. Li and McDonald (2002) recommended that 5 samples were sufficient for reliable estimation on roads carrying a traffic flow higher than 2000 vehicles/hour and this requirement could be further relaxed if traffic flow becomes higher. For this study, a link speed estimate was regarded as valid only if more than 10 samples were available during that time period.

The large number of probe vehicles and long study period allows us a large number of observations not only on freeway links, but also on major arterial links and local streets near the I-35W Bridge. The latter is very important since it represents a significant chunk of total traffic and is unavailable in previous studies relying upon freeway loop detectors. Speed samples on arterial roads in the outer suburbs are generally low. However, speed patterns on these roads were unlikely to be significantly affected by the reopening of new I-35W Bridge. Therefore, speed on roads with insufficient samples were assumed constant through the study and equal to the average speed on all the links of the same functional class defined by the US Census Bureau in their TIGER files (Marx, 1990). [1]

Two major network changes occurred during this study time period: the new I-35W Bridge was reopened on September 18, 2008 and a section of I-94 Bridge was restriped so that the fourth through lane westbound on the between the interchange with I-35W and Mn 280, a major mitigation measure implemented after the bridge collapse in 2007. This freeway segment of I-94 was closed on October 12, 2008 for reconfiguration and the fourth lane of this critical link returned to operation as a bus-only shoulder lane, reactivating the bottleneck on this section due to the capacity drop.

[1] The data can be downloaded from http://www.datafinder.org

Refer to Appendix C and D for maps of the traffic variation after the new bridge opened and after the I-94 lane was reverted, respectively.

Parthasarathi et al. (2009) investigated the speed pattern for the Twin Cities based on both travel survey and loop detector data, and concluded that the morning and the afternoon peak periods (when congestion is sufficient to affect speed) are 6:00am to 9:00am and 14:00 pm to 19:00 pm, respectively. Combining the three time-of-day periods, Morning Peak, Middle of the Day, and Afternoon Peak, with the three phases, August 26 - September 18, September 18 - October 12, and October 12 - November 30, 9 study periods were defined. All speed observations during non-holiday weekdays were pooled for each time period accordingly and average speed for each link with more than 10 samples *in each period* was estimated.[2]

Figure 7.1 shows the changes in morning peak period speed after the reopening of the new I-35W Bridge (Phase 2 (Sep 18 to Oct 12) versus Phase 1 (Aug 25 to Sep 18)). The speed on the I-94 Bridge crossing the Mississippi River and Mn 280, the major alternative route for the I-35W Bridge recommend by Minnesota Department of Transportation (MnDOT) improves moderately. However, travel speed on I-35W upstream and downstream of the bridge drops because of the re-routing of travelers who benefit from the new bridge and reduce their own travel cost. The speed on arterial bridges crossing the Mississippi River improved after some arterial road users switched to the new freeway bridge. The most significant improvement of morning peak speed occurred at the off-ramps upstream and downstream of the collapsed I-35W Bridge and nearby local streets. This implies that many people made local detours after the bridge collapse, which concentrated traffic and caused long queues on streets connected to the north and south ends of the I-35W Bridge.

Figure 7.2 illustrates the changes in morning peak speed after the fourth through lane on I-94 Bridge was removed on October 12 when compared with the speed observed before the bridge reopened. The overall supply for crossing river capacity remains much higher than that before the bridge reopening because the new I-35W Bridge carries 5 lanes in each direction. The I-94 Bridge became extremely congested after this reconfiguration. The traffic condition upstream and downstream of I-35W further deteriorated because long queues on the I-94 Bridge could have pushed some traffic to I-35W. Comparisons for average speed during the middle of the day and afternoon peak hours generated similar results.

Figure 7.3 compares the daily travel demand on the new I-35W Bridge with that on the old I-35W Bridge. Although the new I-35W has higher capacity with one additional lane in each direction, it carries only about 80% (120 000 daily trips) of the demand (140 000 daily trips) that had used the old, smaller bridge. Therefore, it is no surprise that the new I-35W Bridge is almost never congested and enjoys free flow speed. The high speed on this bridge attracted many travelers who want to minimize their own travel time from parallel arterial roads and created bottlenecks upstream and downstream along I-35W, especially southeast of downtown Minneapolis where I-35W southbound meets I-94 westbound.

The hypothesis to be tested is that the cost created by these bottlenecks outweighs the benefit generated by the new bridge, leading to a Braess-like Paradox. Differing from classic examples where only one OD pair exists and everyone is worse off, there are a large number of OD pairs on the real network. Clearly, some travelers, especially those directly connected by the new bridge must be better off. Therefore, this study evaluates overall travel cost and examines the distribution

[2] Because of their minor role in traffic analysis and the small number of observations available, two other time periods, Before Morning Peak and After Afternoon Peak, were ignored in this study.

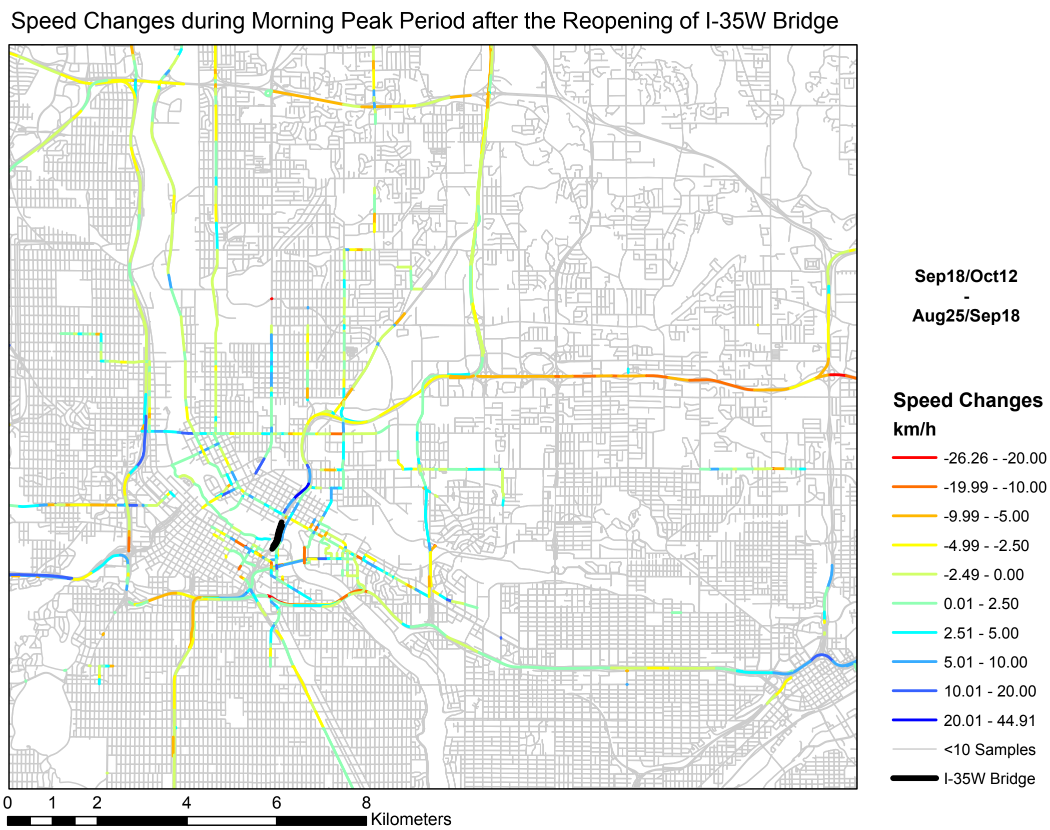

Figure 7.1: Speed changes during morning peak periods after the reopening of new I-35W Bridge

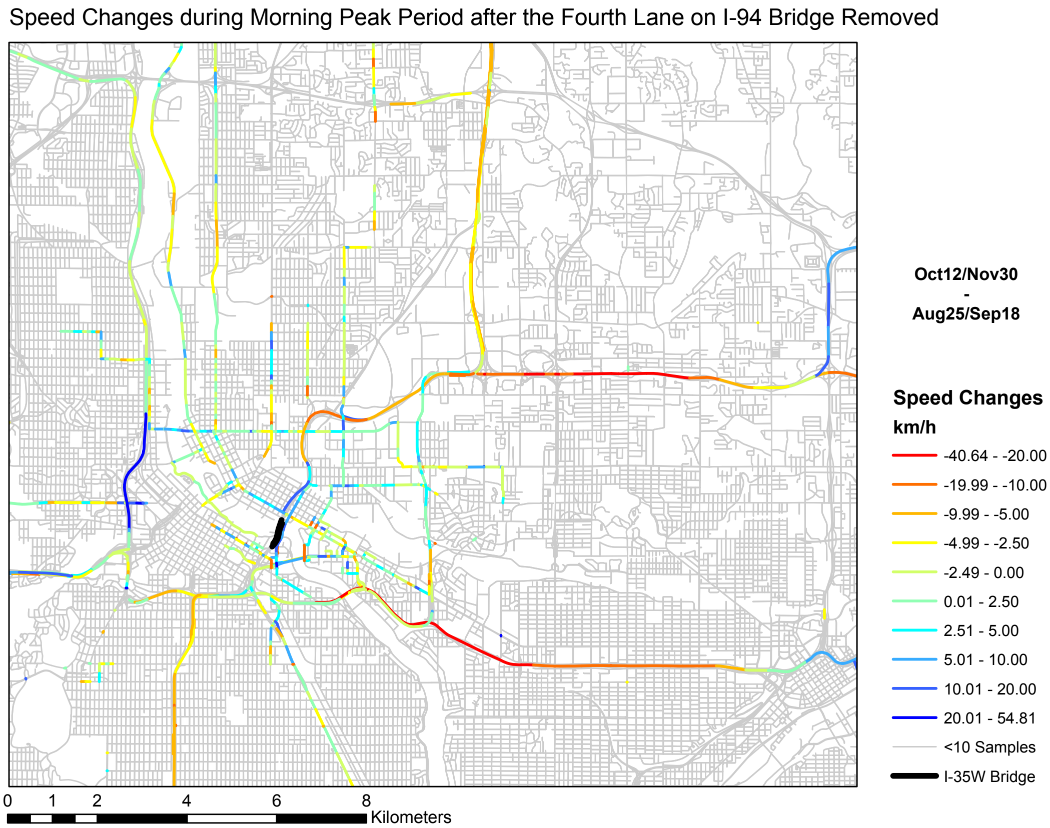

Figure 7.2: Speed changes during morning peak periods after the fourth through lane on I-94 Bridge was removed

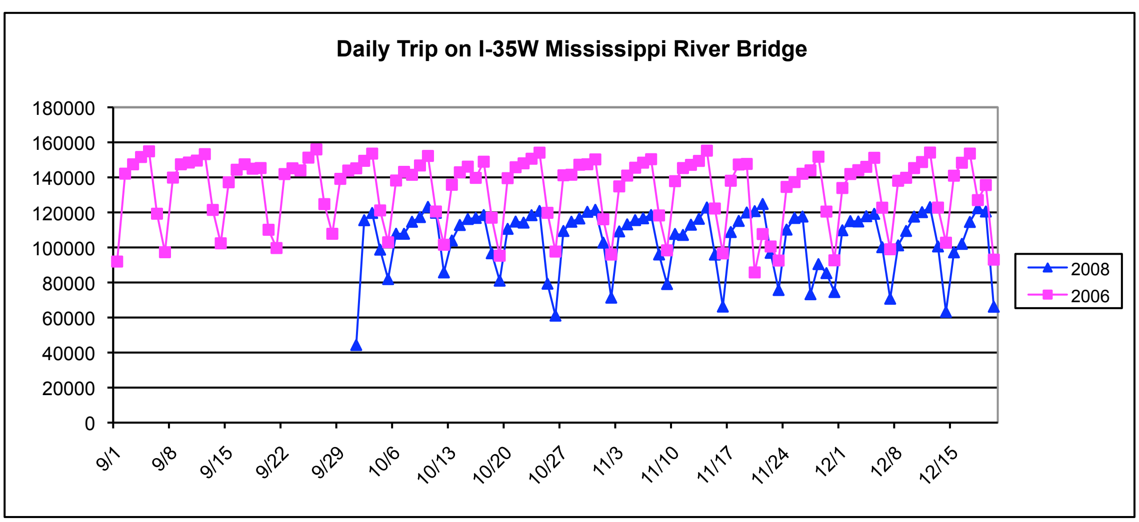

Figure 7.3: Daily traffic on I-35W Bridge

of that cost.

7.2 OD travel costs

Total travel cost is related to the distribution of travel demand across the region, usually defined by the origin-destination tables. Accurate estimation of travel demand on a regional network proves to be very difficult. In this study, three different OD tables, including Longitudinal Employment and Household Dynamics (LEHD) (FHWA, 2006), trip tables from the Metropolitan Council regional planning model, and freeway travel demand measured by the loop detector system, are utilized to evaluate overall travel cost. Although travelers between each OD pair do not necessarily follow the shortest path, travel costs derived from the shortest path assumption still represent the lower bound travelers might experience during different phases. Given congestion effects have been accounted for by the speed estimation from real-world travel trajectories and no route assignment procedure is required here, the shortest travel time path assumption approximates real routing decisions. Therefore, the shortest travel time between each OD pair was evaluated based on the congested speed estimated from GPS data and total Vehicle Hours of Travel (VHT) was calculated. The overall cost during different time periods are then compared.

The LEHD database (FHWA, 2006) maintained by the U.S. Census Bureau contains the residential location and work location for all employees within a region at the Census block level. The latest LEHD data at the Twin Cities (2006) contains 1,364,455 trips within the Twin Cities 7 County area, which form 1,215,357 OD pairs. We evaluate the home-to-work and work-to-home travel cost based on the travel speed during the morning and afternoon peak period, respectively. This calculation serves as an estimate for commute cost during different time periods and results are summarized in Table 7.1. The overall commuting cost in the morning peak period decreased 0.23% after the reopening of the new I-35W Bridge. After the fourth through lane on I-94 was closed, the overall home-to-work commuting cost was 0.20% higher compared to the total cost before the reopening of the bridge. The afternoon cost was consistently lower after the bridge reopened.

Table 7.1: Total travel cost (Vehicles Hours Traveled) for all work trips (LEHD data)

	Morning Peak		Afternoon Peak	
Phase1	$3.87 \cdot 10^5$		$4.27 \cdot 10^5$	
Phase2	$3.86 \cdot 10^5$	-0.23%	$4.26 \cdot 10^5$	-0.26%
Phase3	$3.88 \cdot 10^5$	0.20%	$4.25 \cdot 10^5$	-0.34%

The Metropolitan Council maintains travel demand estimates on the regional network. It defines hourly travel demand among 1,201 Traffic Analysis Zones in the seven county Twin Cities metropolitan area. Although it is not as detailed and accurate as the LEHD data, it is more comprehensive because both work and non-work trips are included. The demand tables were aggregated for the morning peak, the middle of the day, and the afternoon peak periods, respectively. Travel costs are then evaluated for different time periods and summarized in Table 7.2. The result is consistent with what we obtain under LEHD demand.

LEHD and Metropolitan Council Demand are both assumed unchanged during the study time period. Consequently, analysis based on these two demand tables cannot capture the effects of

Table 7.2: Total travel cost (Vehicles Hours Traveled) using Metropolitan Council planning model trip tables

	Morning Peak		Mid-day		Afternoon Peak	
Phase1	$3.71 \cdot 10^5$		$3.81 \cdot 10^5$		$7.29 \cdot 10^5$	
Phase2	$3.70 \cdot 10^5$	-0.18%	$3.79 \cdot 10^5$	-0.31%	$7.27 \cdot 10^5$	-0.23%
Phase3	$3.72 \cdot 10^5$	0.13%	$3.79 \cdot 10^5$	-0.32%	$7.27 \cdot 10^5$	-0.27%

induced demand. Table 7.3 shows the total number of river crossing trips increased by 3.1% after the new bridge opened, revealing that the travel demand has changed to some extent.

To separate out demand effects from re-routing effects, this study evaluates the changes in freeway usage, which is constantly monitored by the loop detector system and documented by MnDOT. There are about 1,000 detector stations across the freeway system. However, not all of them are in operation at any given time. In order to keep all results comparable between different time periods, stations malfunctioning in any of the three time periods are dropped. The metropolitan planning network, which has been conflated to the real-world geometry, was utilized to match the speed estimation from GPS and traffic counts from detector stations. The total freeway Vehicle Kilometers of Travel (VKT) and Vehicle Hours of Travel (VHT) were estimated and summarized in Table 7.4. Freeway VKT dropped during the morning peak period, and increased during the afternoon peak. There are several reasons for VKT changes, one may be due to fewer trips, another would be more efficient trips using shorter paths on the now improved network. The VKT during the middle of the day remained almost unchanged. During the morning peak period, freeway VHT dropped faster than the VKT after the reopening of I-35W Bridge. However, this trend reversed after the fourth through lane on I-94 Bridge was removed, showing a higher congestion level on the freeway. The result is consistent with findings based on the other two demand tables. The shift in travel pattern could have captured travelers' efforts to reduce travel cost by changing departure time.

Table 7.3: Crossing river trips for the I-35W Bridge Collapse and the Bridge Reopening

	Bridge Collapse				Bridge Reopen			
Bridge	Before	After	Increase	Percentage	Before	After	Change	Percentage
I-35W	140000	0	-140000	-100.00%	0	120350	120350	
Arterial total	152311	197566	45255	29.70%	169983	95895	-74088	-43.60%
Freeway total	572274	481040	-91234	-15.90%	488717	583128	94410	19.30%
Total	724585	678606	-45979	-6.30%	658701	679023	20322	3.10%

7.3 Discussion

Analysis based on three different travel demand tables consistently suggests that network conditions improve during the middle of the day and the afternoon peak. The impacts of the new I-35W Bridge during the morning peak are complicated. While the overall travel cost dropped slightly after the reopening of the I-35W Bridge, it increased after a critical section of the fourth through lane on I-94 between I-35W and Mn 280 was restored to a bus-only shoulder lane. *The benefits generated*

Table 7.4: Evolution in freeway Vehicles Hours Traveled and Vehicle Kilometers Traveled

		Morning Peak		Mid-day		Afternoon Peak		Sum	
Phase1	VHT	$9.50 \cdot 10^4$		$1.20 \cdot 10^5$		$1.79 \cdot 10^5$		$3.94 \cdot 10^5$	
	VKT	$8.01 \cdot 10^6$		$9.91 \cdot 10^6$		$1.36 \cdot 10^7$		$3.15 \cdot 10^7$	
	Speed	$84.3km/h$		$82.4km/h$		$75.9km/h$		$79.9km/h$	
Phase2	VHT	$9.40 \cdot 10^4$	-1.02%	$1.20 \cdot 10^5$	-0.37%	$1.81 \cdot 10^5$	1.13%	$3.95 \cdot 10^5$	0.15%
	VKT	$7.94 \cdot 10^6$	-0.89%	$9.91 \cdot 10^6$	0.06%	$1.38 \cdot 10^7$	1.37%	$3.16 \cdot 10^7$	0.39%
	Speed	$84.4km/h$	0.14%	$82.8km/h$	0.44%	$76.0km/h$	0.24%	$80.1km/h$	0.23%
Phase3	VHT	$9.38 \cdot 10^4$	-1.12%	$1.20 \cdot 10^5$	-0.47%	$1.81 \cdot 10^5$	1.31%	$3.95 \cdot 10^5$	0.16%
	VKT	$7.85 \cdot 10^6$	-1.90%	$9.89 \cdot 10^6$	-0.19%	$1.38 \cdot 10^7$	1.78%	$3.16 \cdot 10^7$	0.22%
	Speed	$83.7km/h$	-0.71%	$82.6km/h$	0.28%	$76.2km/h$	0.46%	$79.9km/h$	0.06%

by adding a 10-lane bridge are outweighed by removal of one lane on a parallel bridge. While we do not find a Braess paradox, we do see this unusual result.

We further investigate how travel costs are distributed among travelers. Figures 7.4 and 7.5 summarize changes in morning commute cost for commuters working in each Census block after September 18 and October 12, 2008, respectively. The geographic distribution of winners and losers due to the new I-35W Bridge by workplace is consistent with what has been observed on the speed maps. Table 7.3 suggests that the majority of I-35W Bridge users were previous arterial bridge users who switched to freeways to benefit from this new fast link. Therefore, the crossing river demand for freeway bridges increased significantly (19.30% according to Table 7.3). However, the capacity of the downstream bottleneck where I-35W meets I-94 and other on-ramps from local streets was not improved. Consequently, congestion propagated backwards (upstream) from this bottleneck. This pattern prevailed after a section of the fourth through lane on I-94 between I-35W and Mn 280 was converted to bus-only shoulder, since it created a new bottleneck (restored a previous bottleneck that was remediated by the traffic restoration projects) which not only affected local travelers, but also river crossing trips. This phenomenon is similar to the concept of Capacity Paradox introduced by Yang and Bell (1998): because of selfish routing, some capacity at the bottleneck was taken by drivers who could have taken an alternative for slightly longer travel time. The overall results could be either positive or negative, depending on the impact zone we defined and the elasticity of travel demand.

This pattern is clearer if we evaluate the average morning commute time by residential location (Figures 7.6 and 7.7). Most people who live along I-35W are better off, especially those who reside to the north of the I-35W Bridge and had crossed the I-35W Bridge to work in downtown Minneapolis, creating a circle around the bridge. Outside of this circle, most residents experience a longer commute time. People who live to the east of the I-94 Bridge suffered the largest loses regarding commute time. Therefore, the I-35W Bridge fails to relieve congestion on the I-94 Bridge, as most people would imagine, since the I-94 Bridge looks like an almost perfect substitute and alternative to I-35W Bridge for longer distance I-35W travelers[3]. However, Table 7.3 suggested that the overall demand on I-94 Bridge only drops about 10.8% by mid-November. However, about 25% of capacity was lost by removing one lane.

Although the new I-35W Bridge provides a higher capacity and has not experienced any con-

[3]The converse does not hold, I-35W is not a perfect substitute for I-94 travelers

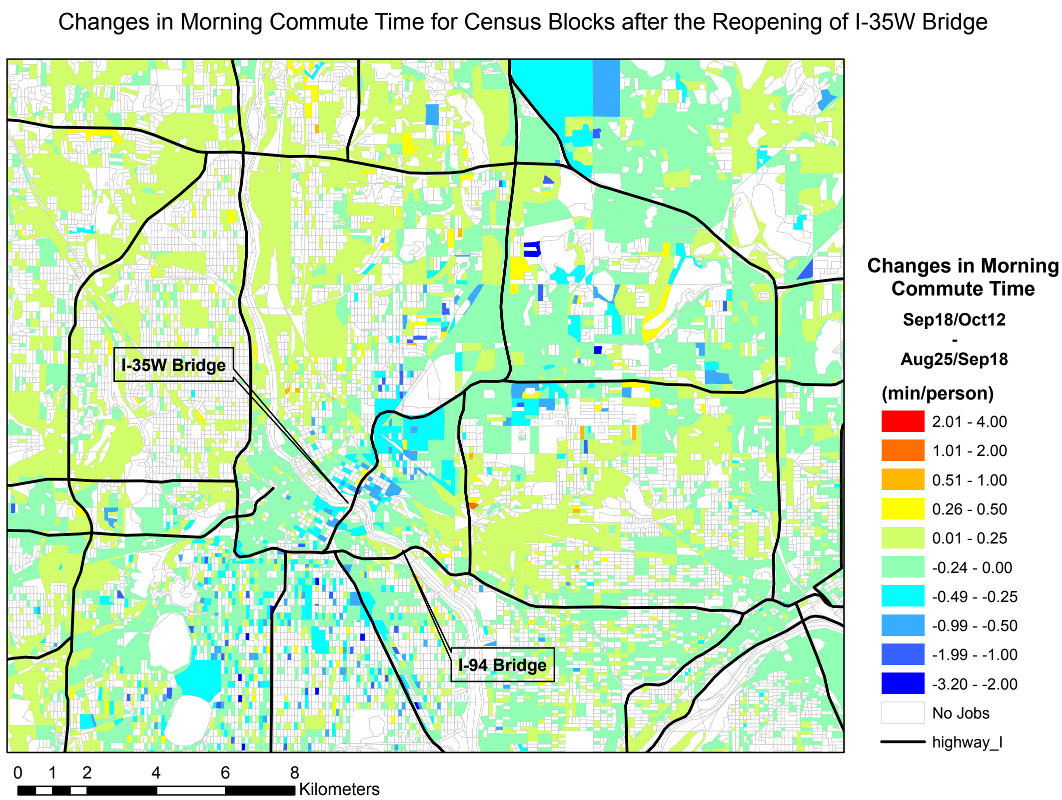

Figure 7.4: Changes of morning commute cost per person after the reopening of new I-35W Bridge by workplace

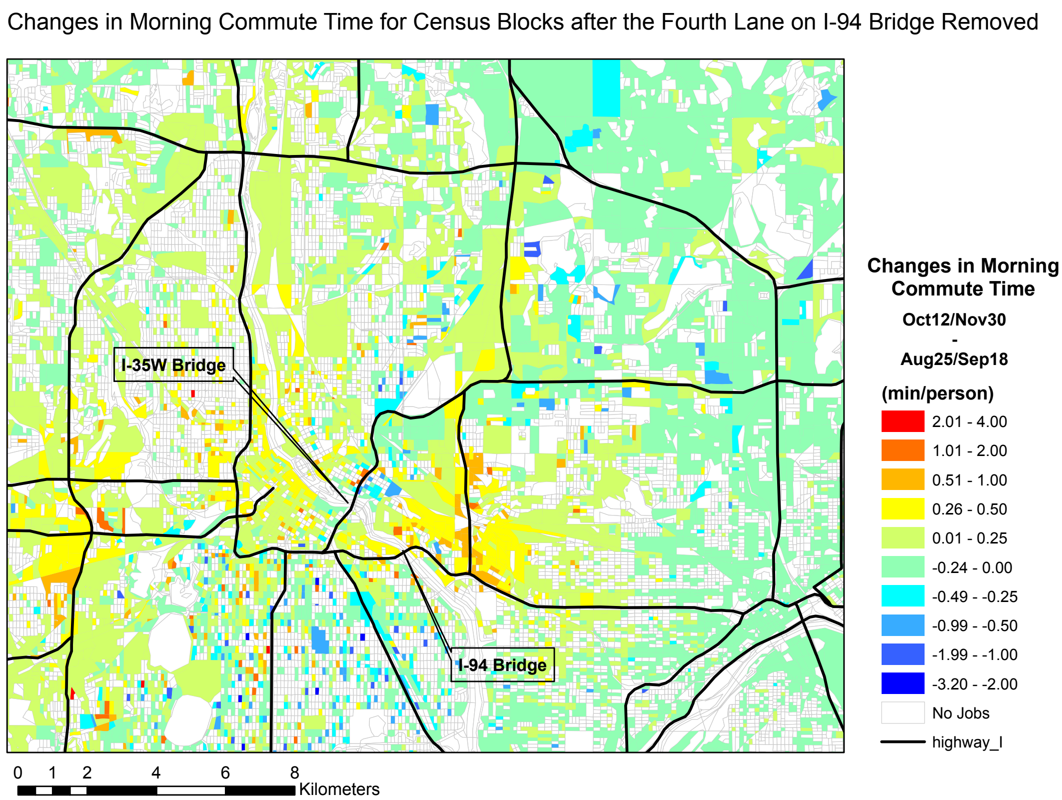

Figure 7.5: Changes of morning commute cost per person after the 4th lane on I-94 Bridge was removed by workplace

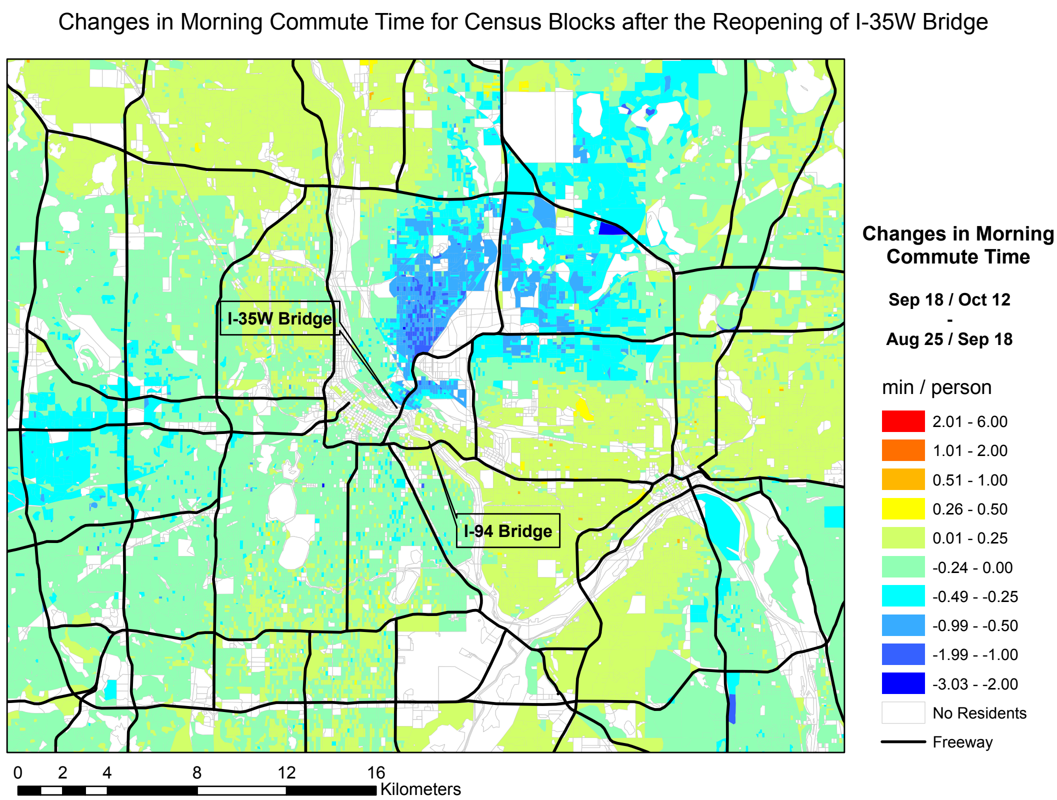

Figure 7.6: Changes of morning commute cost per person after the reopening of new I-35W Bridge by residential location

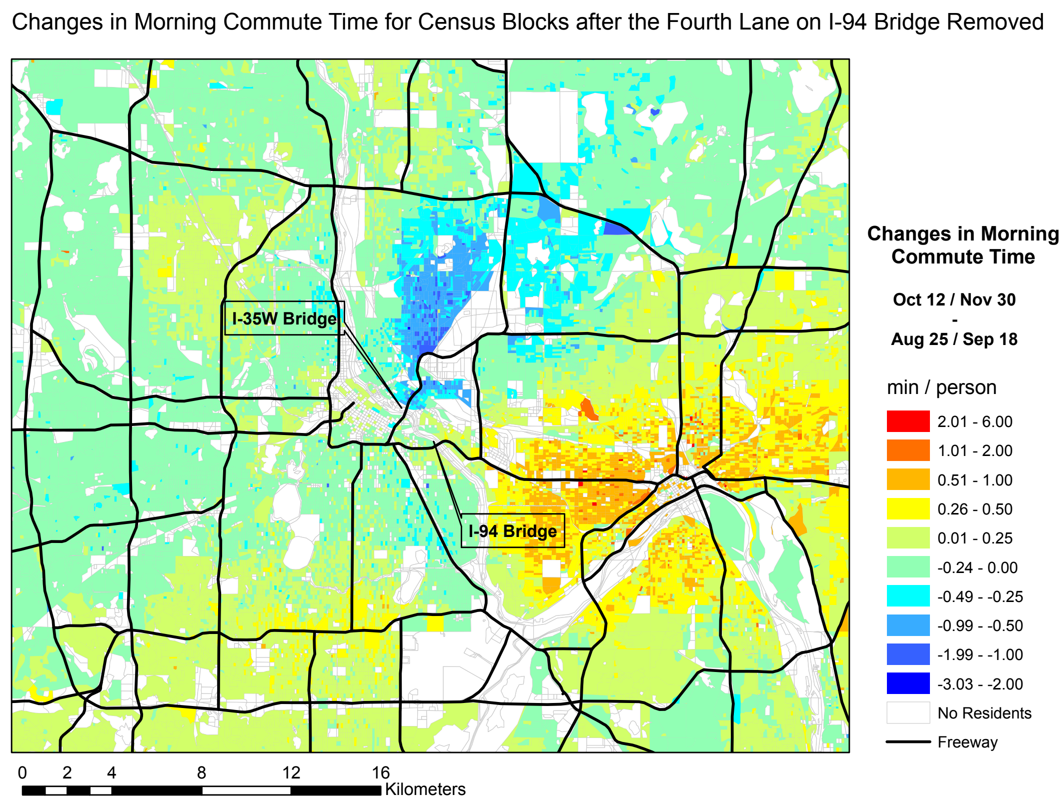

Figure 7.7: Changes of morning commute cost per person after the 4th lane on I-94 Bridge was removed by residential location

gestion since its opening, it failed to attract much traffic from the I-94 Bridge. The overall travel demand was smaller compared to that of one year ago, likely due to prevailing economic conditions. However, the daily traffic on the I-94 Bridge is as high as it was before the I-35W Bridge collapse. One possible explanation is the stickiness of driving habit and the reluctance to change routes. If we look at changes in morning commute cost by Census block, most commuters experienced an increase of less than 2 minutes and the highest change in commute cost per person is 6 minutes. According to one survey conducted in the Twin Cities area after the I-35W Bridge collapse, on average, people are unwilling to change route unless the time saved exceeds 10 minutes. To date, most studies on performance evaluation and demand analysis are equilibrium-based, which fails to consider the role of behavioral changes. Their impacts could become very significant after major incidents such as the bridge collapse. It might also be noted that after the collapse, users of I-35W had to find alternate routes or switch destinations. After the reopening of the bridge, users had the choice whether to switch.

The selection of the impact zone also influences the result. We investigated the number of winners and losers (Figure 7.8 and 7.9), regarding the morning commute time changes, within different radii from the I-35W Bridge after the reopening of I-35W Bridge and after the removal of the fourth through lane on I-94 Bridge, respectively. It is clear that most beneficiaries of the new bridge concentrate in the area within 5 kilometers of the new I-35W Bridge. As the impact zone becomes larger, the number of losers catches the number of winners. While the total number of commuters who saved time exceeded the number of commuters who suffered longer commute time (7.3×10^6 versus 6.3×10^6) across the Twin Cities area before the fourth through lane of I-94 Bridge was removed, the number of losers exceeds slightly the number of winners (7.4×10^6 versus 6.2×10^6) after. If we focus on their geographic distribution, the majority of commuters with significant savings or losses after October 12th reside within 20 kilometers of the I-35W Bridge. Therefore, any selected impact zone that is smaller than that may exaggerate the potential savings by ignoring some long-distance commuters who traveled through the congested segments. Researchers should be very careful when selecting the proper impact zone.

Although the bridge and subsequent changes created losers as well as winners (and in some cases nets out negative), that of itself is not determinative of whether the bridge was worthwhile. Other considerations, including equity and network reliability to further shocks, need to be accounted for before such a conclusion can be drawn.

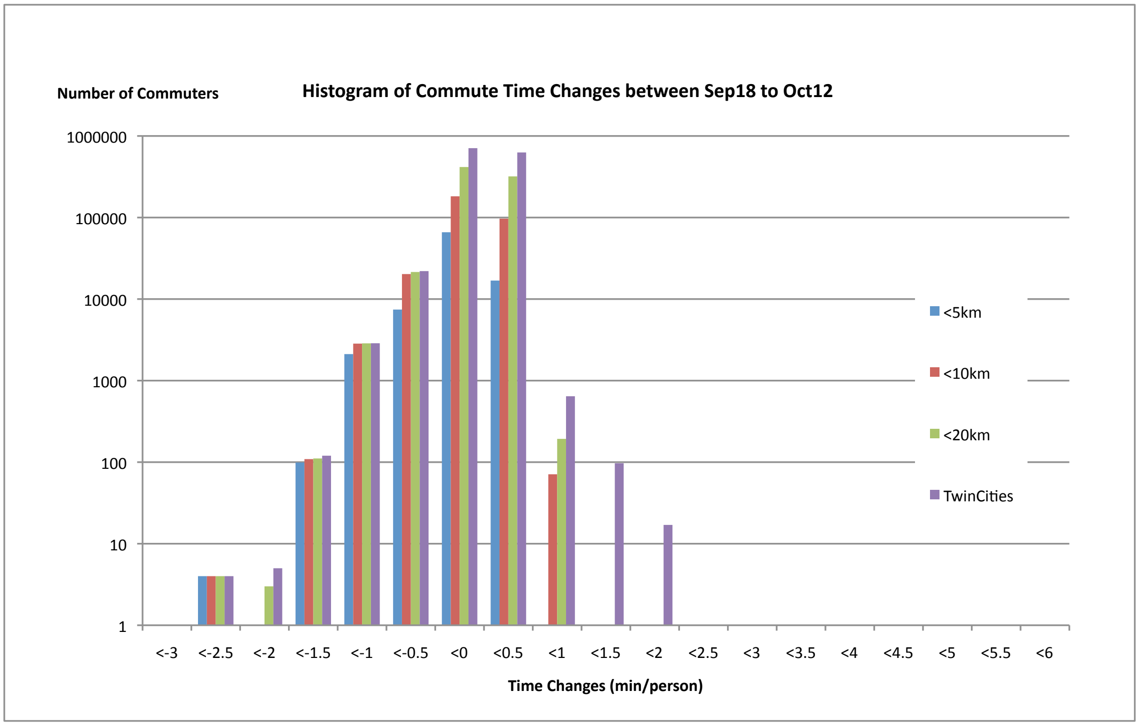

Figure 7.8: The histogram of commute time changes after the reopening of new I-35W Bridge by residential location

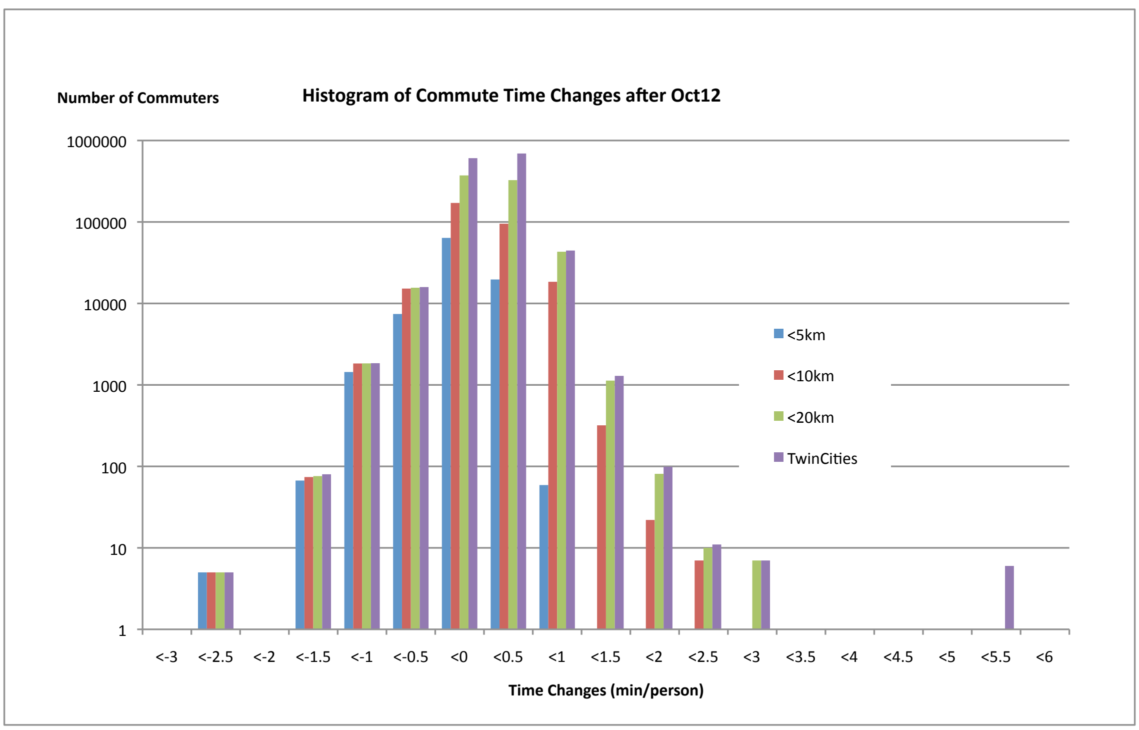

Figure 7.9: The histogram of commute time changes after the 4th lane on I-94 Bridge was removed by residential location

Chapter 8

Conclusions

This study investigates the traffic dynamics following prolonged network disruptions and identifies two distinguished traffic patterns for unexpected disruptions and for the common, preplanned disruptions, respectively. Following an unexpected disruption, an avoidance phenomenon is observed, where drivers initially avoid the disruption site until the perceived risk of the area gradually diminishes. Consequently, an oscillation of travel demand occurred surrounding the event sites. The scale and longevity of such oscillation diminishes as the area of analysis becomes larger and the number of meaningful alternative routes increases. After the I-35W Bridge collapse, the traffic stabilized in about six weeks immediately around the bridge site, while the overall demand within the I-494/I-694 beltway never changes too much. A similar phenomenon is observed in the San Francisco Bay Area network after a similar disaster. In contrast, preplanned disruptions, even with similar magnitude, generate much smaller impacts. Neither the T.H 36 construction (closure and reopening) nor the opening of the replacement I-35W Bridge have generated significant oscillation of traffic. Such difference in flow pattern may be due to the psychological shock brought by unexpected events and unpreparedness during the adaptation to new traffic condition. Therefore, this research suggests that a quick, widely advertised, and well-designed detour plan could help to improve traffic conditions by mitigating the psychological shock and assist travelers in developing alternative travel plan.

Analysis in this study suggests that travelers can well adapt to the new traffic condition during a relatively short time period after the collapse of I-35W Bridge. Redundant capacity, such as the fourth through lane on I-94 Bridge and several arterial bridges, are critical for absorbing the traffic detoured from the collapsed bridge. The importance of the fourth through lane on I-94 Bridge becomes more evident after considering the congestion emerging after that lane was reverted to bus-only shoulder operations. In short, the I-94 Bridge is a good replacement of I-35W Bridge. In contrast, I-35W Bridge is not an ideal replacement of I-94 bridge. This observation may inform future analysis of network robustness and have significant implications for network design.

Analysis based on three different demand tables (which are the most accurate ones available under current practice) consistently suggest that the new I-35W Bridge helped to reduce total travel cost most of the time, but the magnitude of such benefit is limited (0.2% 0.3% of metropolitan Twin Cities VHT). This result based on field observations is consistent with conclusions drawn in a early analysis by Xie and Levinson (2009) based on Metropolitan Council planning models. Similarities in conclusions drawn in both studies imply that a travel demand model with feedback (elastic demand) can provide a good estimation of the overall impacts due to such network degeneration scenarios. Therefore, such models could play a significant role in developing mitigation plans and assisting decision-making. Similar procedure could also be applied to analyze future road or bridge closure scenarios.

Using the Metropolitan Council Planning travel demand tables, the new bridge saved travelers $3.5 * 10^3$ hours from 6am to 7pm per day (we did not calculate the changes in travel cost outside of this time window because of the lack of speed observations and low demand). If we assume travel time worth $14/hour, then the new bridge generated a benefit of \$ $49,000$ dollars per day during this time period due to travel time savings. Given the travel demand in early morning and in the late evening is low, the overall travel time savings should be slightly larger but close to this number. This estimate is close to the lower bound of detour costs estimated by Xie and Levinson (2009) immediately after the bridge collapse. Given the longevity (more than 13 months) of this network disruption, some people have changed their travel destinations and frequency, if not residential location and jobs. These changes in origin-destination demand tables, together with inertia in route decisions, may have reduced some potential benefits in travel time savings. In retrospect, the necessary monetary incentives for speeding up the construction of the new I-35W Bridge may have been overestimated if we consider user costs alone. Other potential benefits, such as network reliability and robustness to another network disruption, mitigating impacts to local residents and businesses, are not included here.

This study also identified an unusual travel time increase in the morning peak time period after adding a faster link with high capacity (10 lanes) to the network while removing one through lane in each direction from the I-94 Bridge. The redistribution of travel demand from arterial streets to freeway system due to the new bridge is detrimental to the system efficiency and may help to explain the congestion emerging at the upstream of the merge point between I-94 and I-35W. The inertia in individual travel habit may also have contributed to this phenomenon.

For individual bridge users, the most common reaction to the I-35W Bridge collapse was changing routes and changing departure time, both of which were reported by more than 70% of survey respondents. Although the increase of public transit usage was detectable in both aggregate ridership data and in survey results after the bridge collapse, such increase was moderate.

Through the travel cost analysis across the whole Twin Cities area, this study found that the travel cost has not been consistently reduced for all travelers by adding a faster link with high capacity (10 lanes) to the network. Some travelers experience an increase in travel time due to the redistribution of travel demand and new bottlenecks emerging after the bridge reopening. Such observations from macroscopic analysis are echoed by results from individual surveys. Although the scale of travel time increase is small (less than 2 minutes for residents from most census blocks), it should be considered in future decision making.

The collapse of the I-35W Bridge crossing the Mississippi River arouses concerns about safety issues to maintain bridges with partial closure. Given the flexibility in individual travel patterns (even during peak periods, most trips are non-work) and capacity redundancy of the Twin Cities network observed in this study, it may be more beneficial to conduct future bridge maintenance with full closure. The travel time savings due to shorter maintenance period and improvement in safety, plus the lowered construction costs, may outweigh the users costs due to extra travel caused by full closure. A transportation planning model with full feedback between travel costs and travel demand (elastic demand) can help to weigh the potential benefit and cost under partial and full closure scenarios, respectively, and assist future decision-making.

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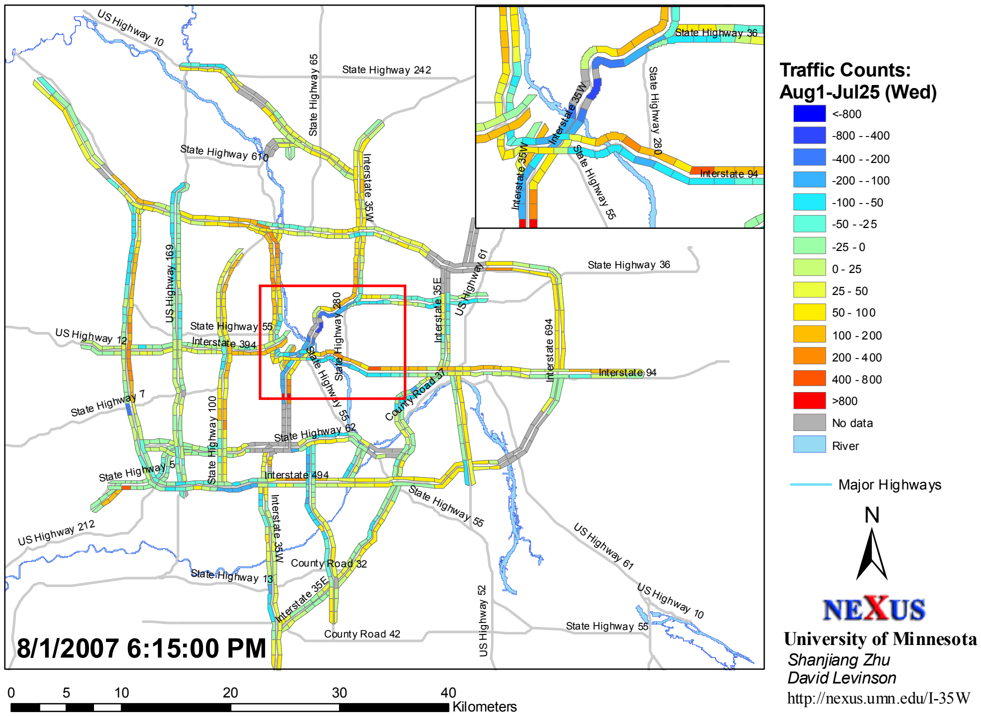
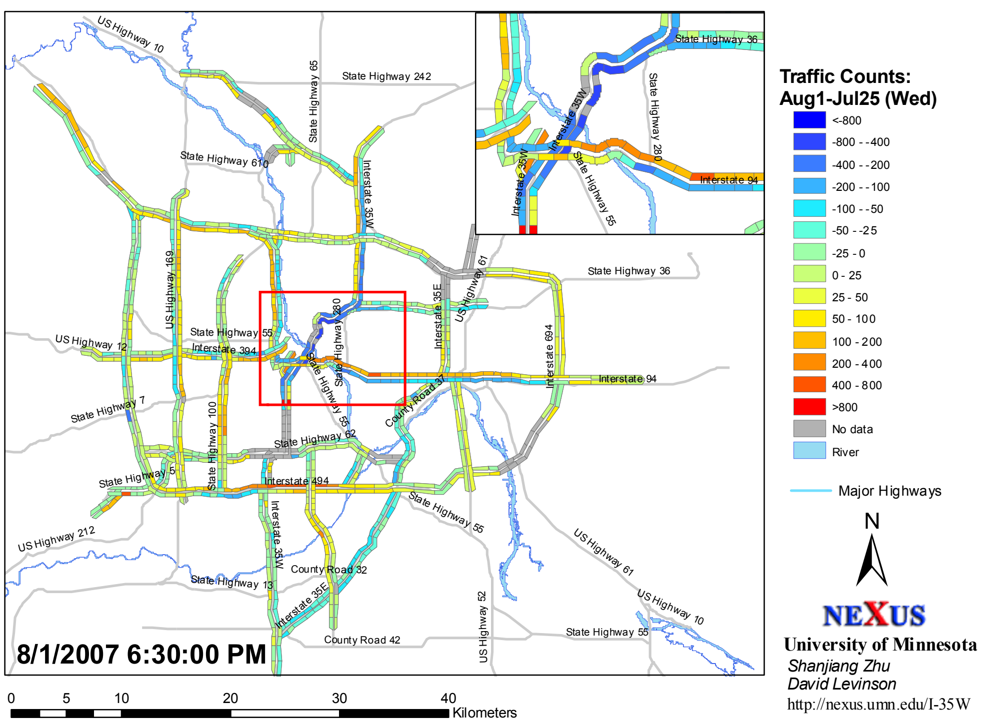
Appendix A

Changes in freeway traffic counts for every 15 minutes on August 1st 2007 after the bridge collapse when compared with the demand level at the same time one week ago (Wednesday).

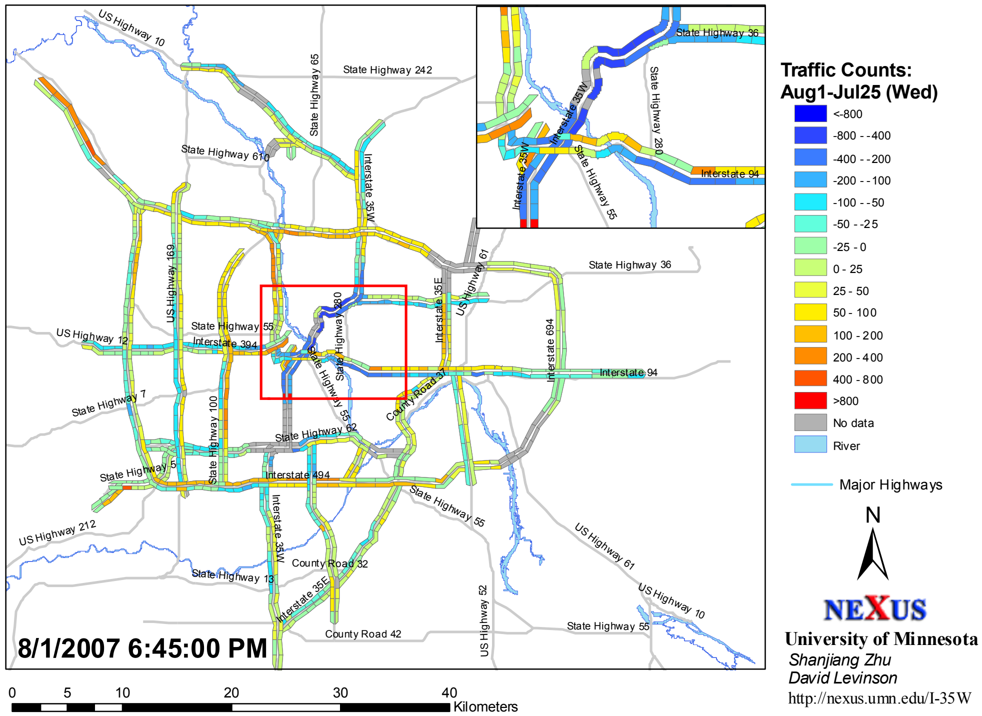
Volume Difference for every 15 Minutes



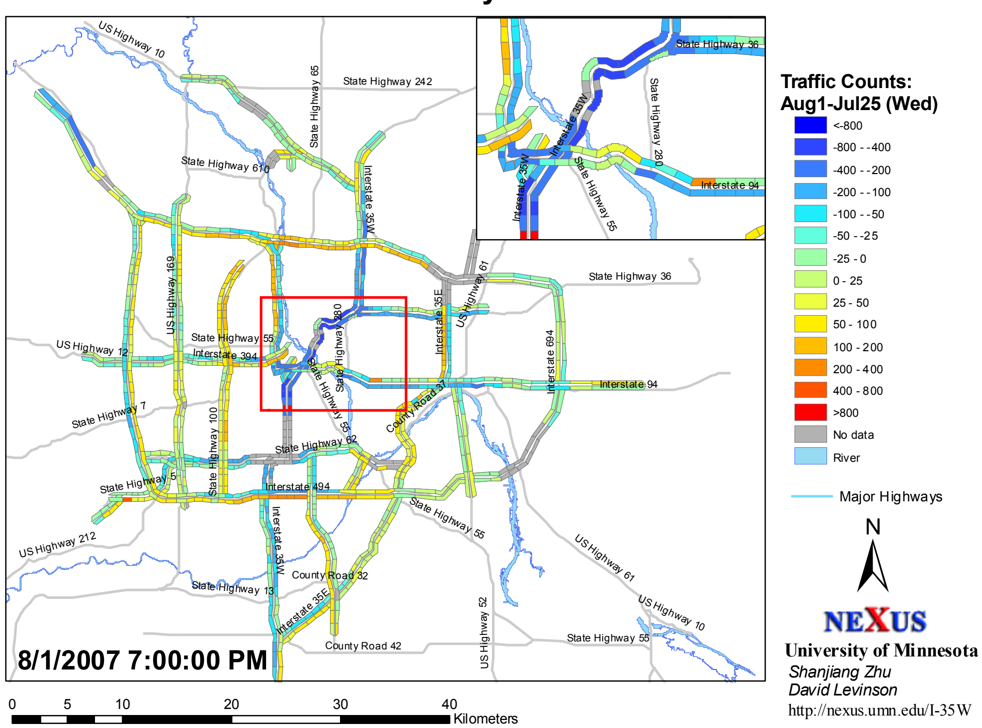
Volume Difference for every 15 Minutes



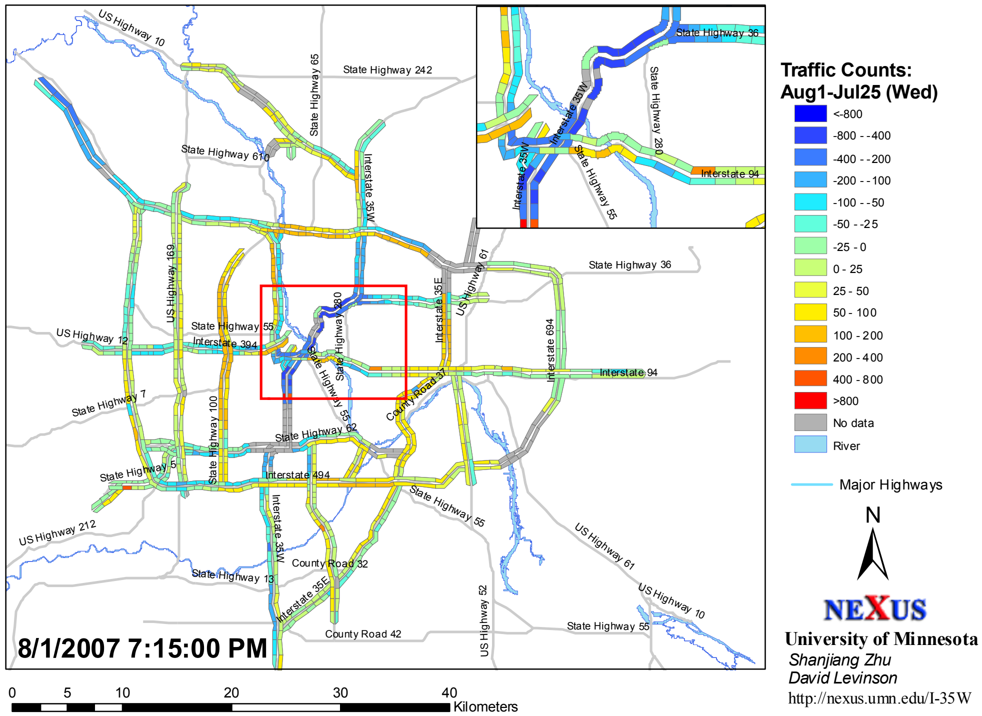
Volume Difference for every 15 Minutes



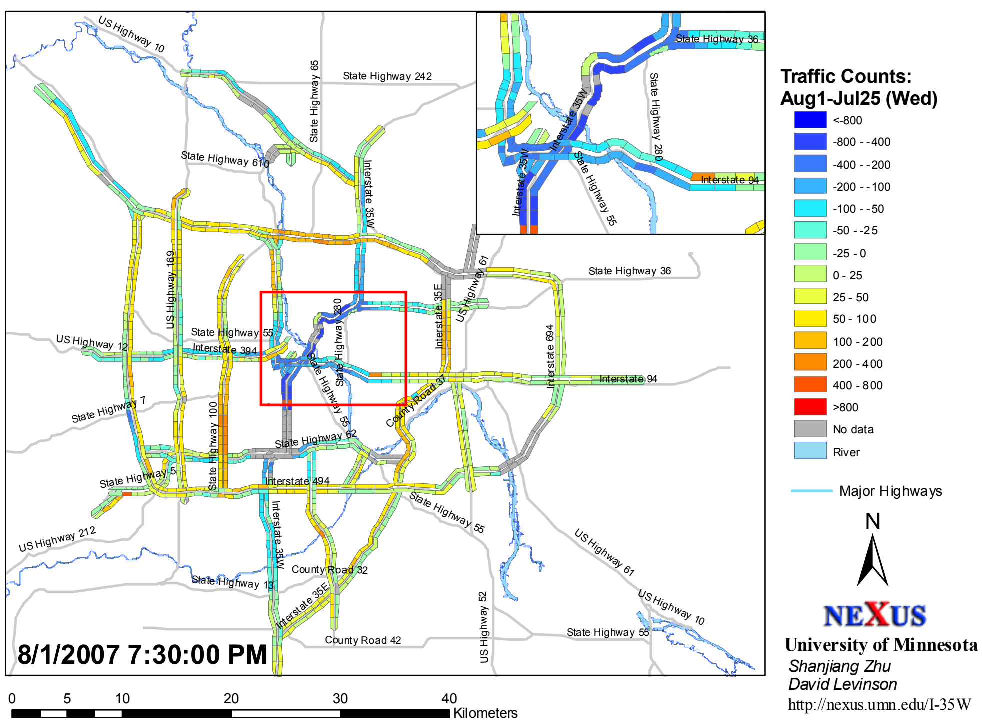
Volume Difference for every 15 Minutes



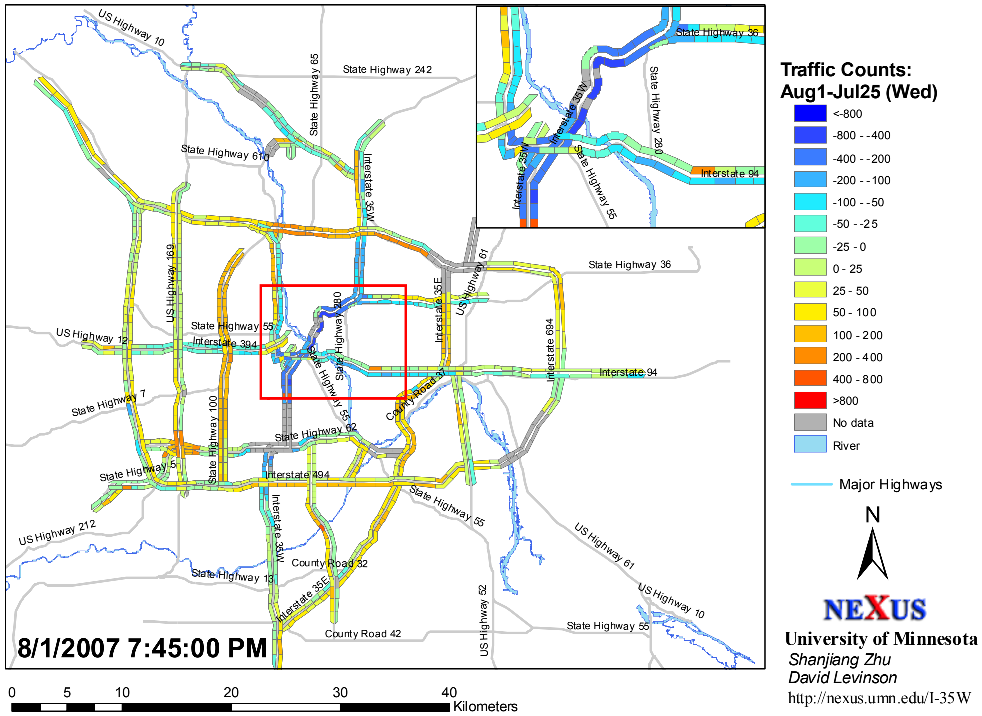
Volume Difference for every 15 Minutes



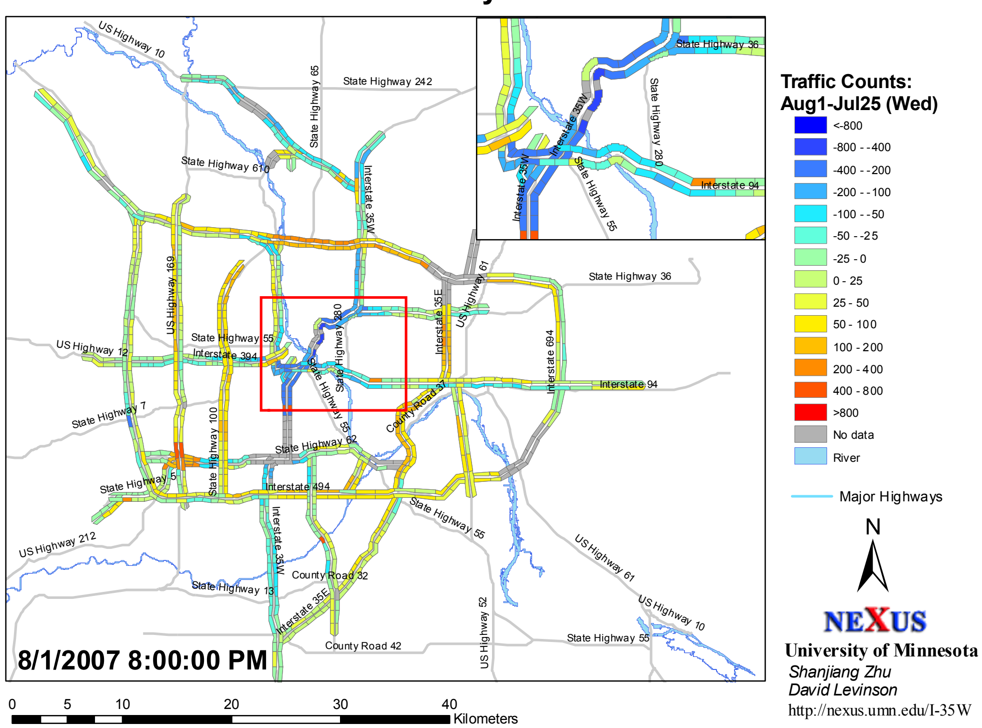
Volume Difference for every 15 Minutes



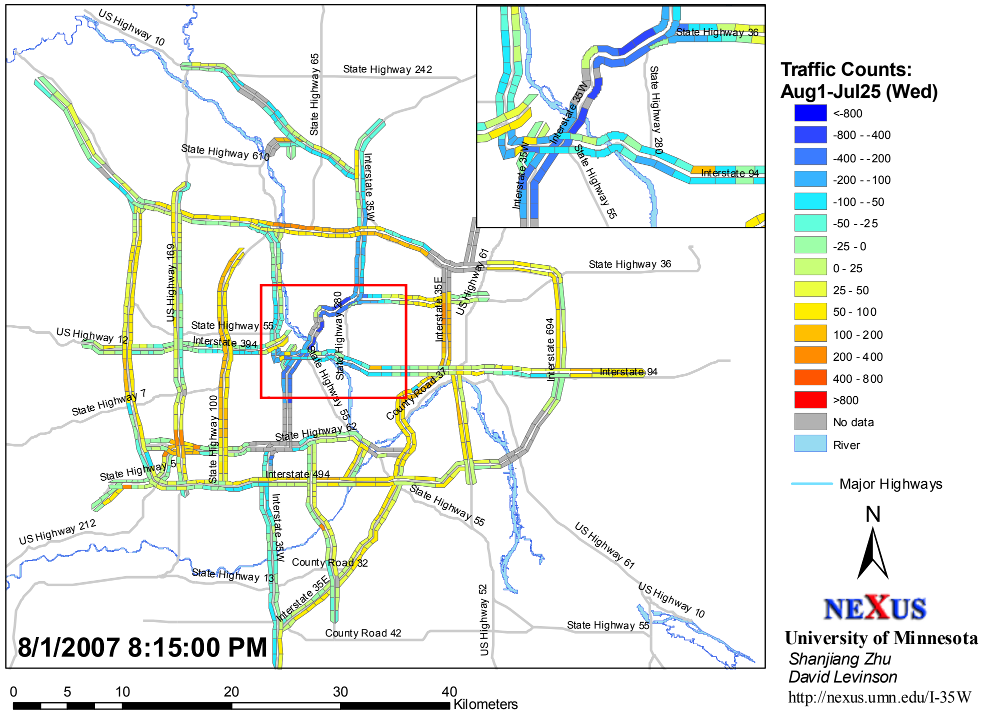
Volume Difference for every 15 Minutes



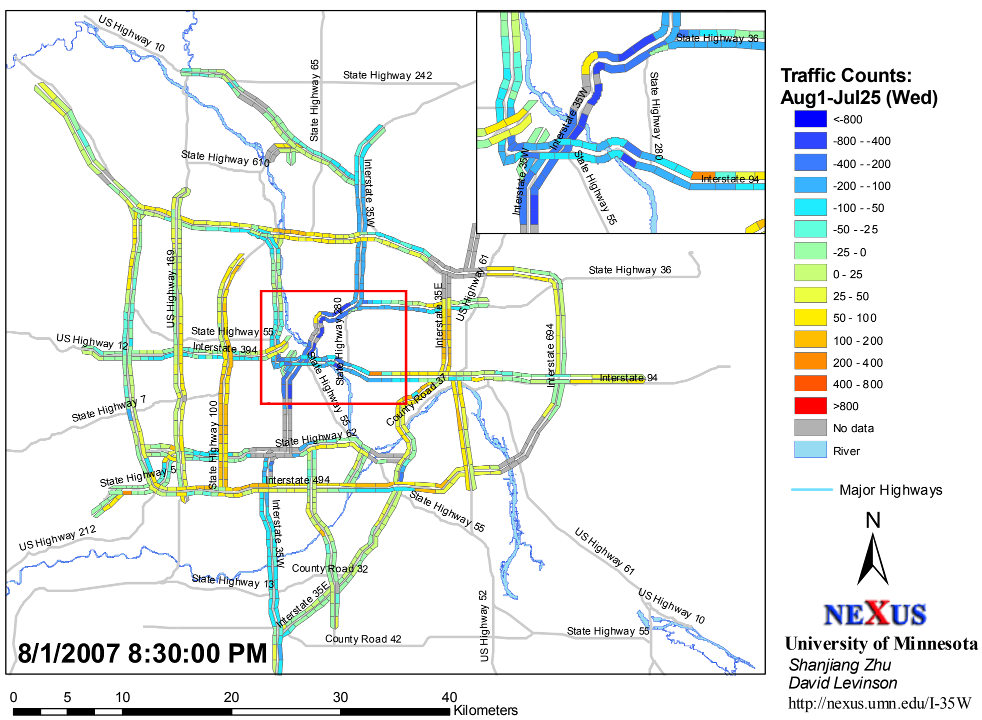
Volume Difference for every 15 Minutes



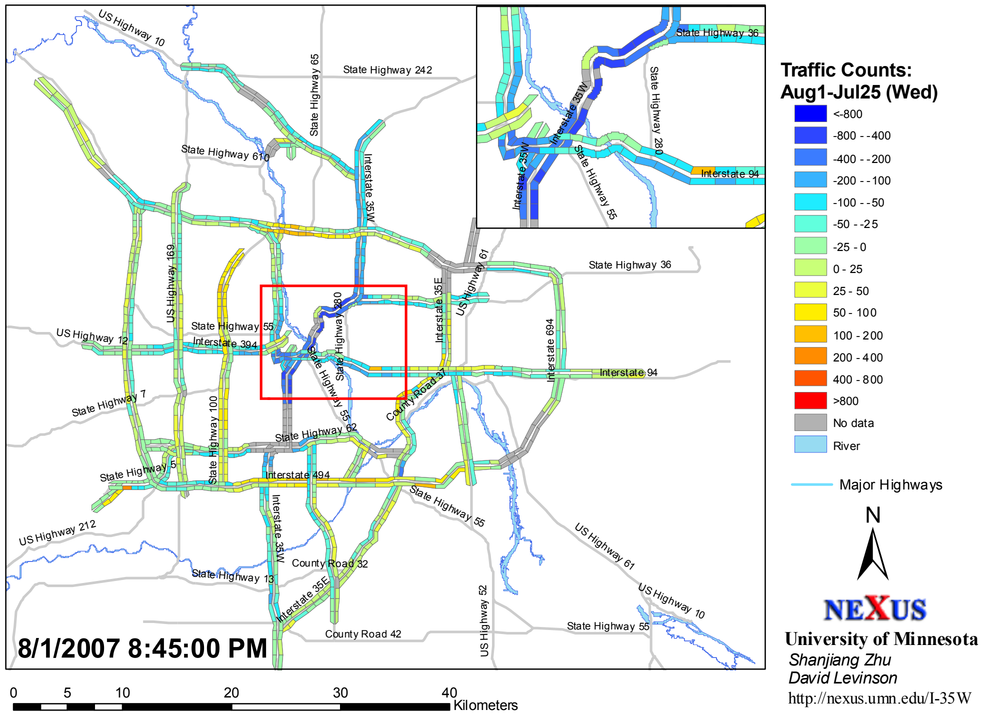
Volume Difference for every 15 Minutes



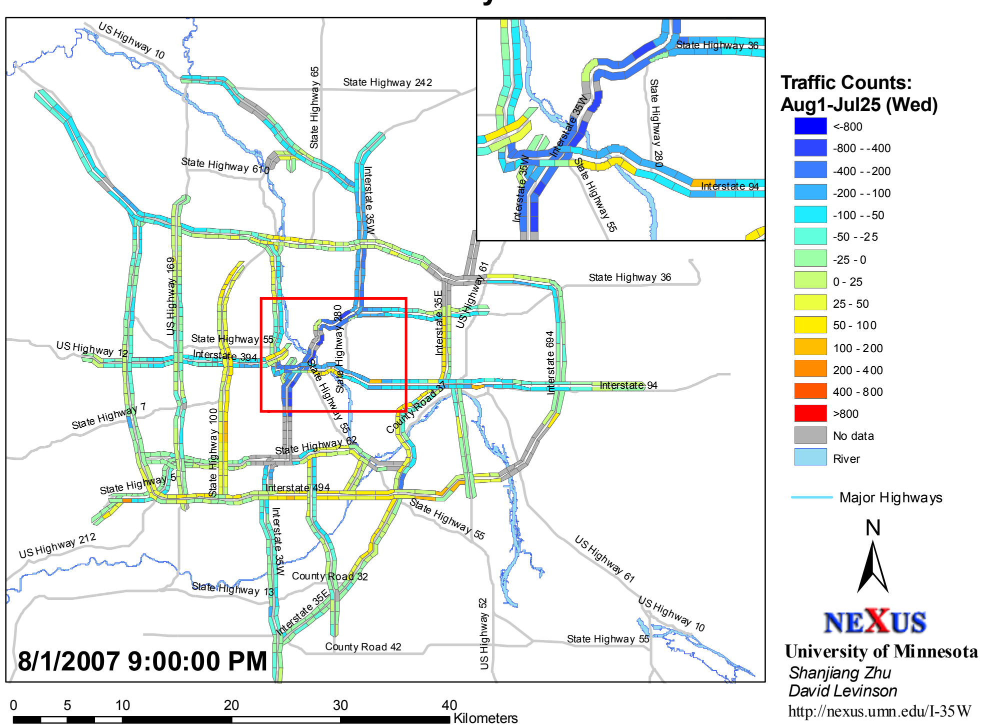
Volume Difference for every 15 Minutes



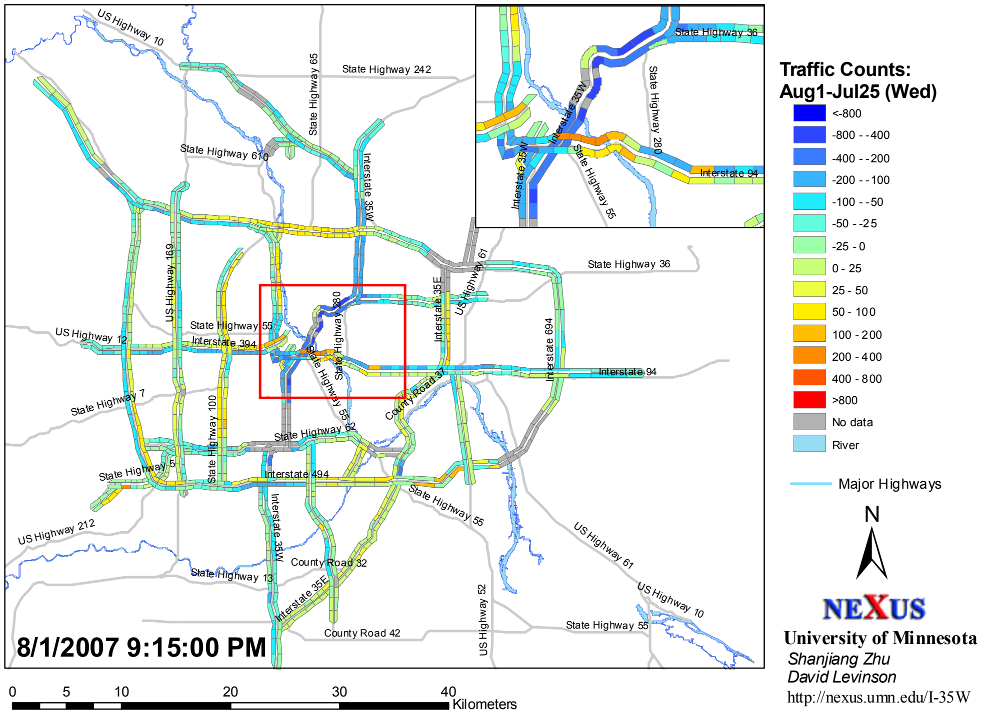
Volume Difference for every 15 Minutes



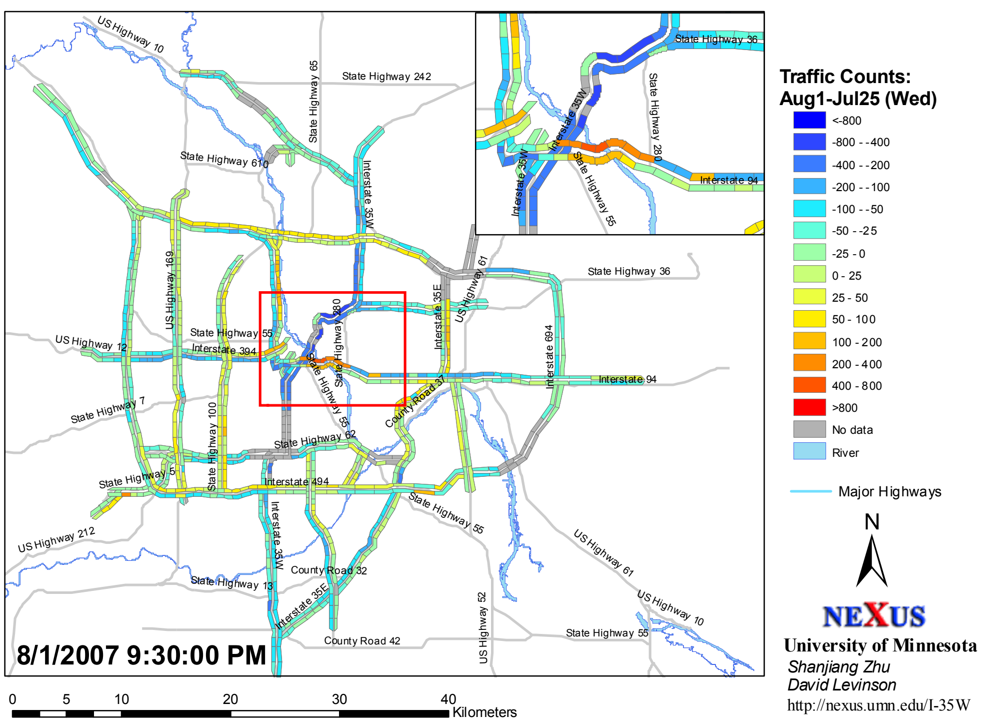
Volume Difference for every 15 Minutes



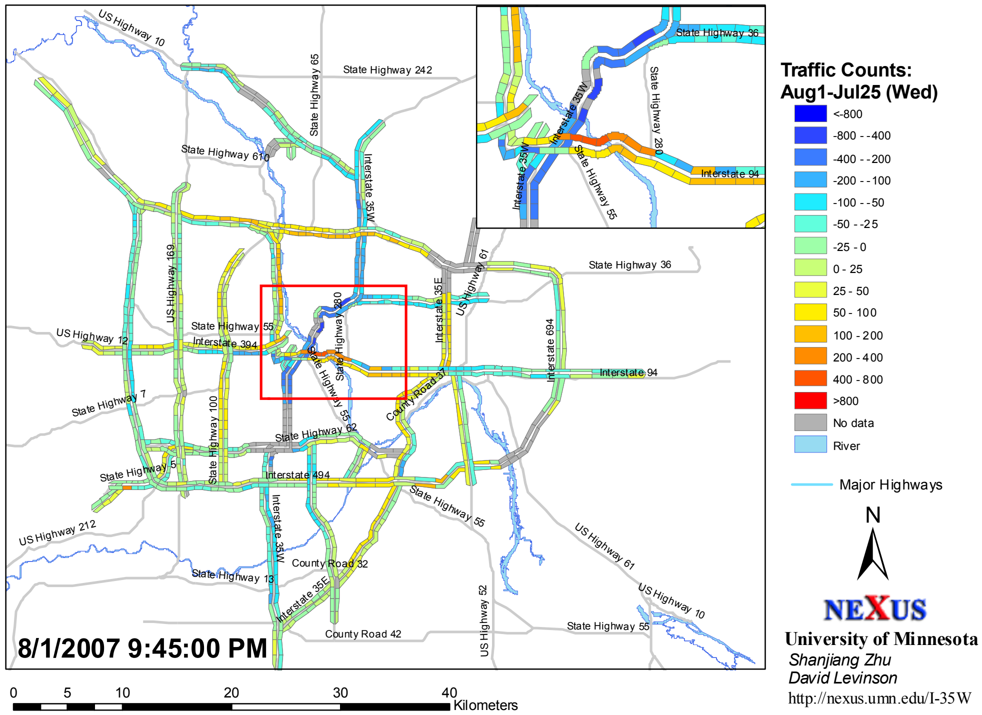
Volume Difference for every 15 Minutes



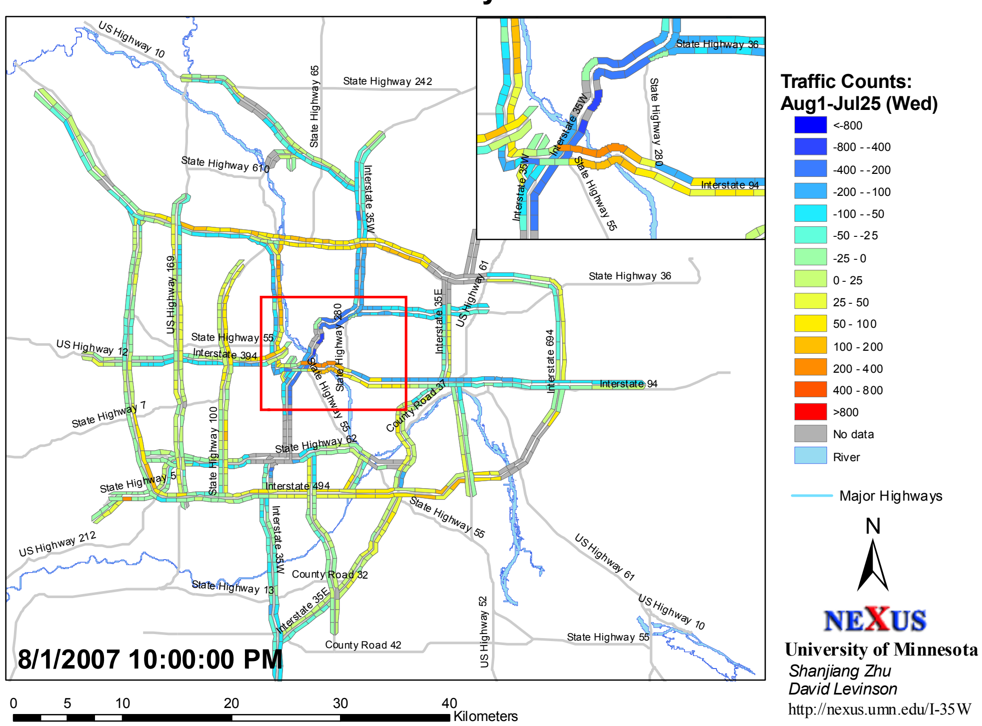
Volume Difference for every 15 Minutes



Volume Difference for every 15 Minutes



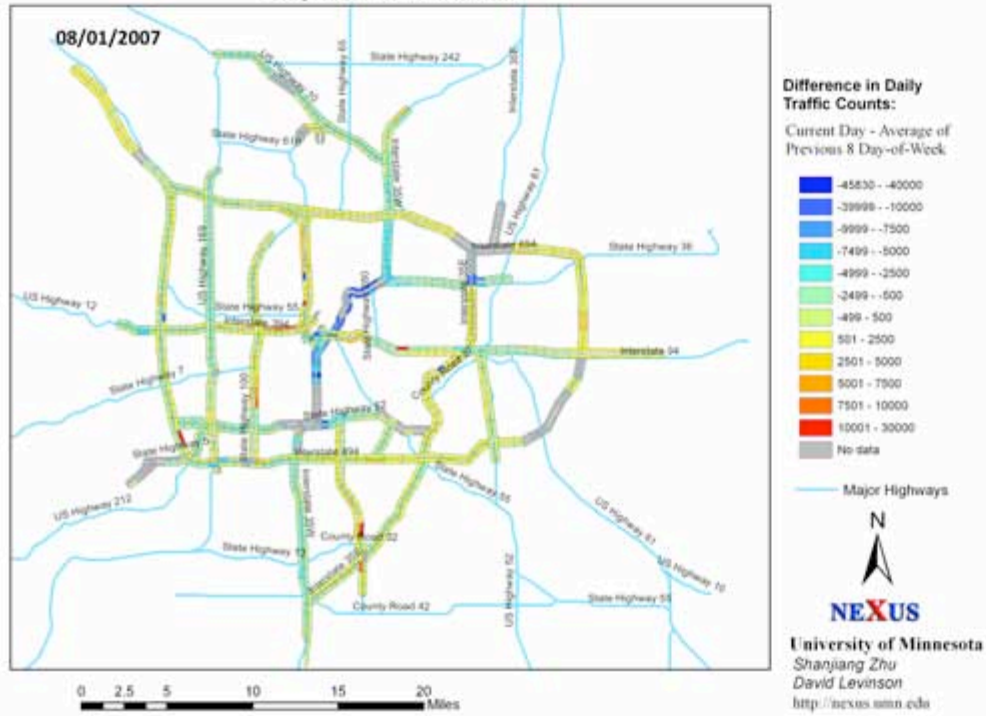
Volume Difference for every 15 Minutes



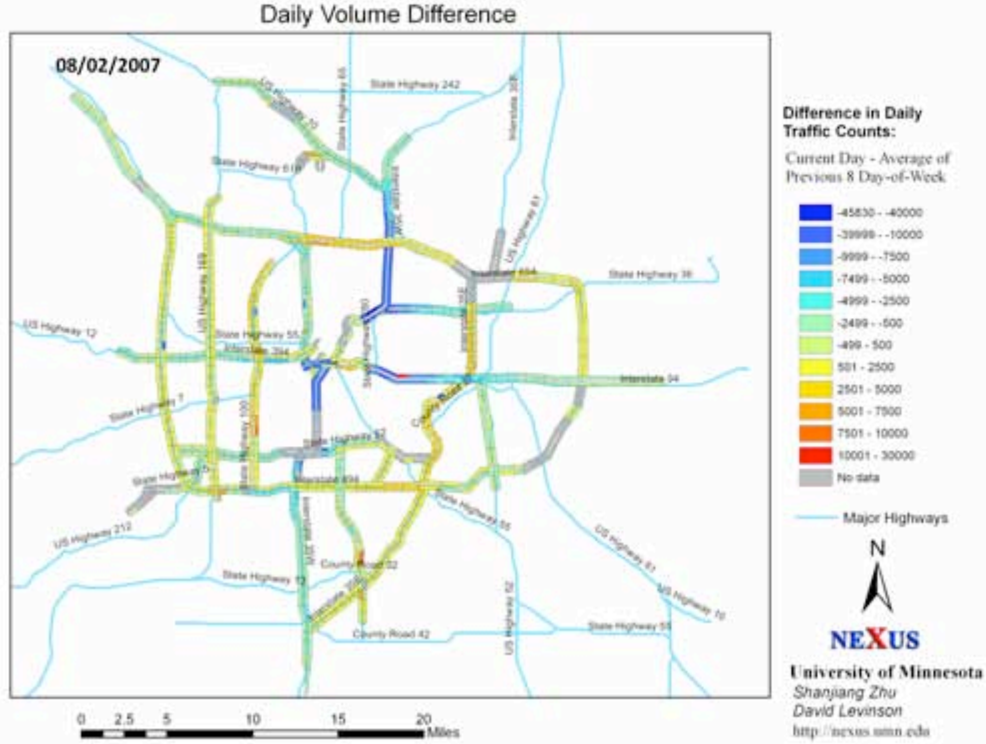
Appendix B

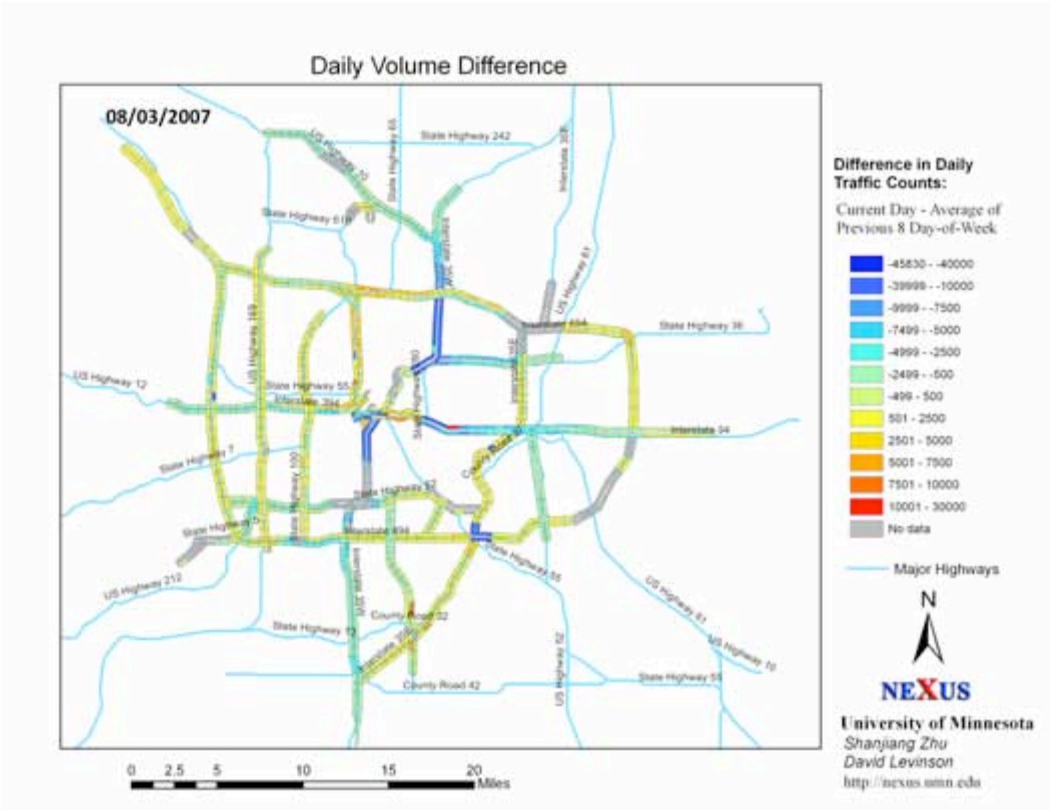
Changes in daily freeway traffic counts in August and Semptember 2007 after the bridge collapse when compared with the average demand level on the same day during previous eight weeks.

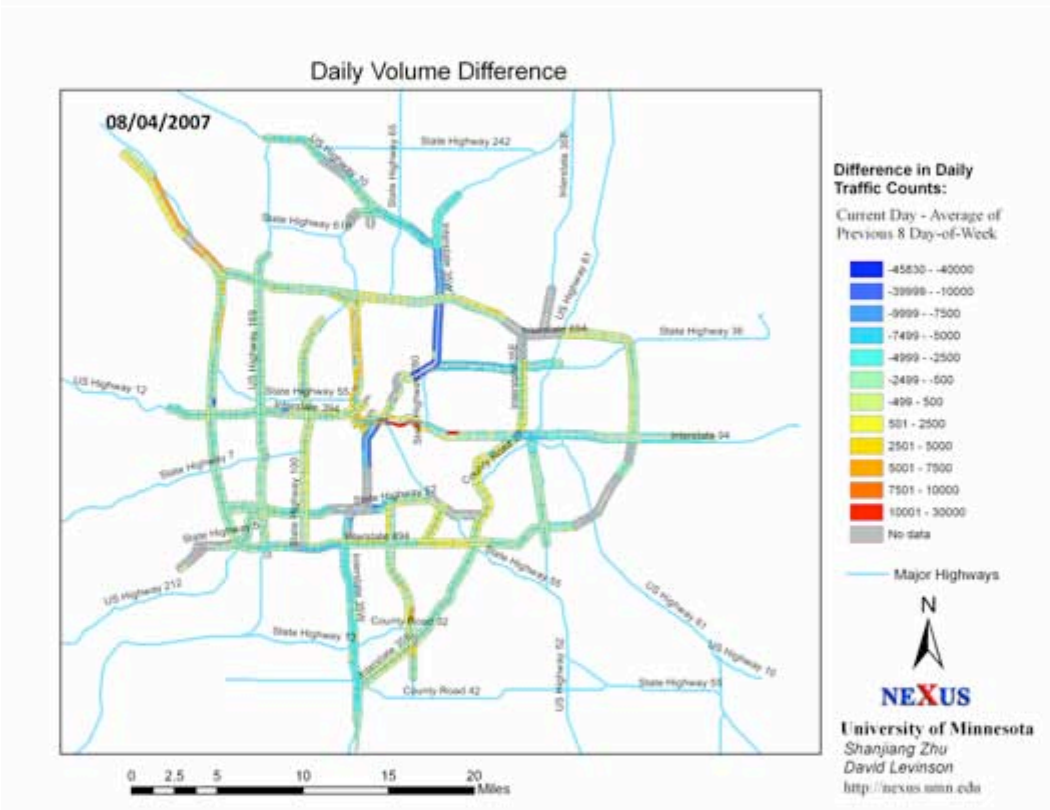
Daily Volume Difference



Daily Volume Difference




Daily Volume Difference
08/03/2007
Difference in Daily Traffic Counts:
Current Day - Average of Previous 8 Day-of-Week
-45830 - -40000
-39999 - -10000
-9999 - -7500
-7499 - -5000
-4999 - -2500
-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 30000
No data
Major Highways
N
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles


Daily Volume Difference
08/04/2007
Difference in Daily Traffic Counts:
Current Day - Average of Previous 8 Day-of-Week
-45830 - -40000
-39999 - -10000
-9999 - -7500
-7499 - -5000
-4999 - -2500
-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 30000
No data
Major Highways
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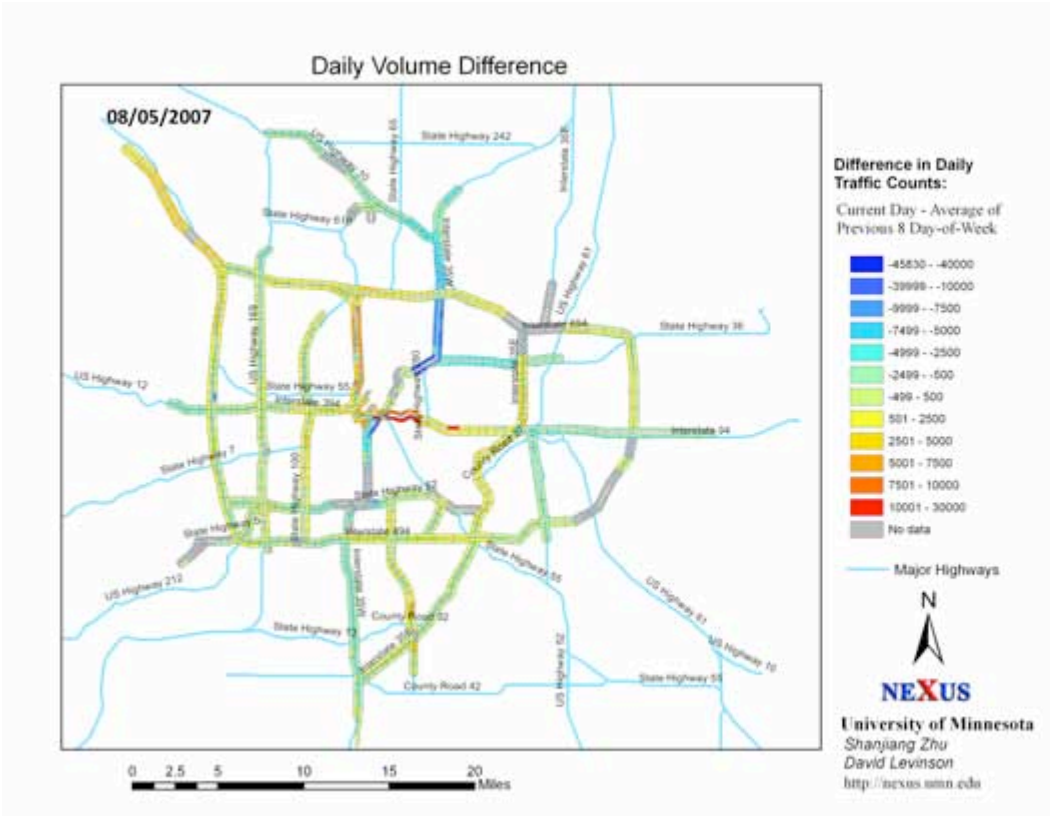
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles


Daily Volume Difference
08/05/2007
Difference in Daily Traffic Counts:
Current Day - Average of Previous 8 Day-of-Week
-45830 - -40000
-39999 - -10000
-9999 - -7500
-7499 - -5000
-4999 - -2500
-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 30000
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Major Highways
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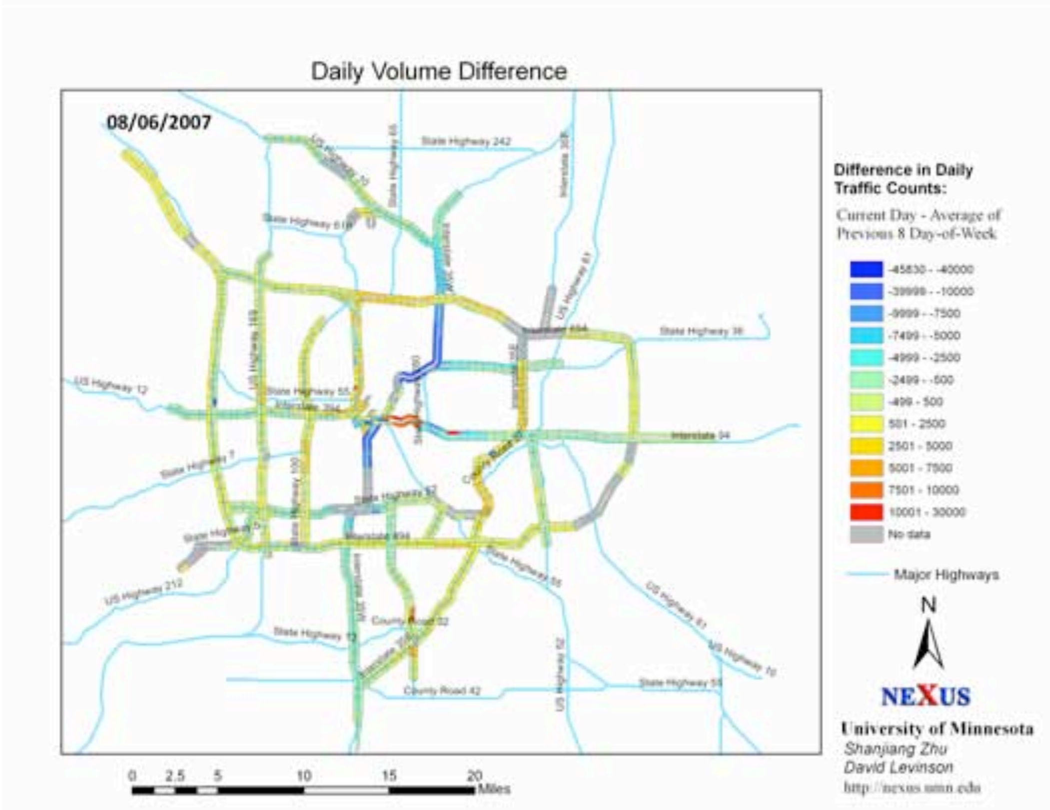
Daily Volume Difference
08/06/2007
Difference in Daily Traffic Counts:
Current Day - Average of Previous 8 Day-of-Week
-45830 - -40000
-39999 - -10000
-9999 - -7500
-7499 - -5000
-4999 - -2500
-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 30000
No data
Major Highways
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NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
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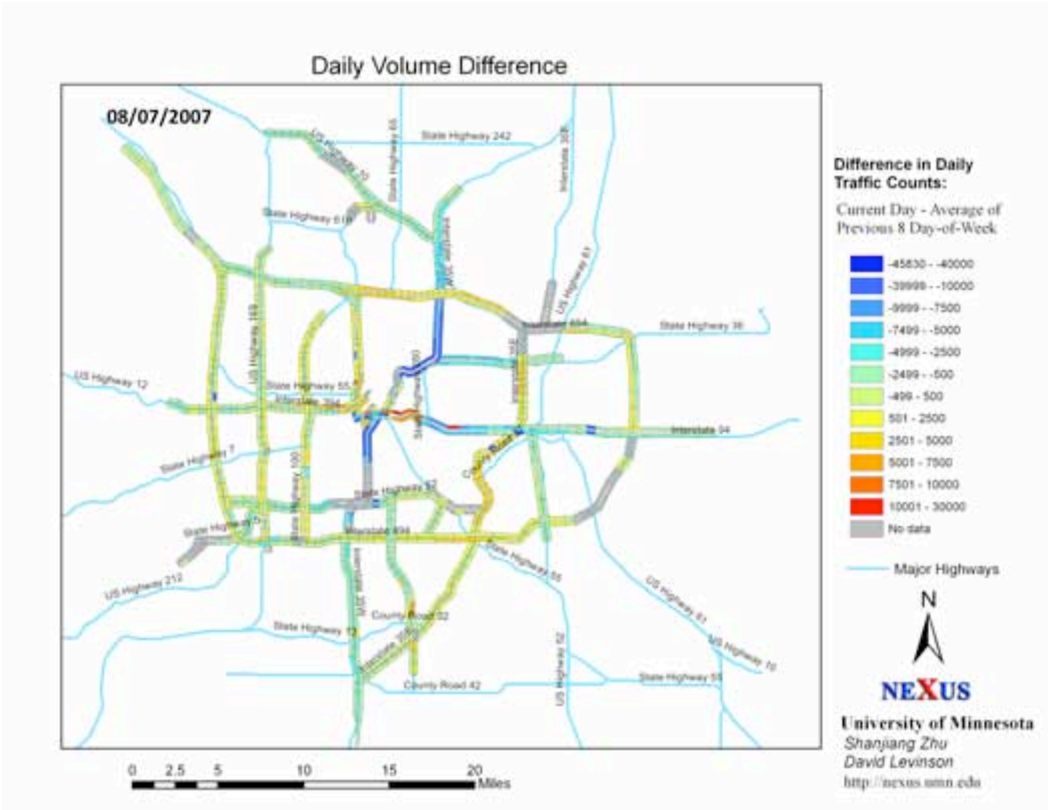
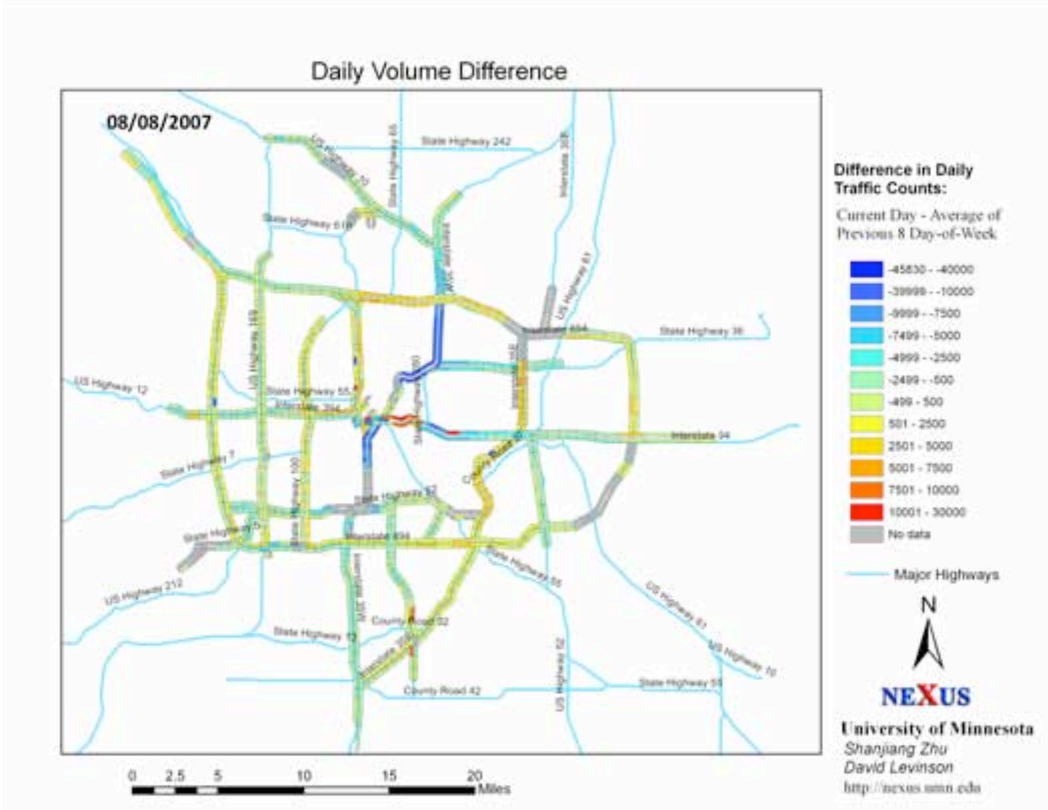
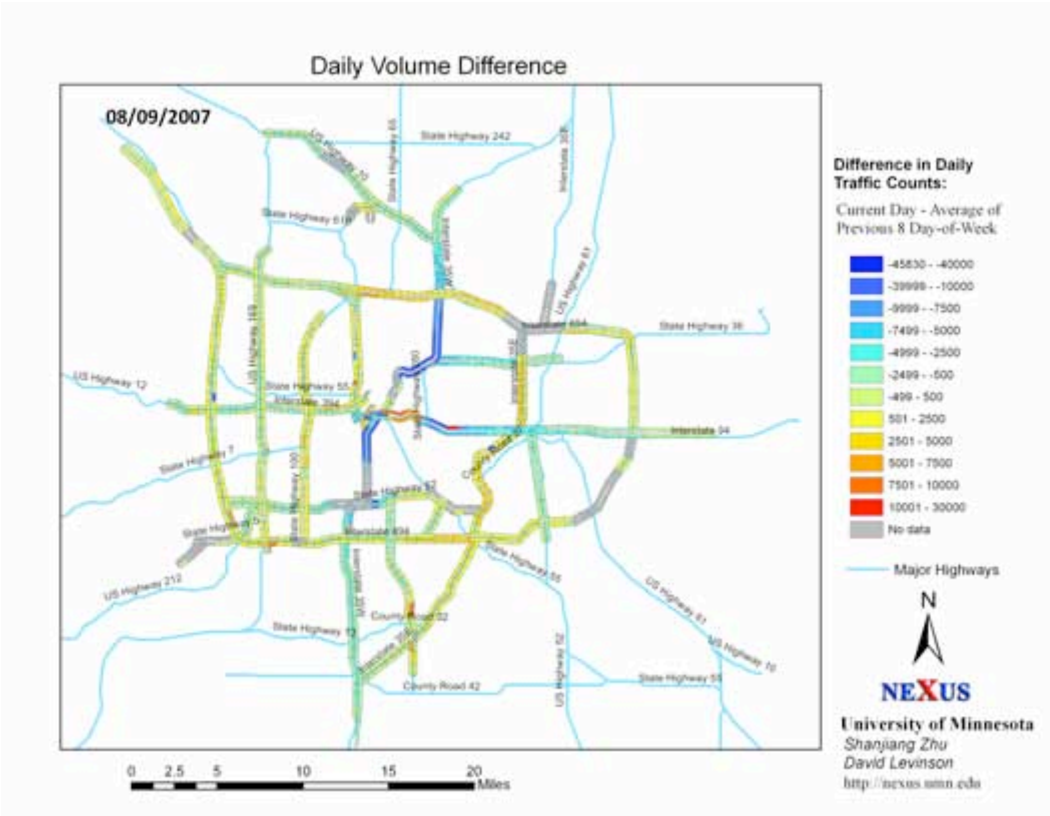

Daily Volume Difference
08/07/2007
Difference in Daily Traffic Counts:
Current Day - Average of Previous 8 Day-of-Week
-45830 - -40000
-39999 - -10000
-9999 - -7500
-7499 - -5000
-4999 - -2500
-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 30000
No data
Major Highways
N
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles
State Highway 242
US Highway 12
Interstate 94
State Highway 36
US Highway 212
County Road 42
State Highway 55


Daily Volume Difference
08/08/2007
Difference in Daily Traffic Counts:
Current Day - Average of Previous 8 Day-of-Week
-45830 - -40000
-39999 - -10000
-9999 - -7500
-7499 - -5000
-4999 - -2500
-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 30000
No data
Major Highways
N
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles
State Highway 242
US Highway 12
Interstate 94
State Highway 36
US Highway 212
County Road 42
State Highway 55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08/09/2007
Difference in Daily Traffic Counts:
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2501 - 5000
5001 - 7500
7501 - 10000
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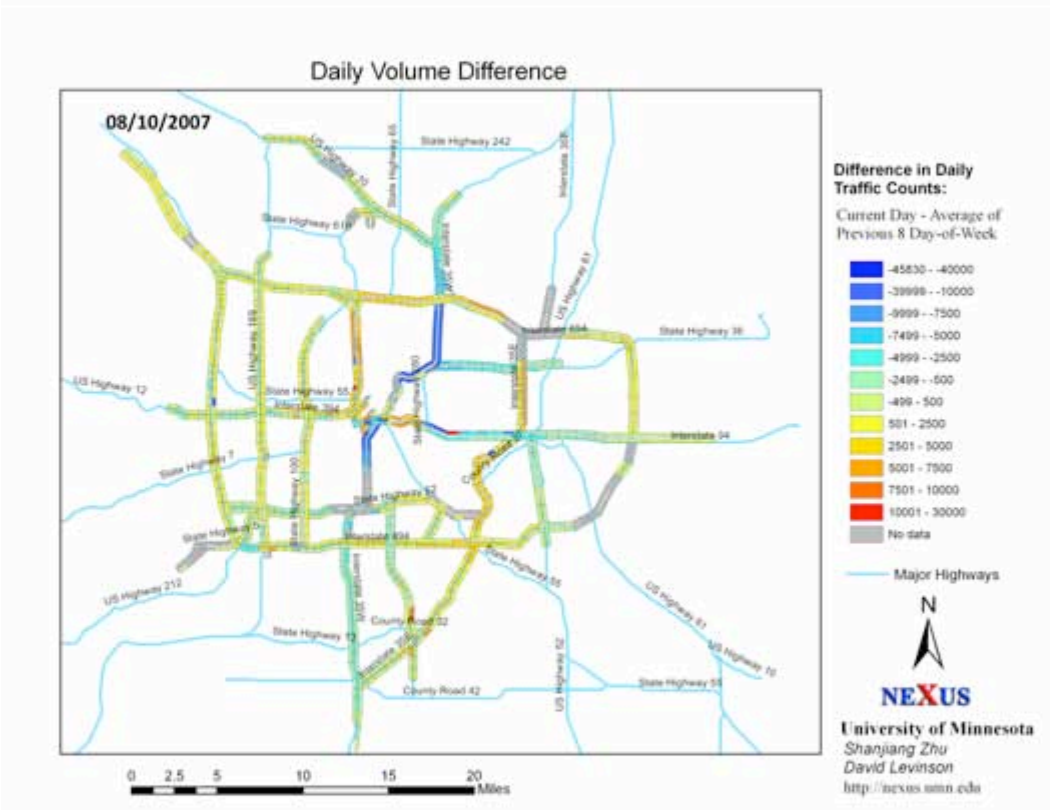
Major Highways
N
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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2501 - 5000
5001 - 7500
7501 - 10000
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Major Highways
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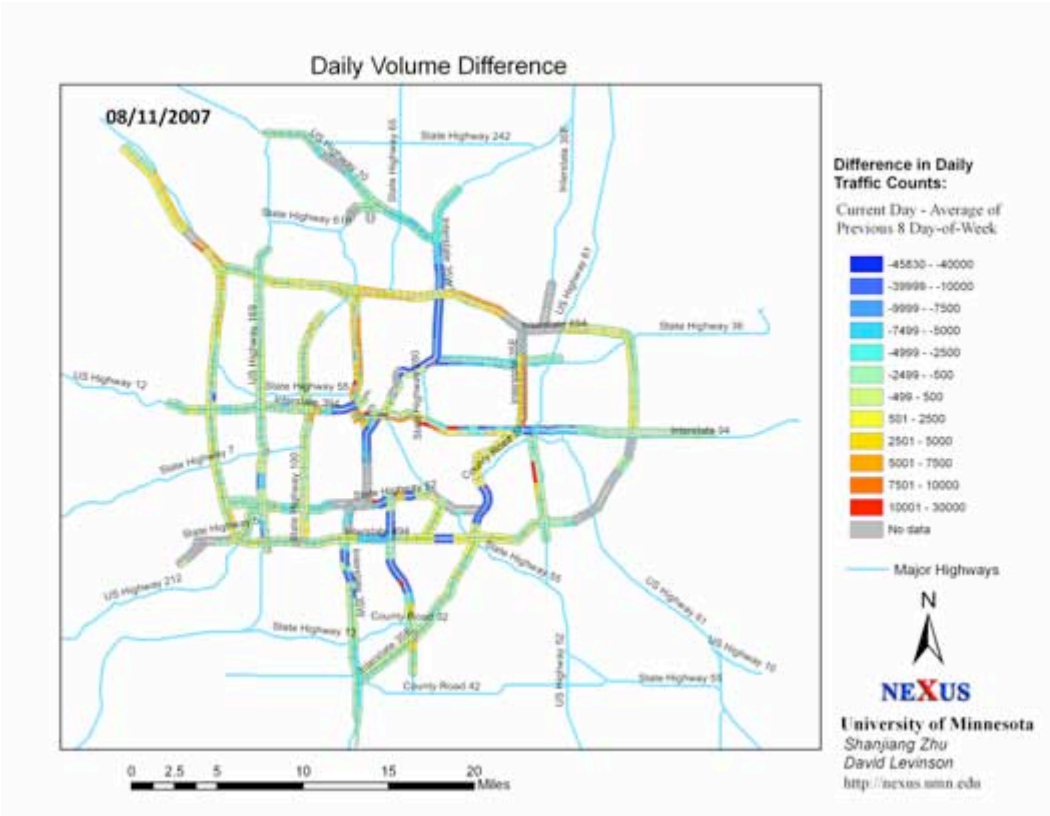
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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5001 - 7500
7501 - 10000
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Major Highways
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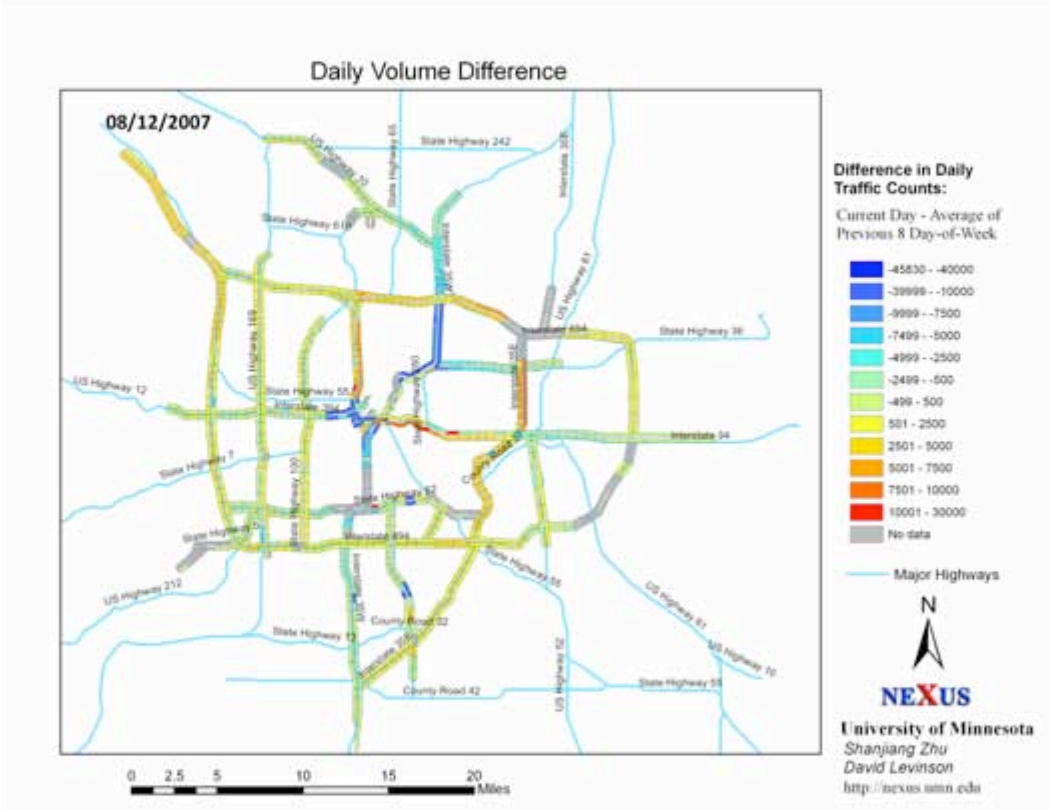
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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5001 - 7500
7501 - 10000
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Major Highways
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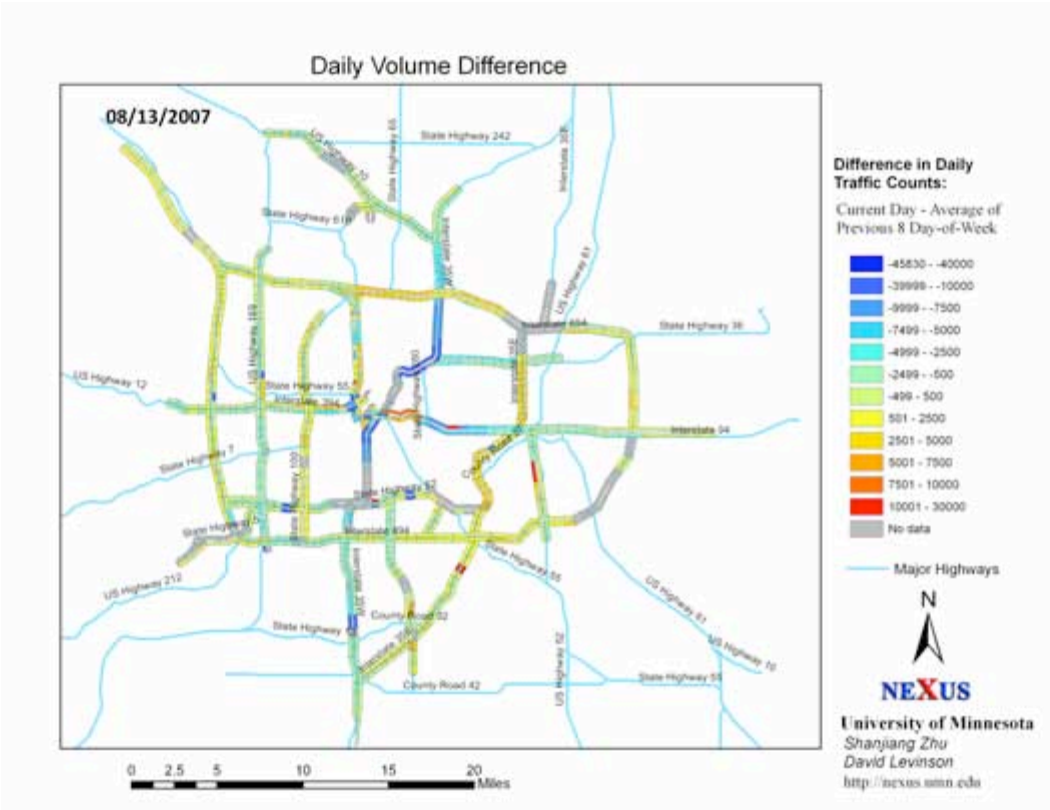
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles



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5001 - 7500
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Major Highways
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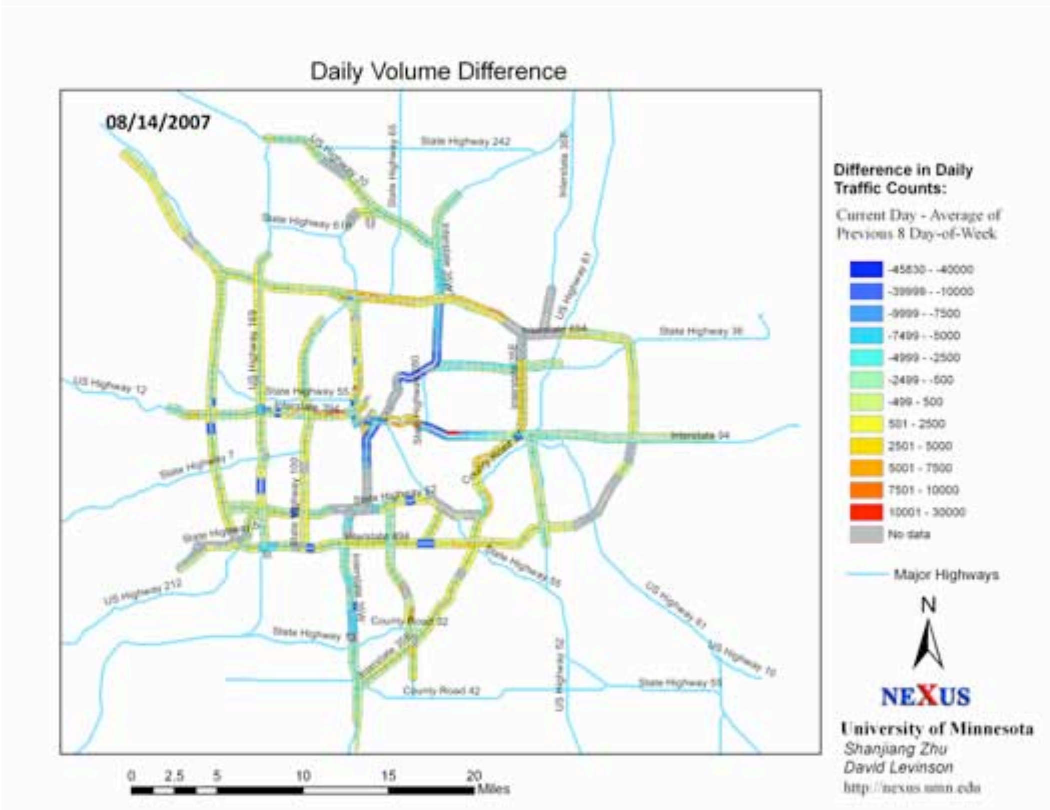
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles



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5001 - 7500
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Major Highways
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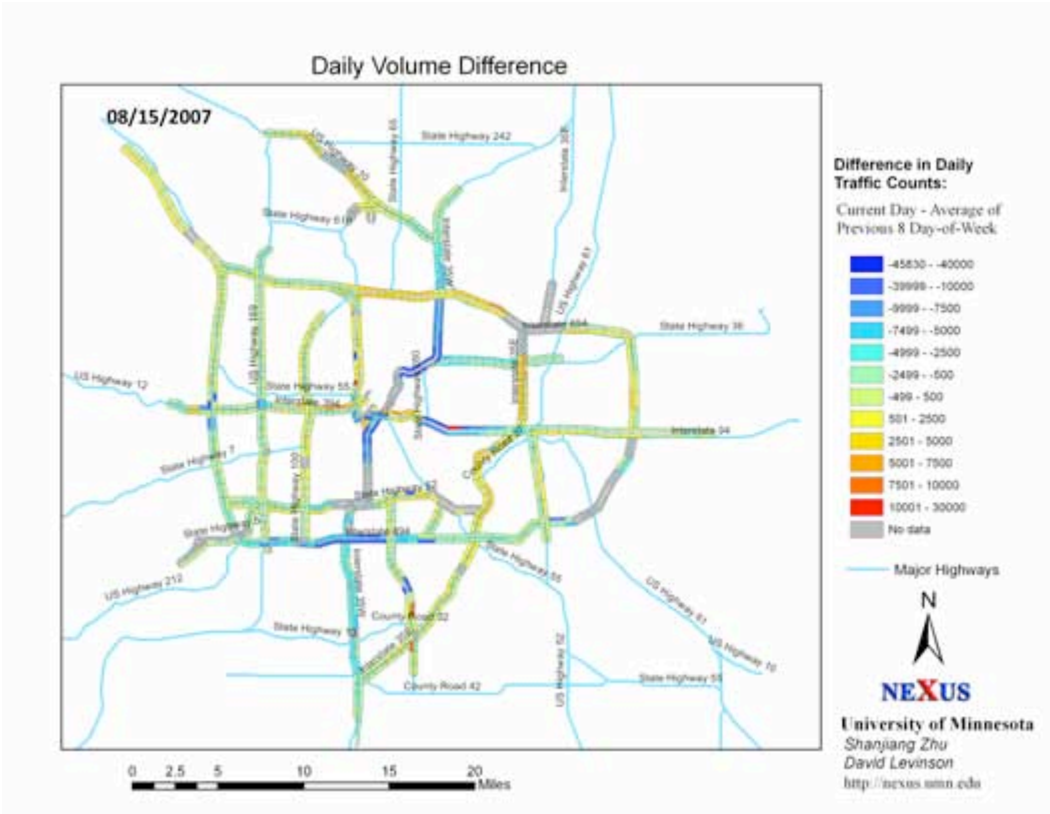
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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5001 - 7500
7501 - 10000
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Major Highways
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University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
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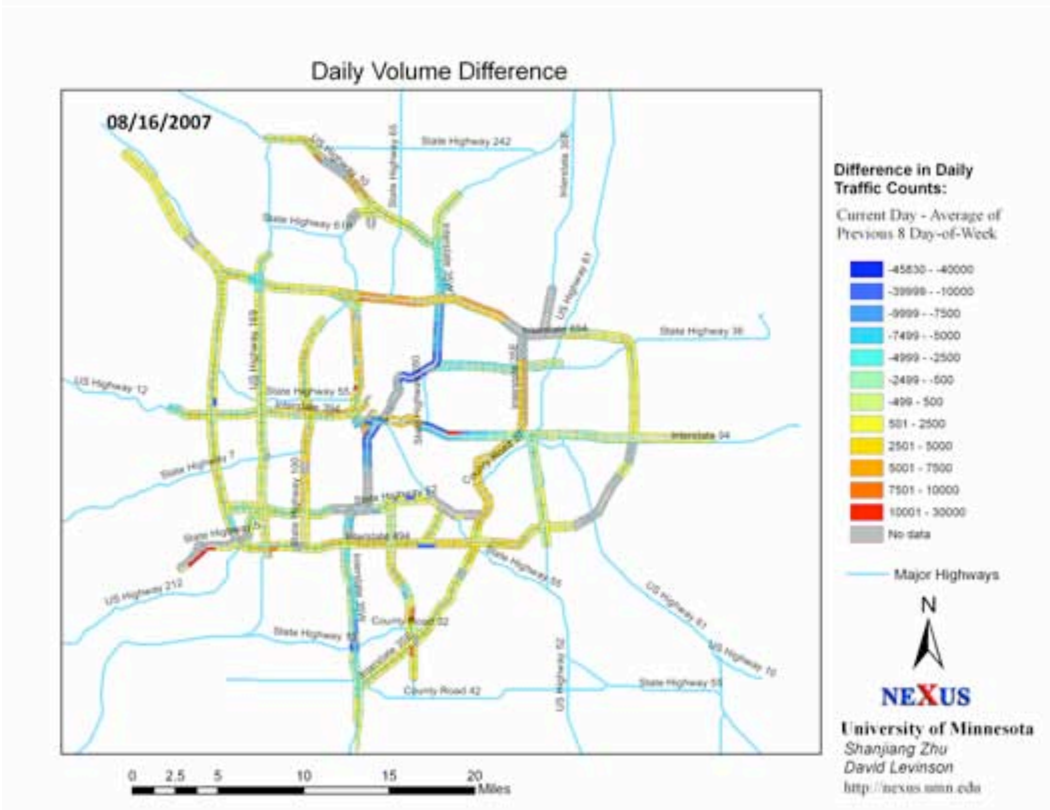
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5001 - 7500
7501 - 10000
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Major Highways
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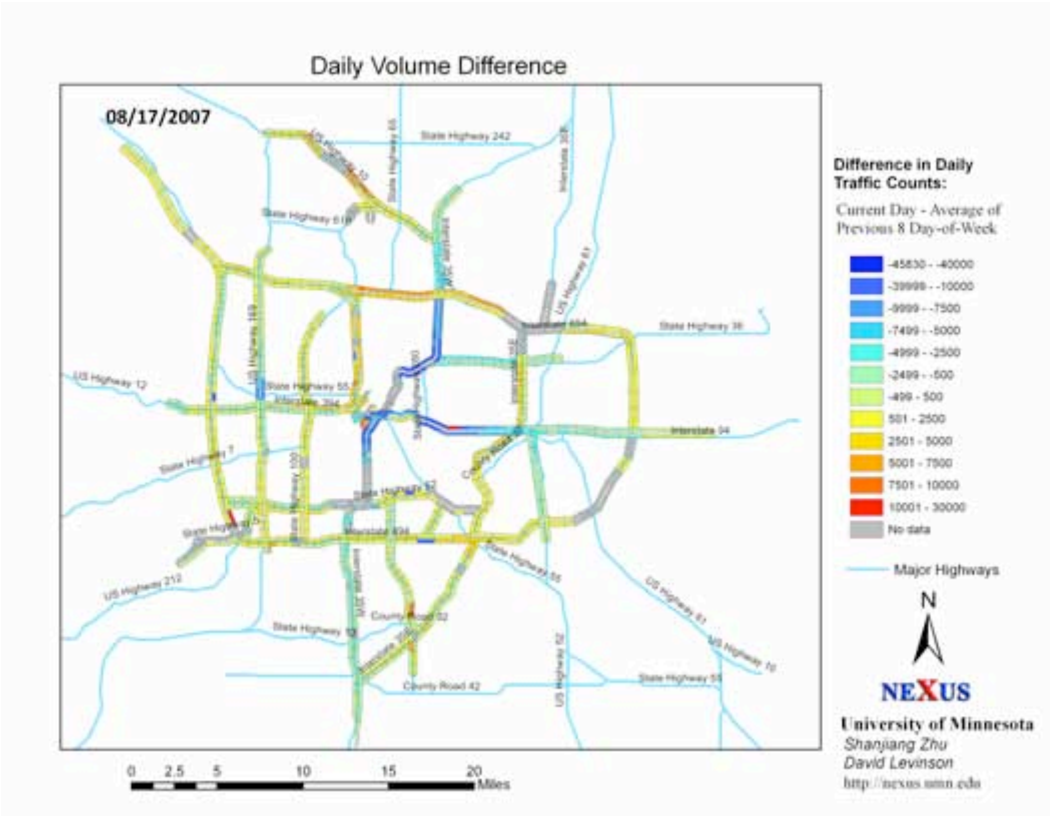
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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Major Highways
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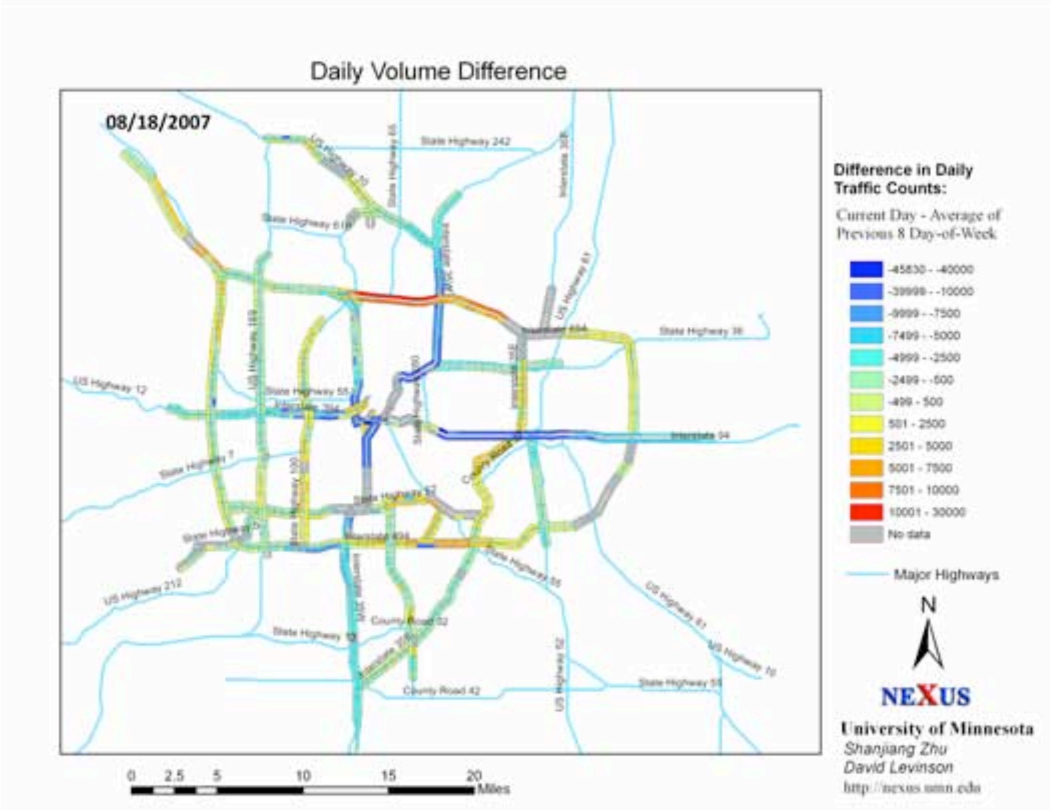
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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Major Highways
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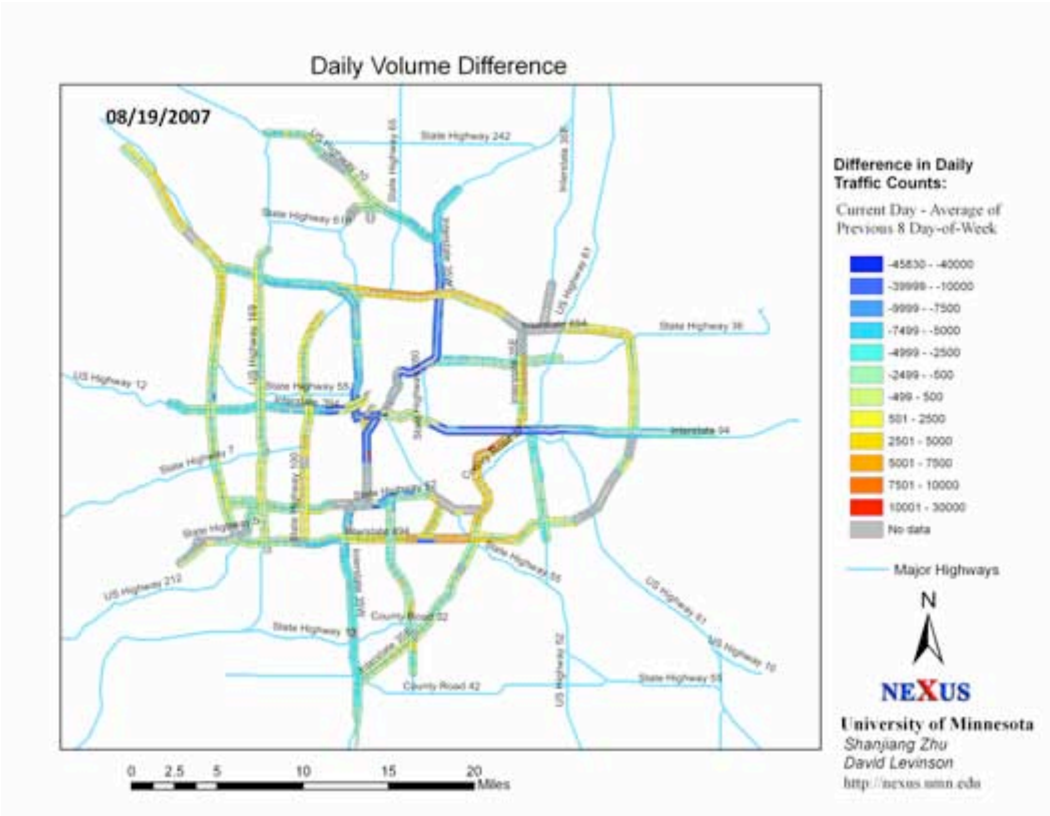
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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Major Highways
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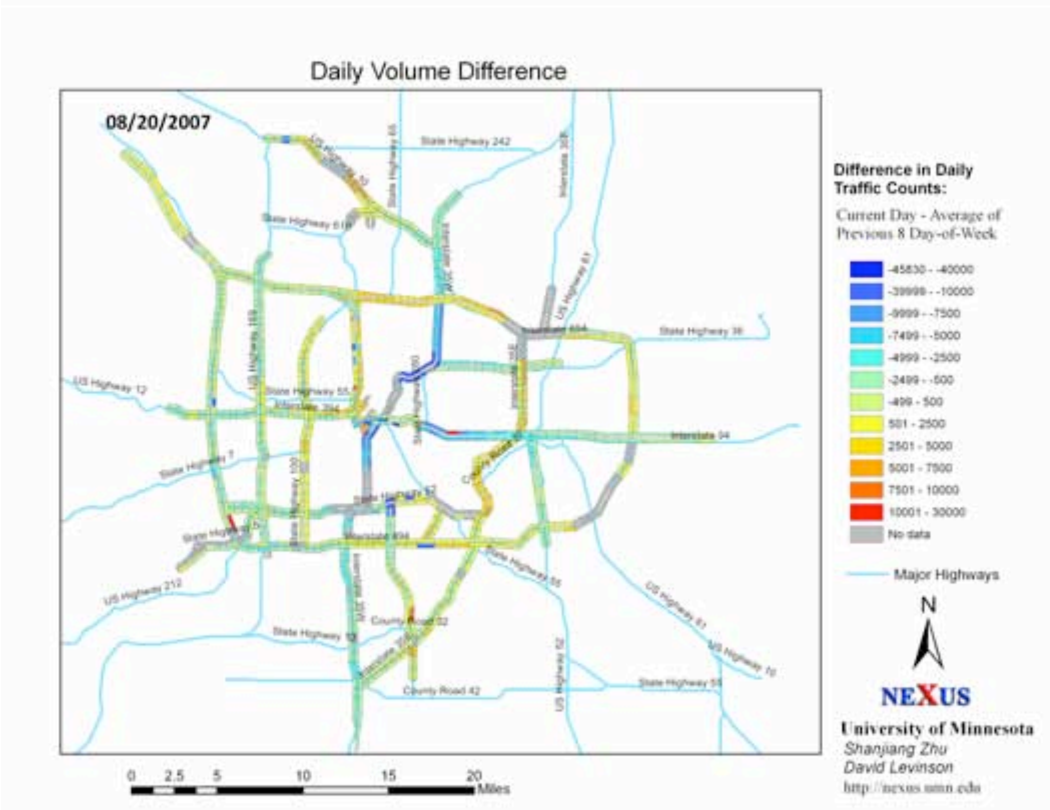
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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Major Highways
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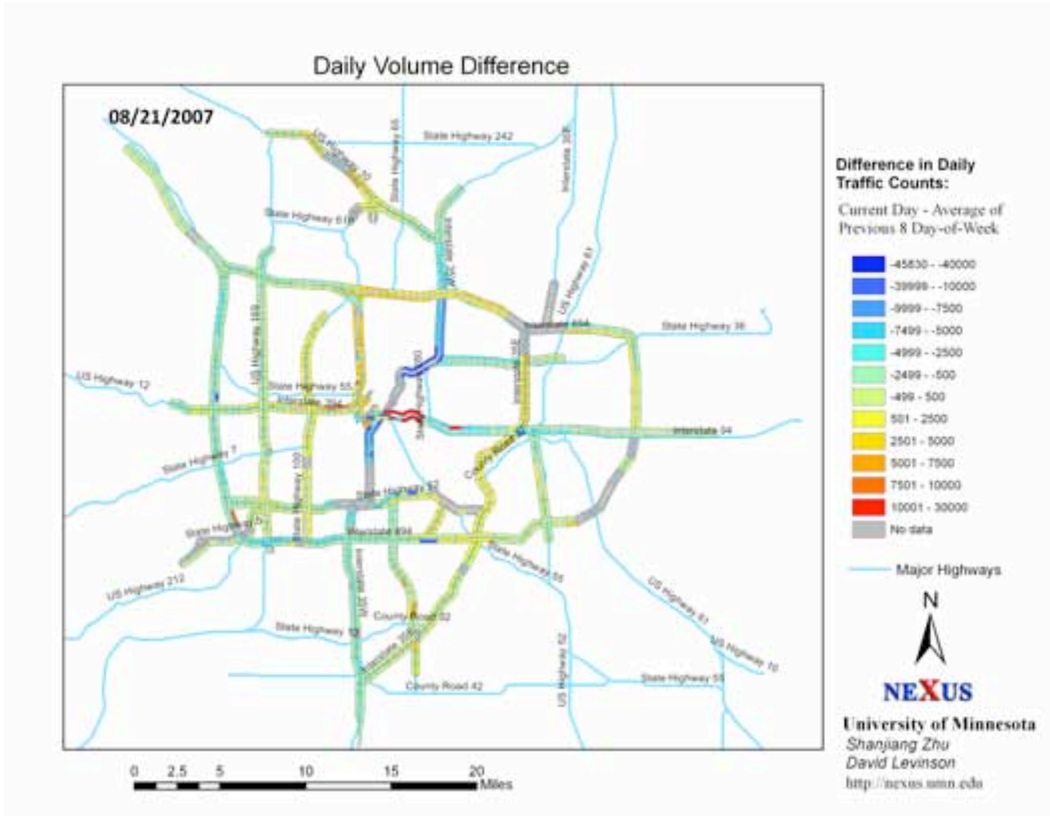
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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Major Highways
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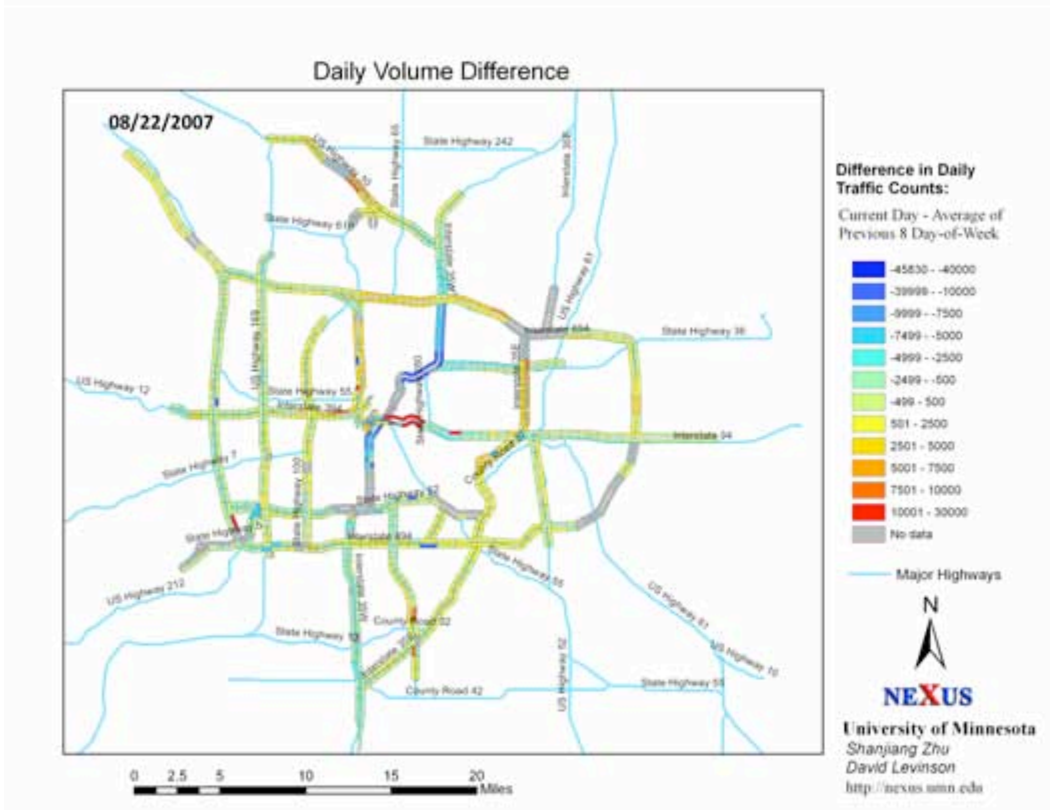
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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Major Highways
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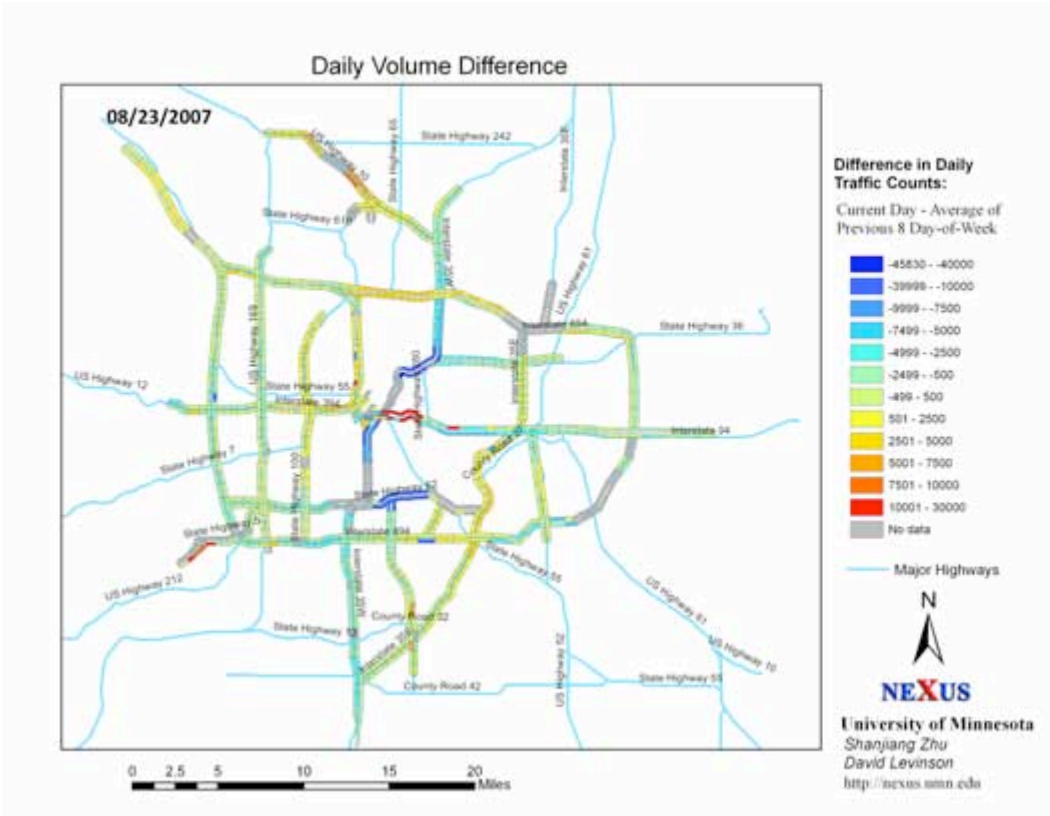
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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Major Highways
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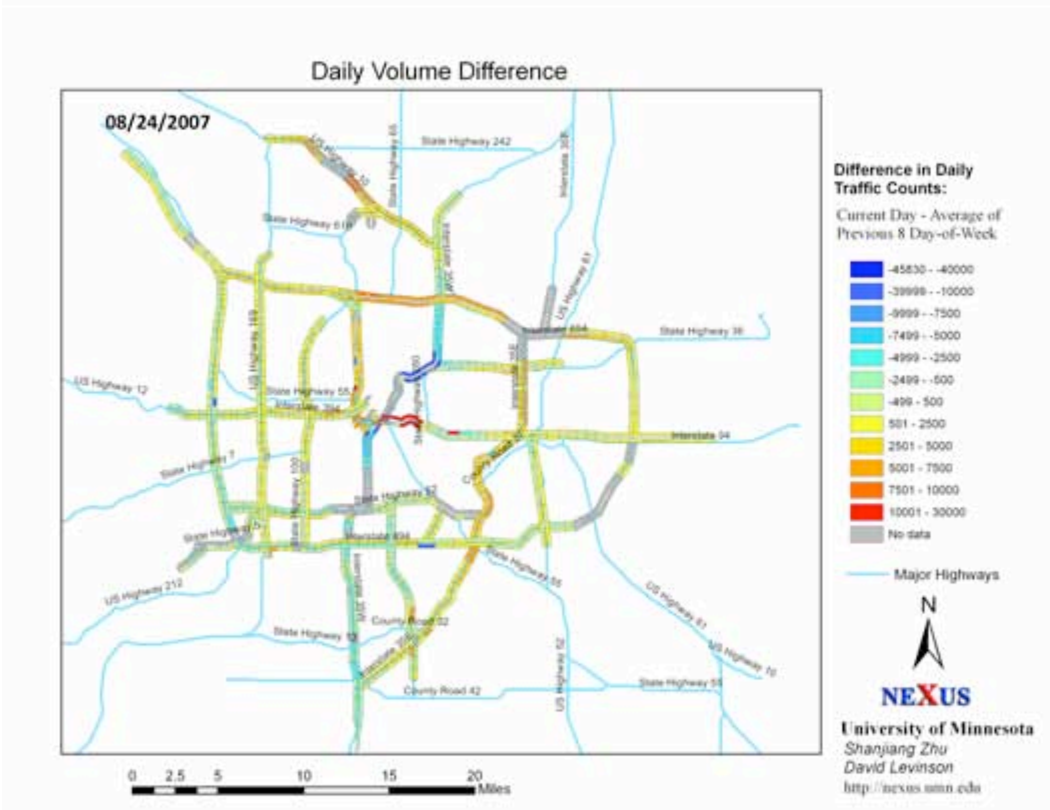
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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7501 - 10000
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Major Highways
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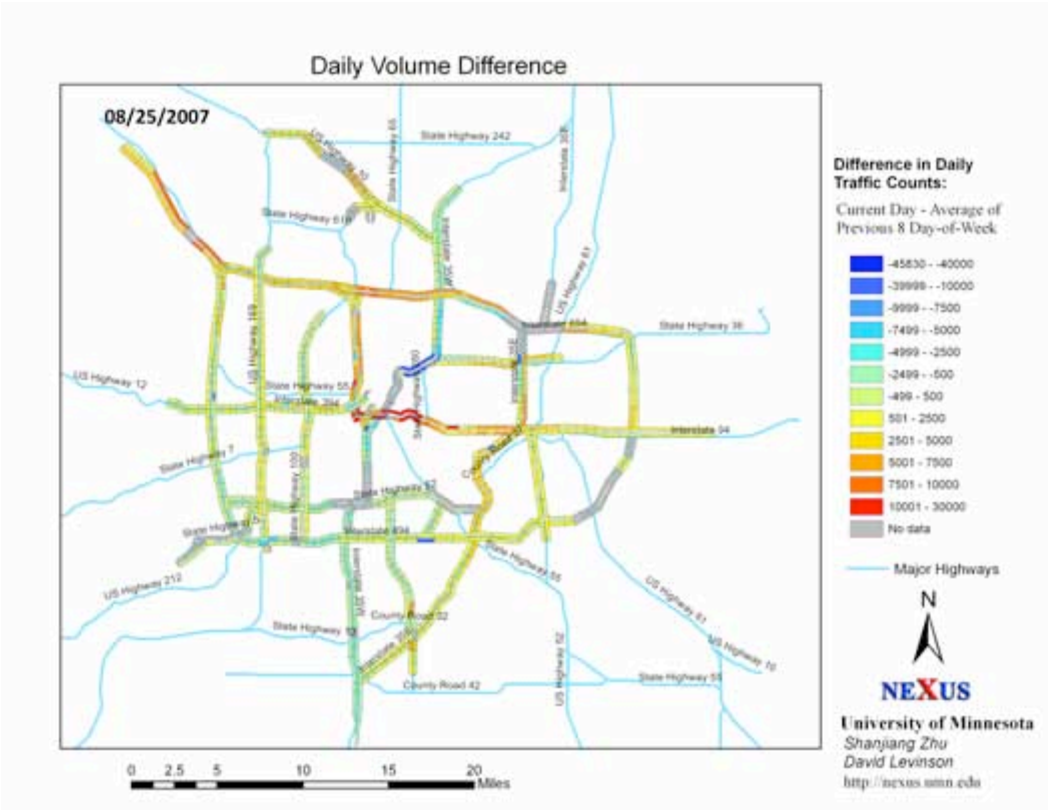
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 2.5 5 10 15 20 Miles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5001 - 7500
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Major Highways
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University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
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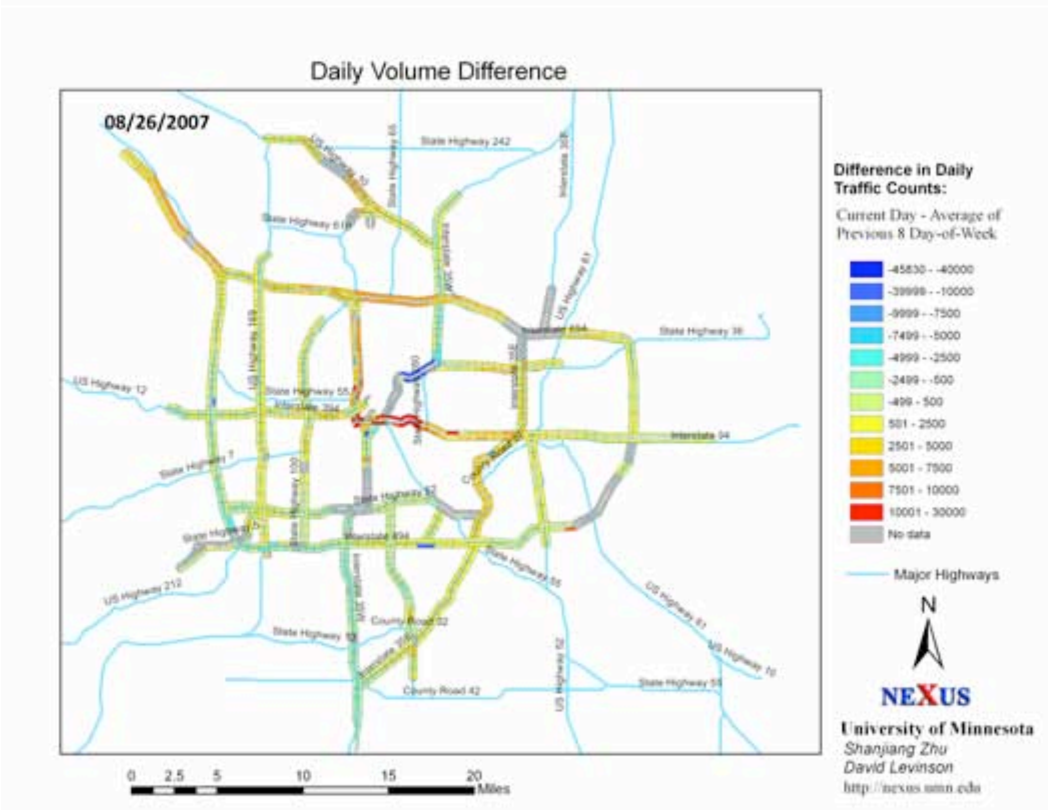
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Major Highways
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University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
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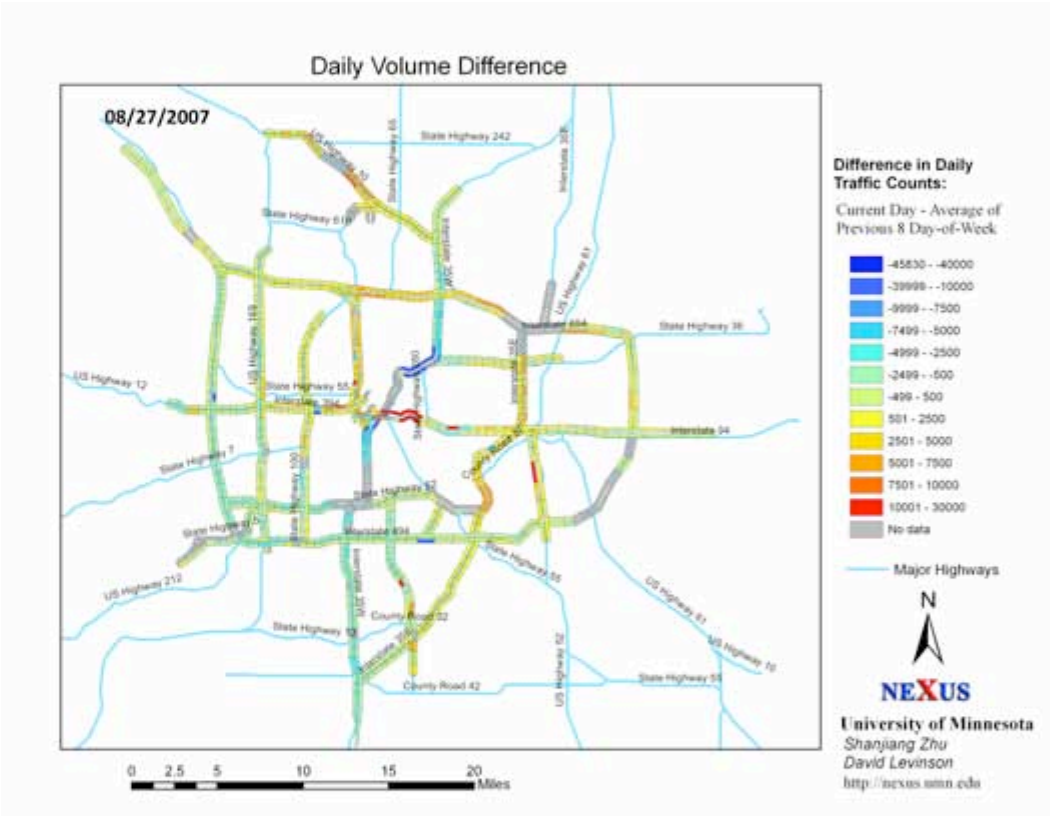
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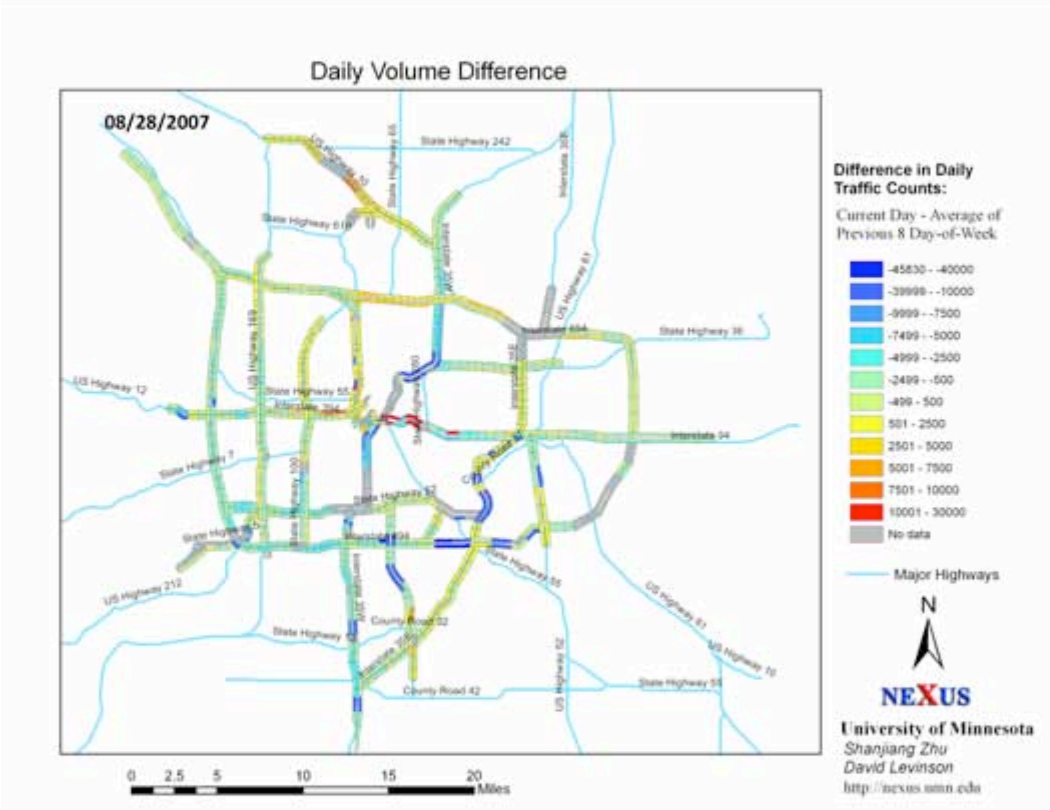
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Major Highways
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David Levinson
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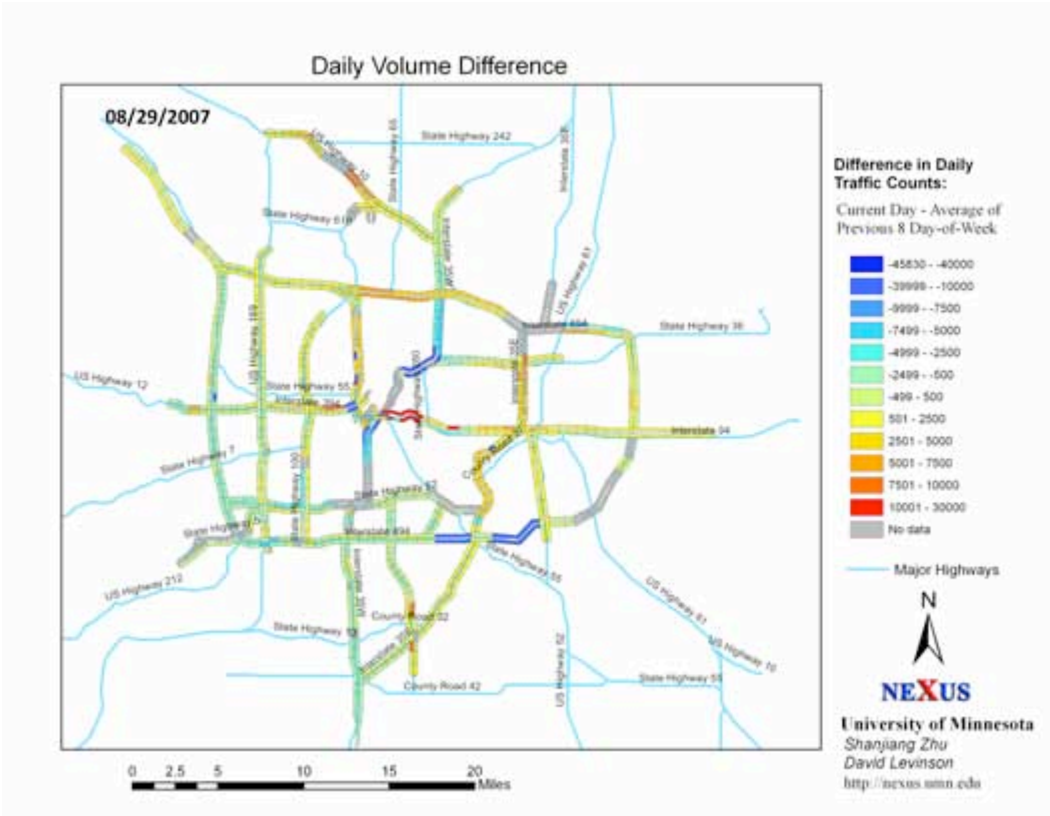
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Major Highways
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Shanjiang Zhu
David Levinson
http://nexus.umn.edu
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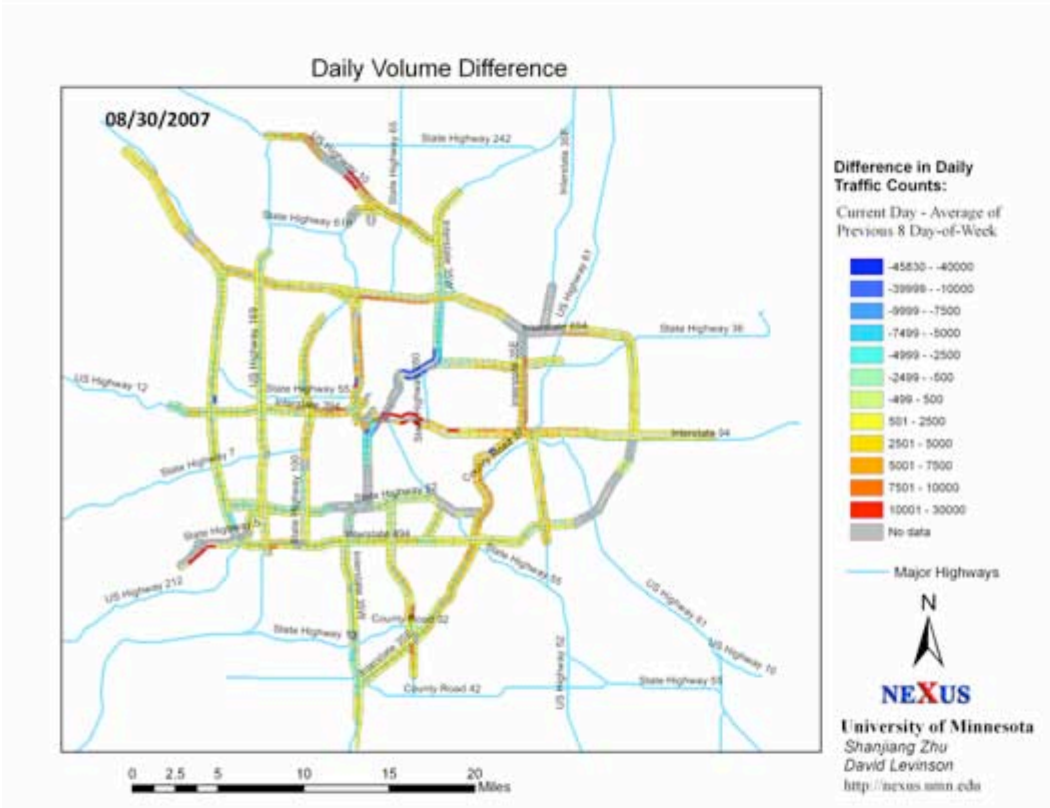
Miles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Major Highways
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David Levinson
http://nexus.umn.edu
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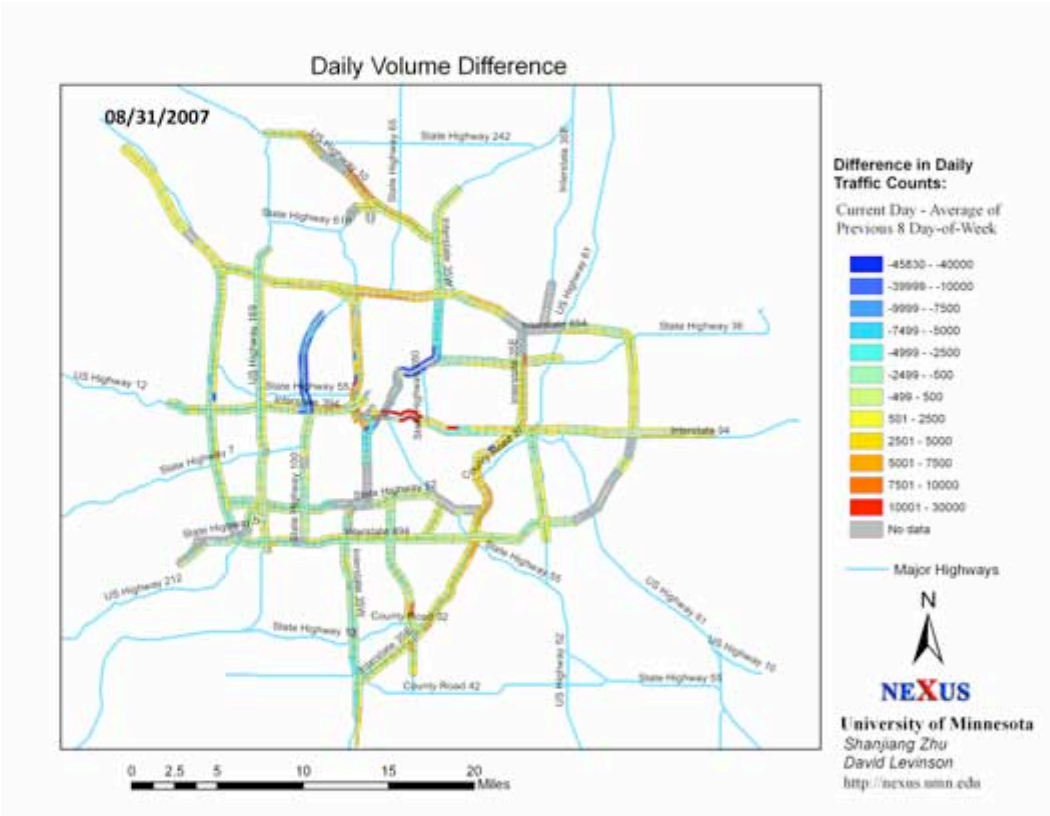
Miles



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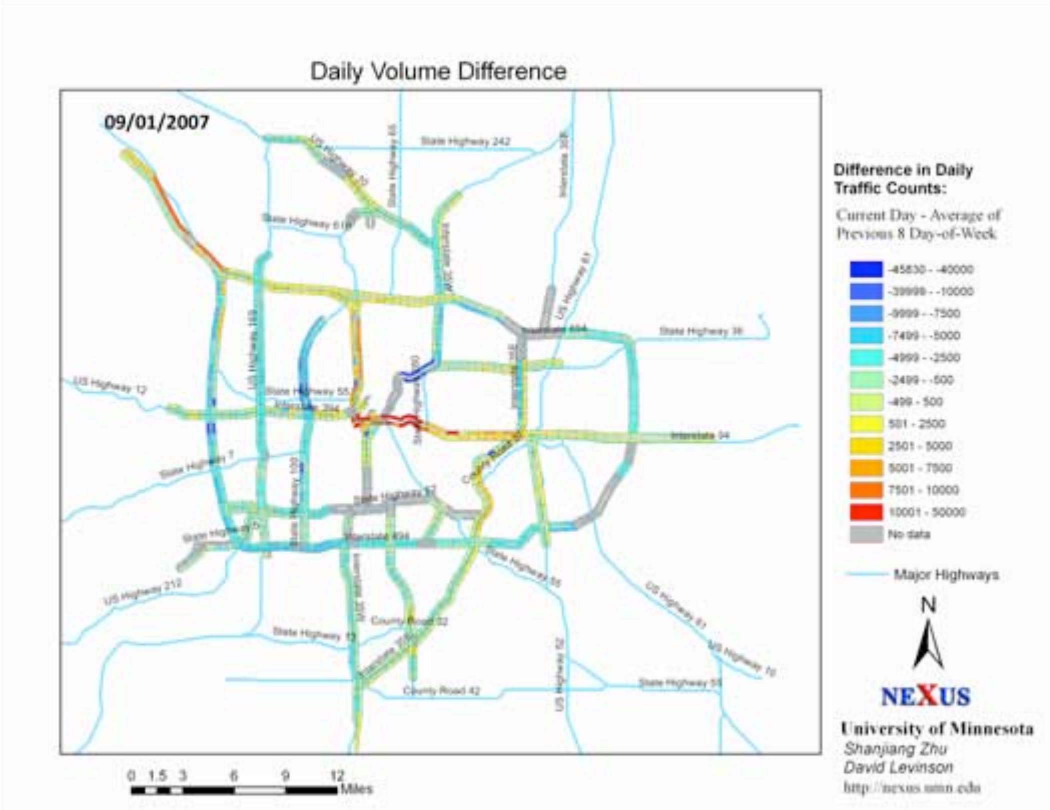

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Shanjiang Zhu
David Levinson
http://nexus.umn.edu
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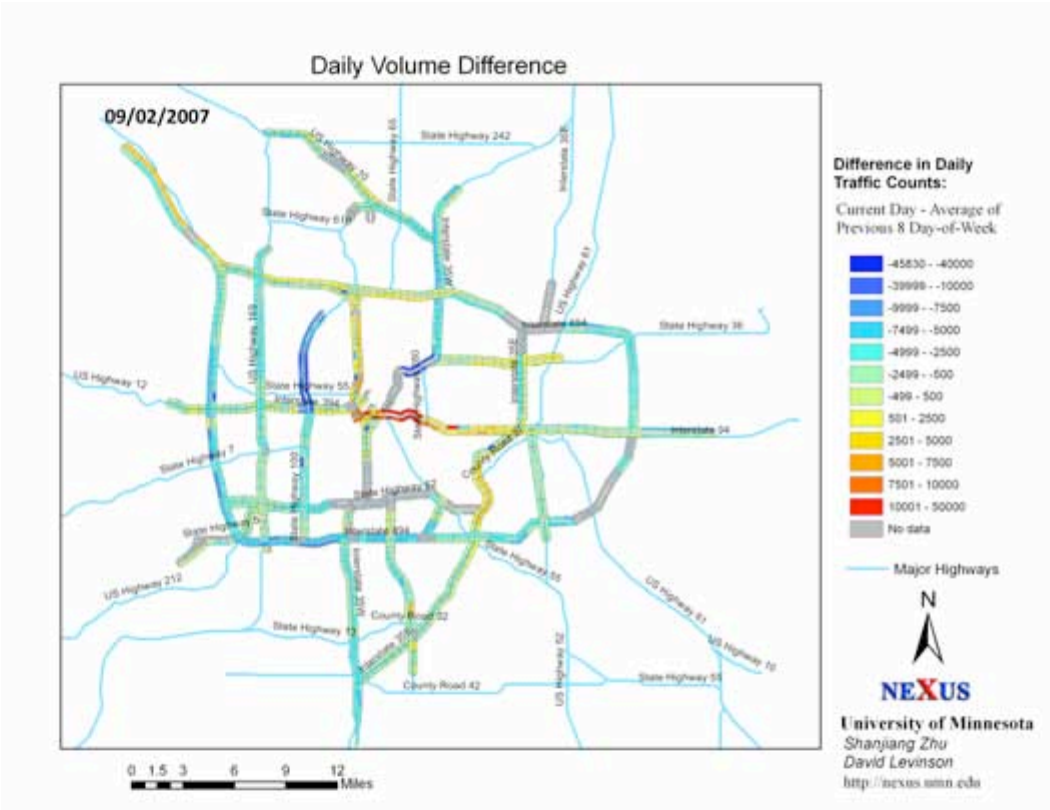
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Major Highways
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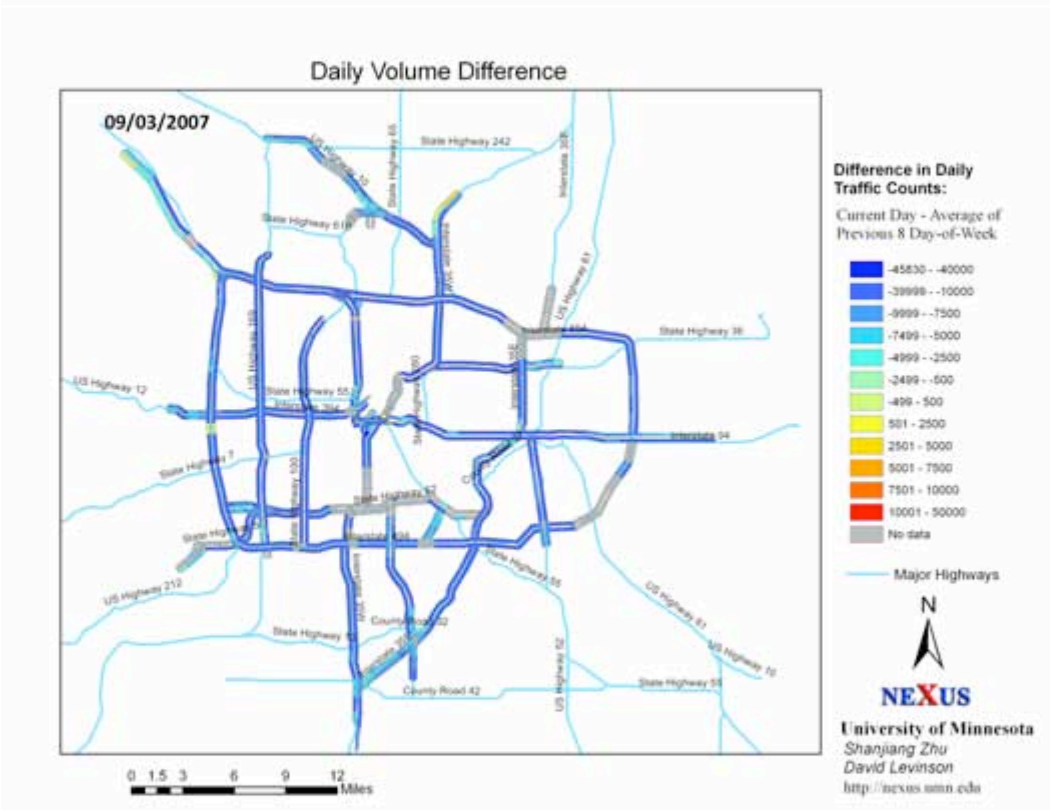
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Major Highways
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NEXUS
University of Minnesota
Shanjiang Zhu
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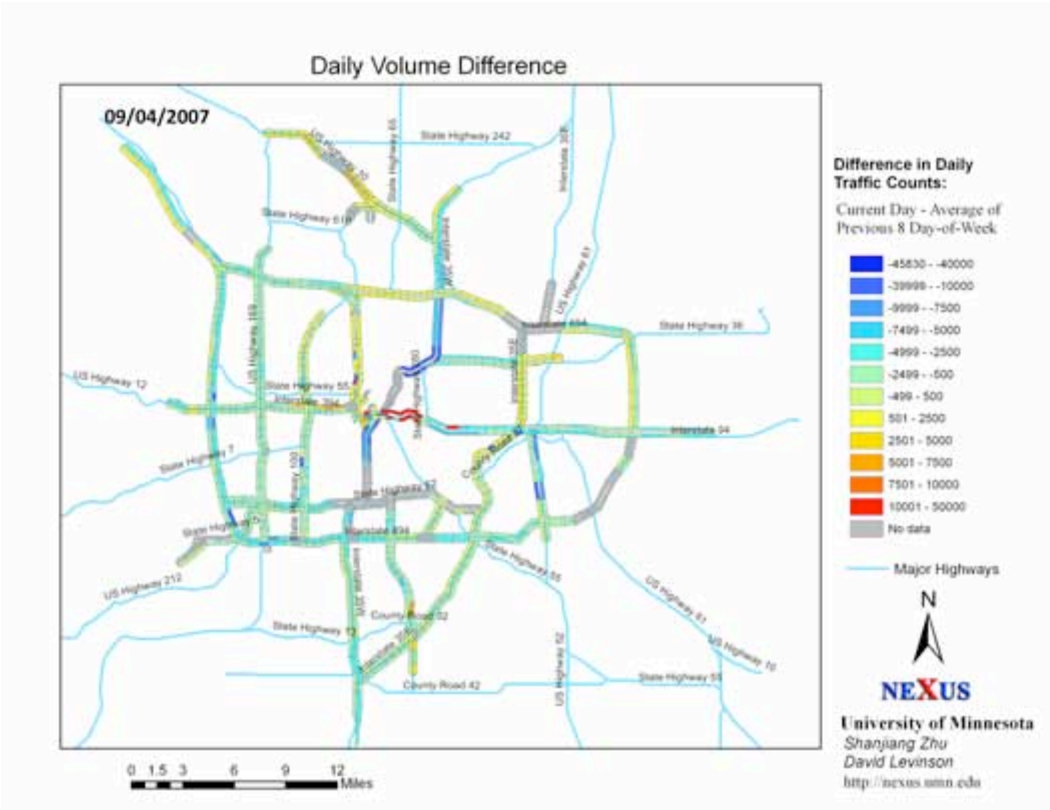
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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Major Highways
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NEXUS
University of Minnesota
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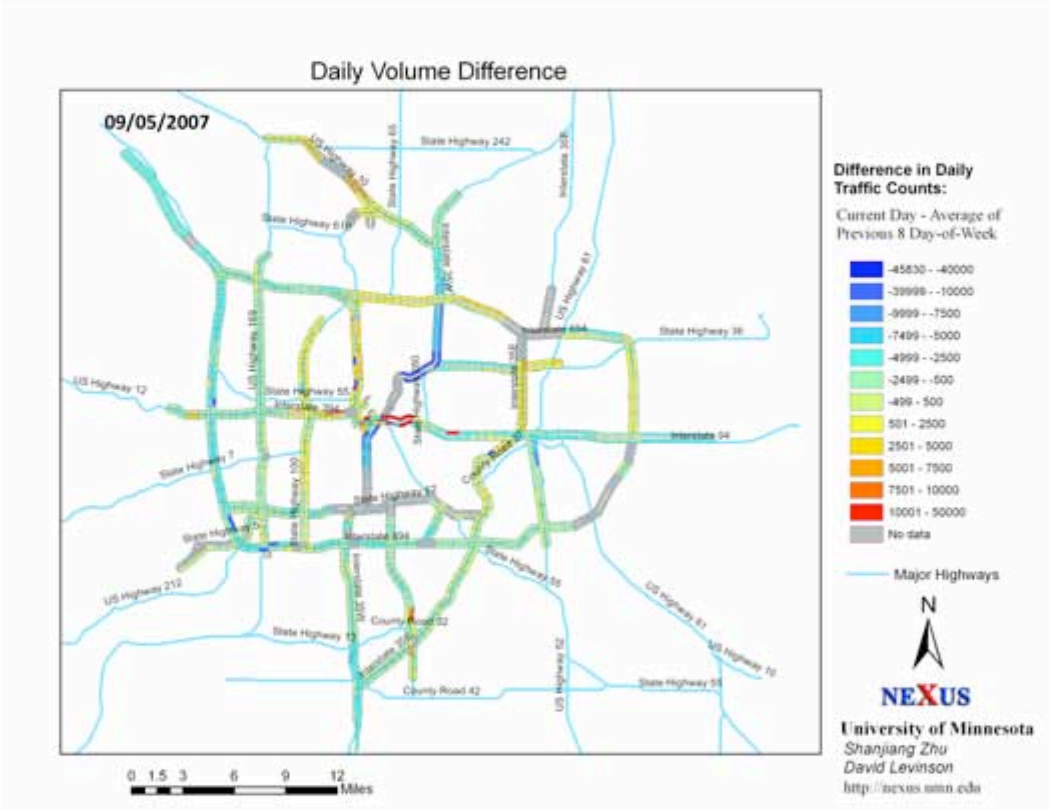
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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Major Highways
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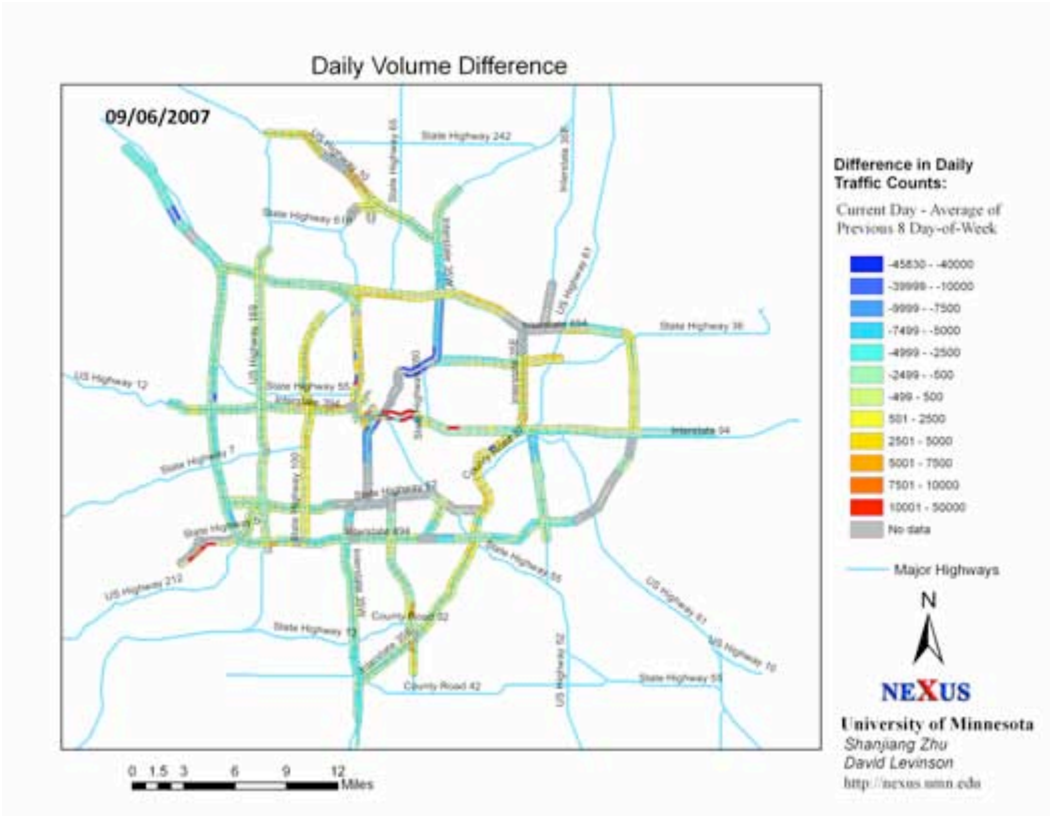
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles



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No data
Major Highways
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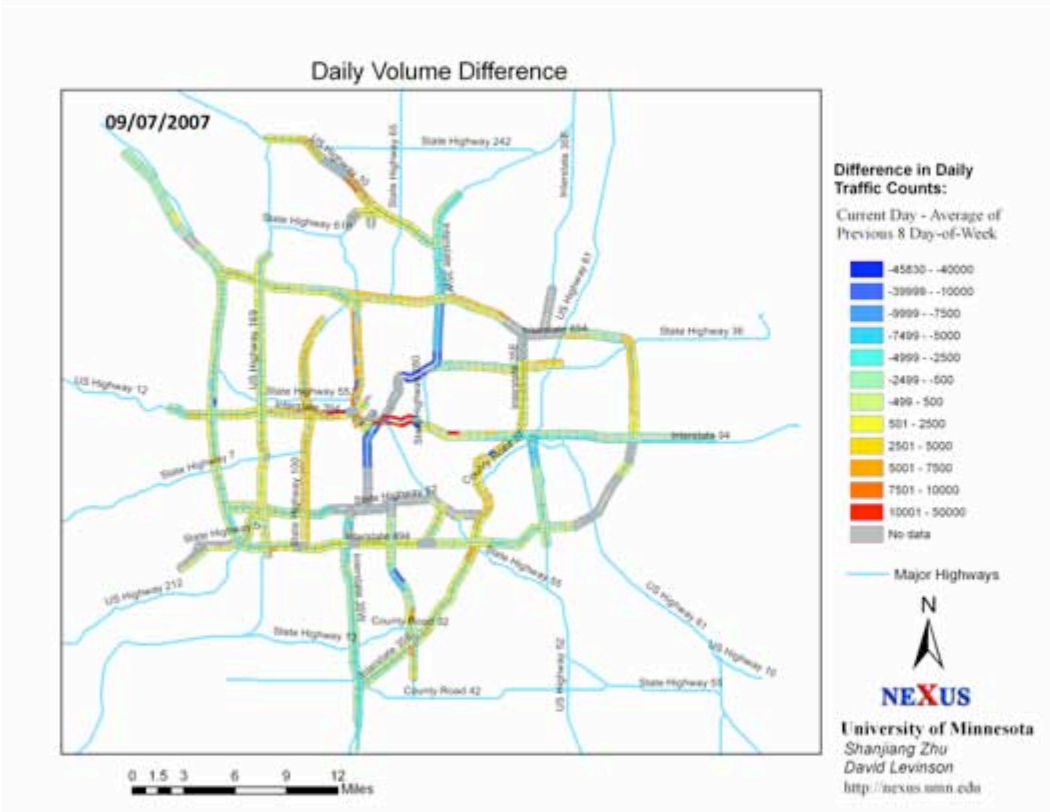
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles



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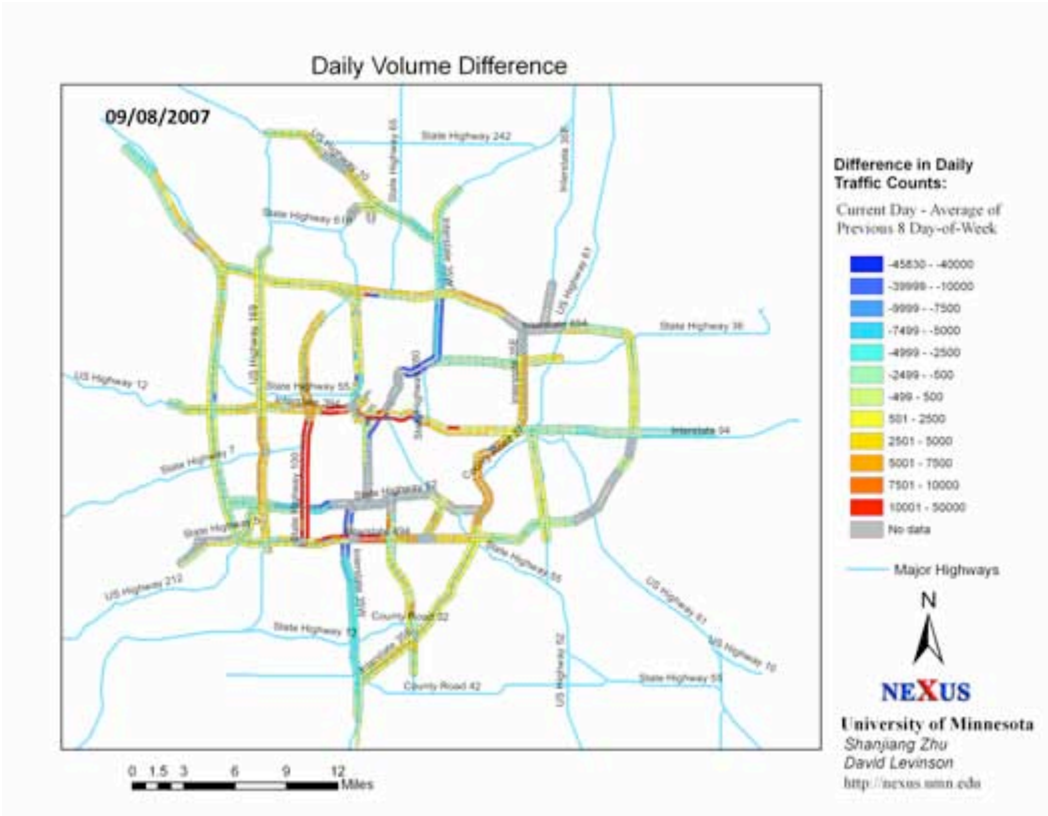
-7499 - -5000
-4999 - -2500
-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
No data
Major Highways
N
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
No data
Major Highways
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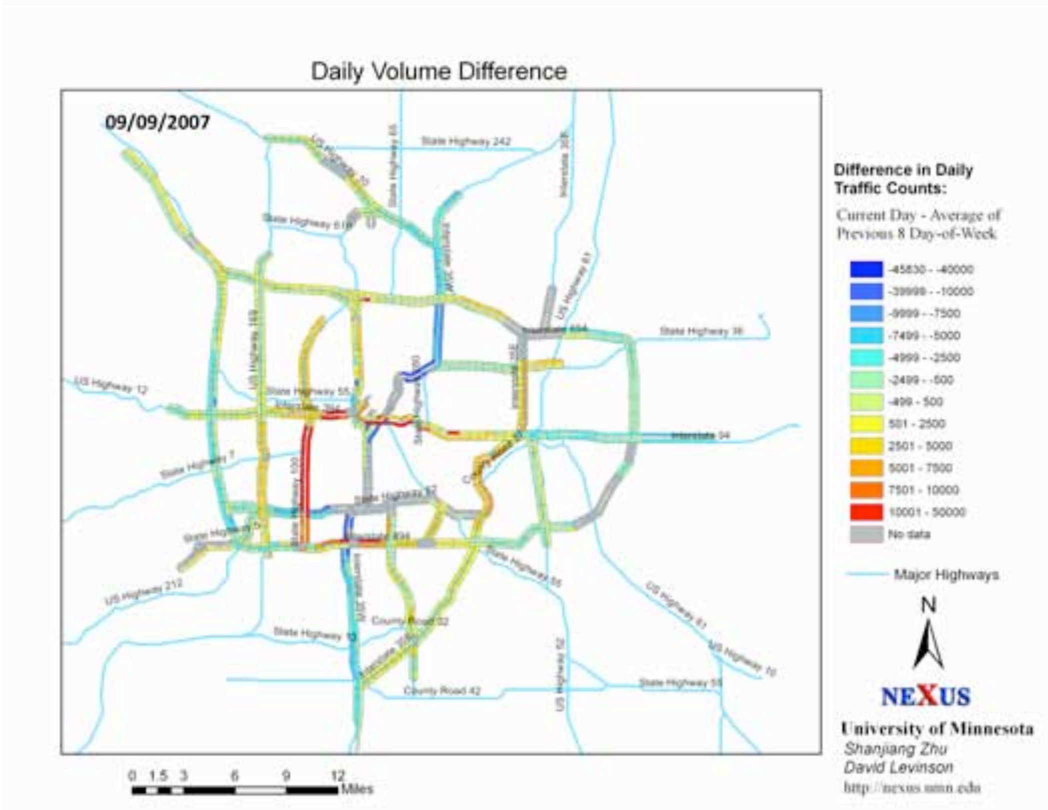
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
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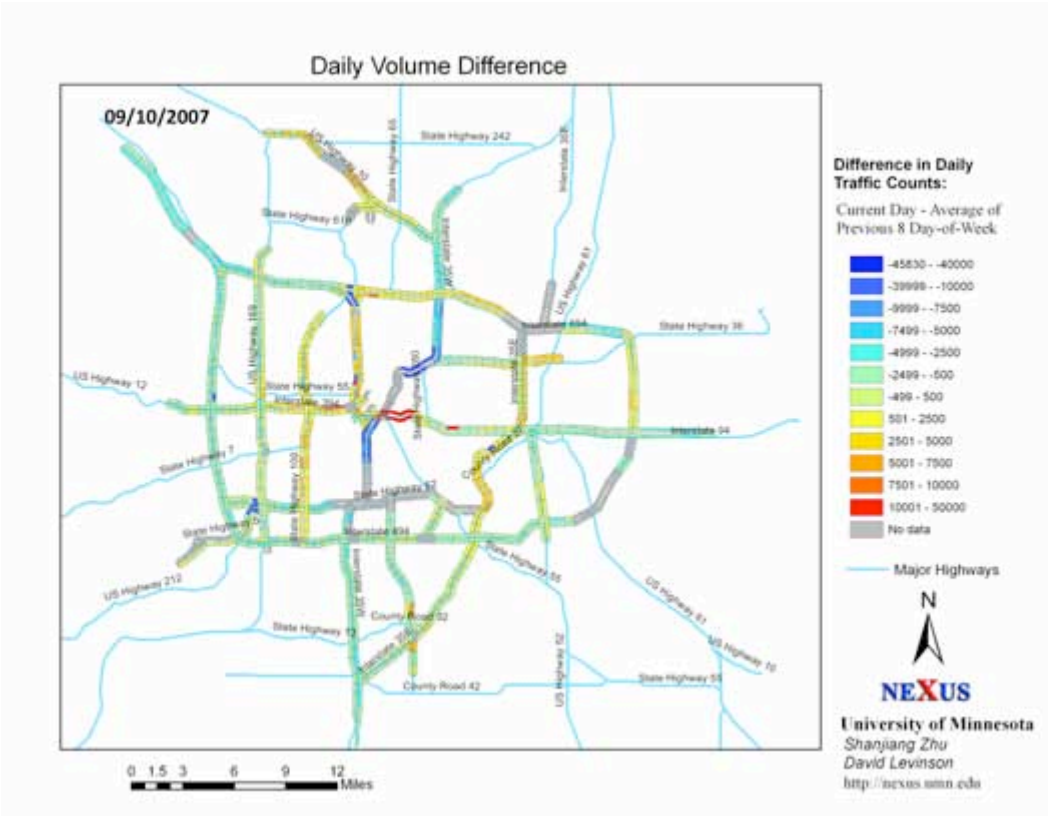
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
No data
Major Highways
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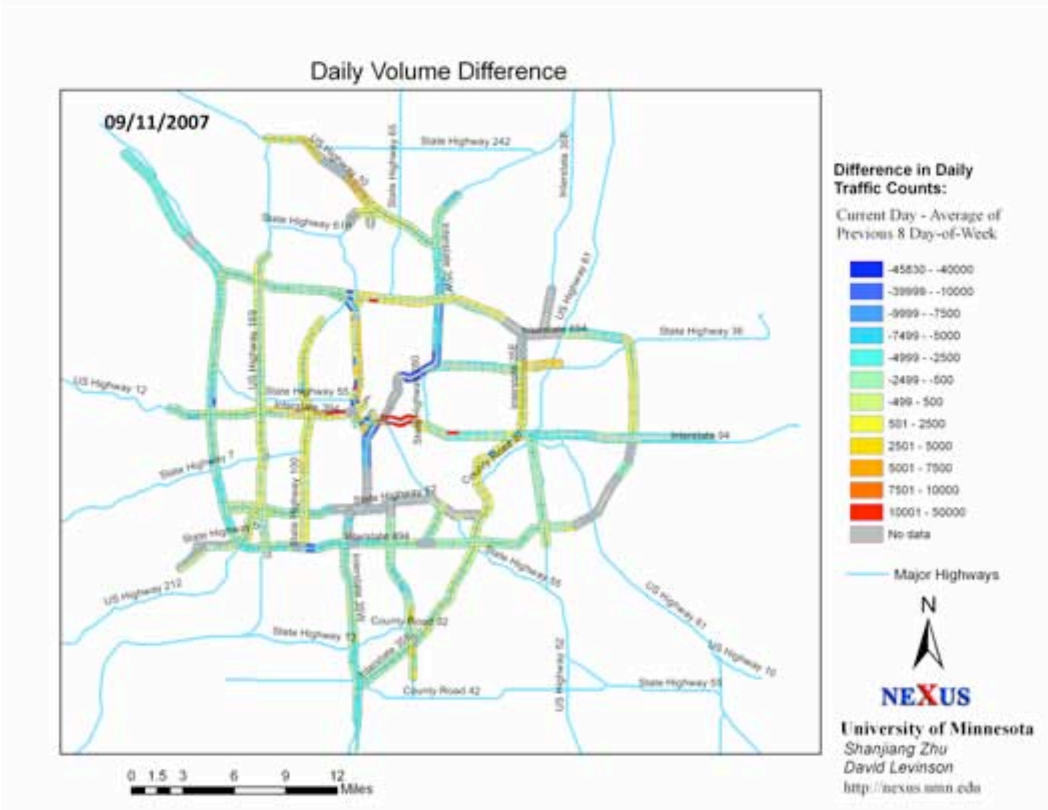
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12
Miles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-4999 - -2500
-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
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Major Highways
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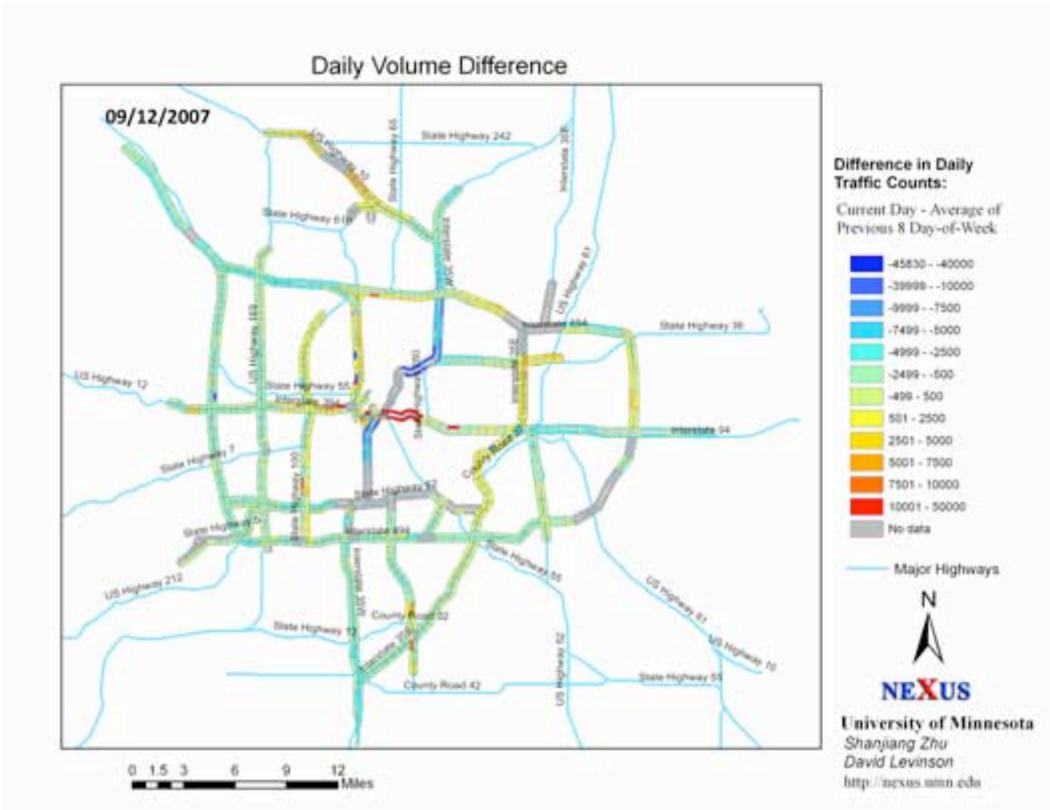
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12
Miles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-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
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Major Highways
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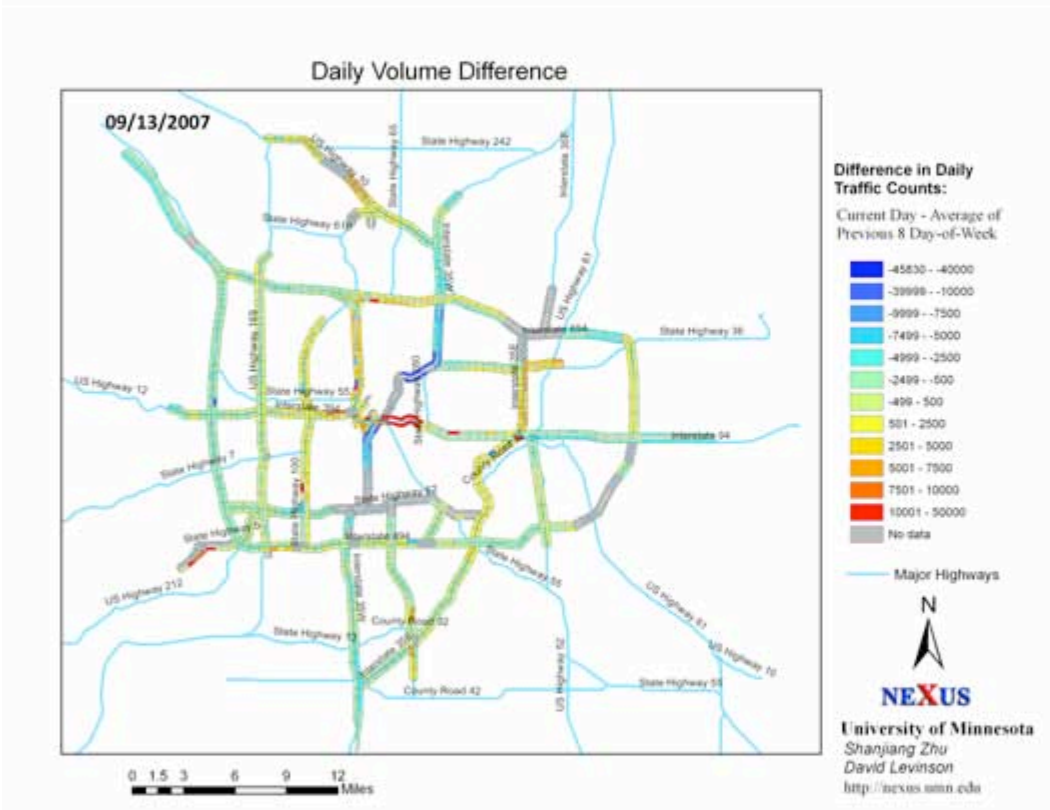
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
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Major Highways
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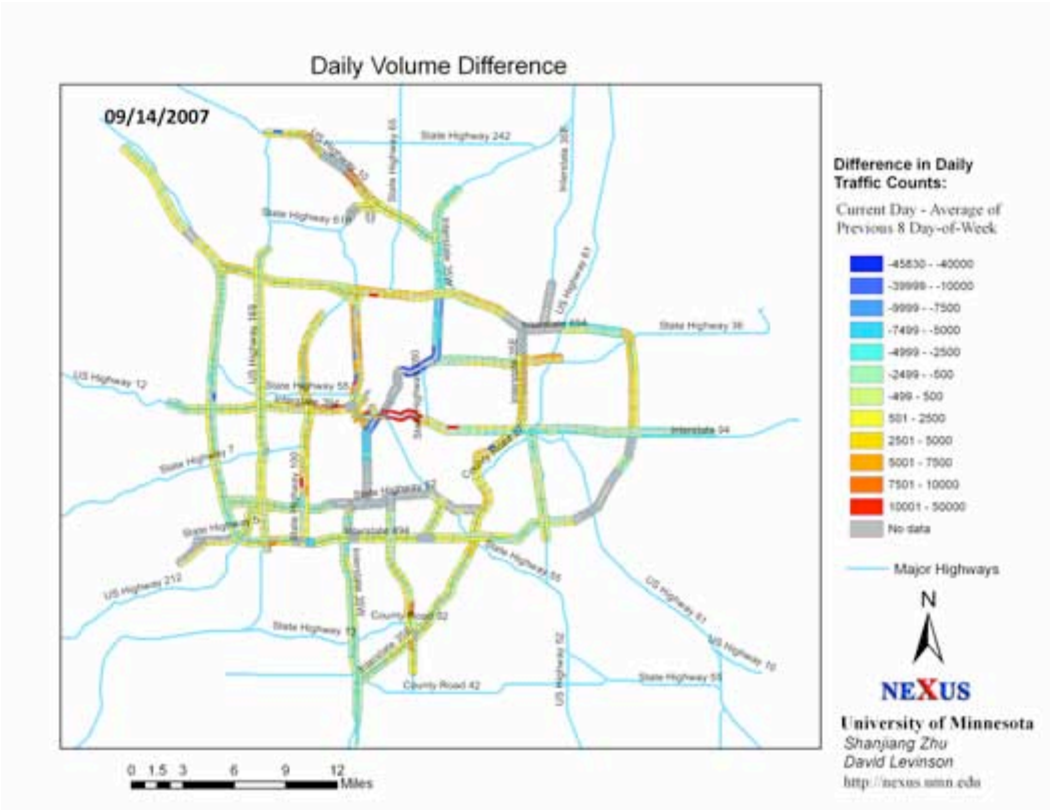
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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-7499 - -5000
-4999 - -2500
-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
No data
Major Highways
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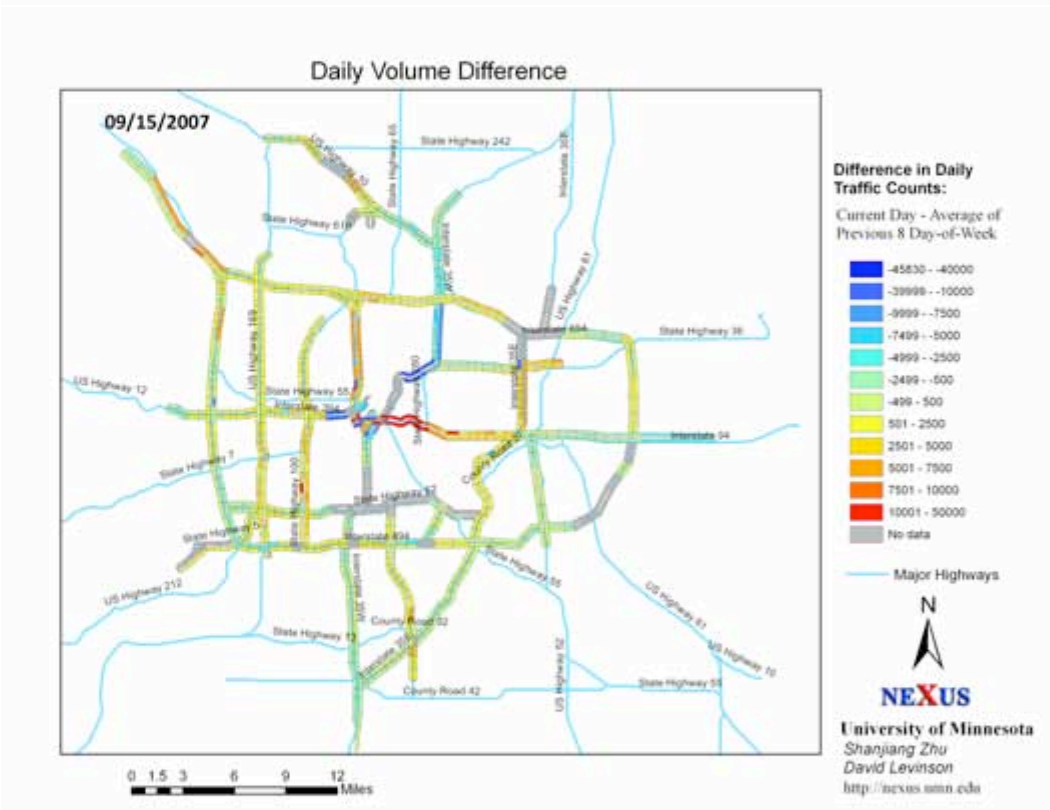
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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-7499 - -5000
-4999 - -2500
-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
No data
Major Highways
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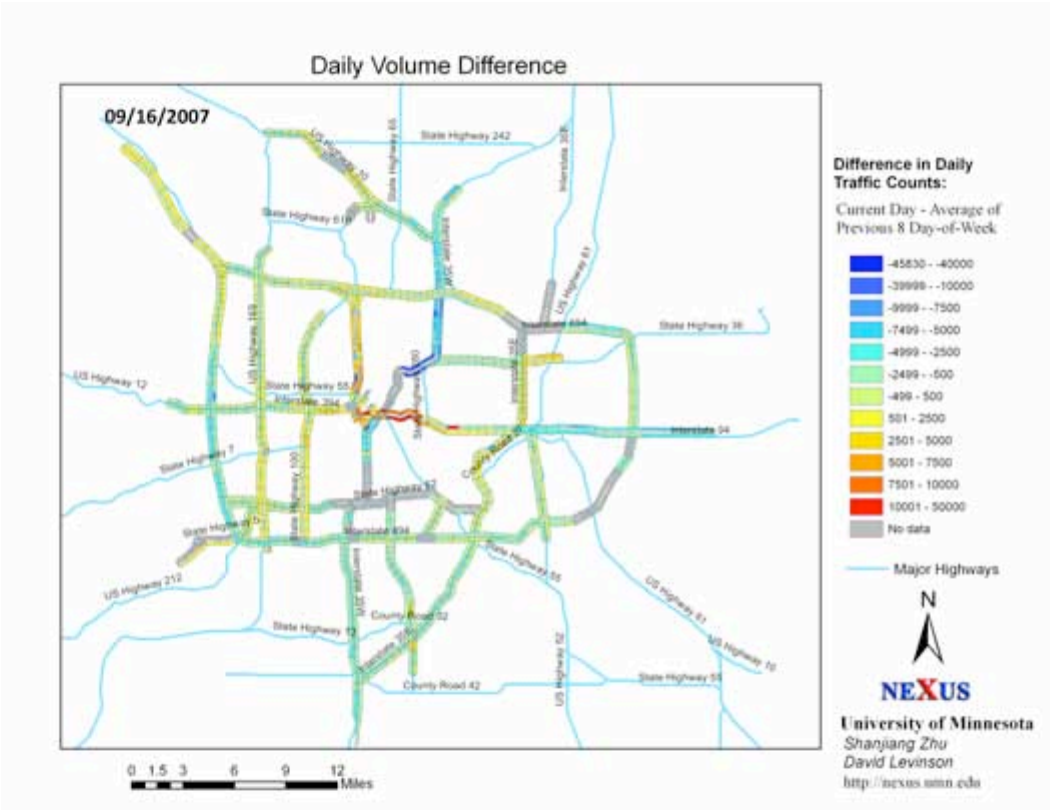
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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-2499 - -500
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501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
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Major Highways
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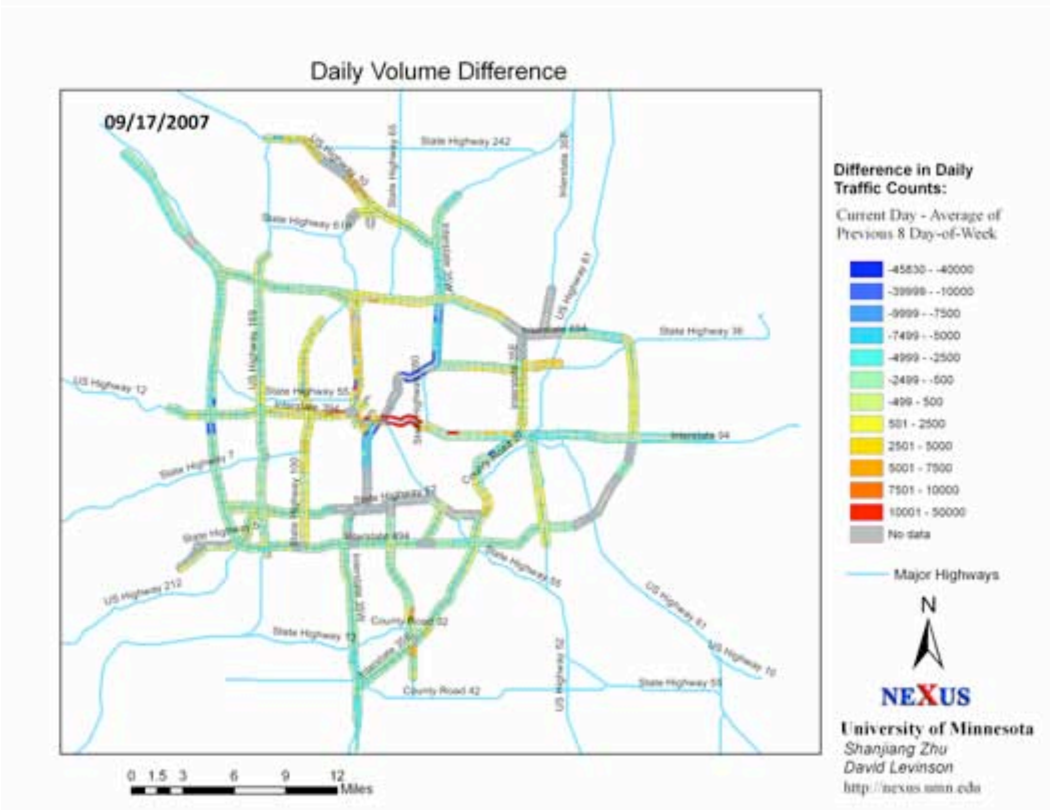
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
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No data
Major Highways
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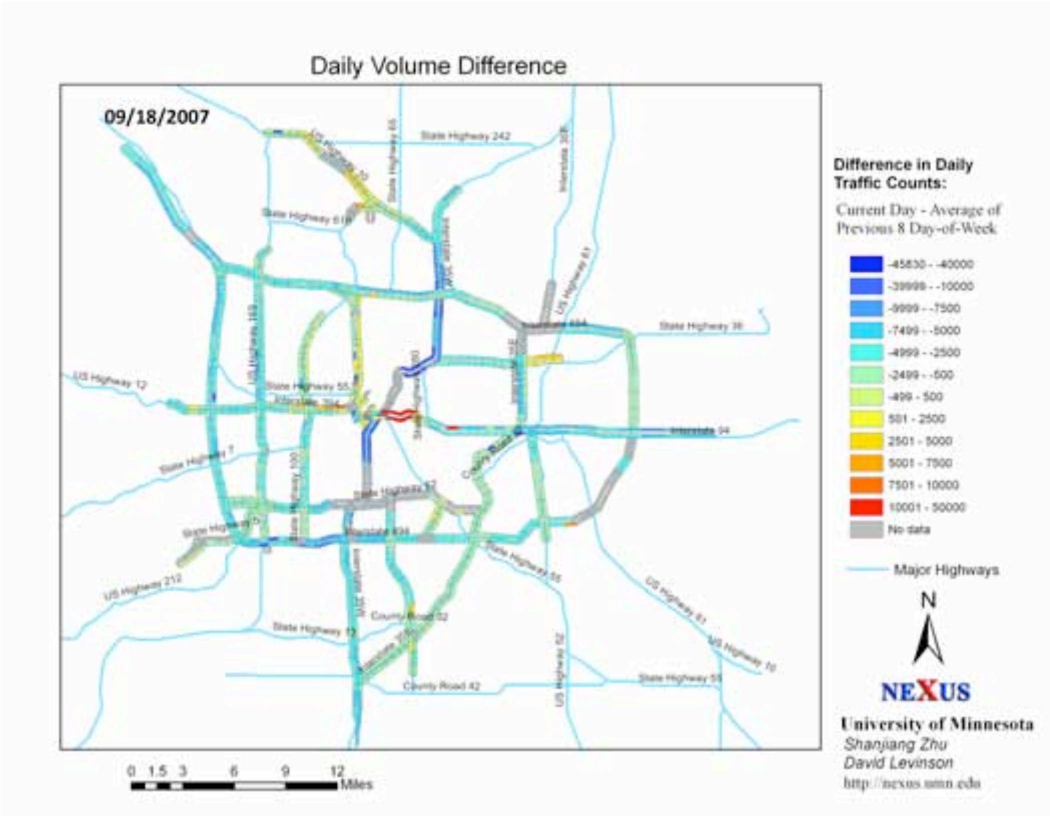
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
No data
Major Highways
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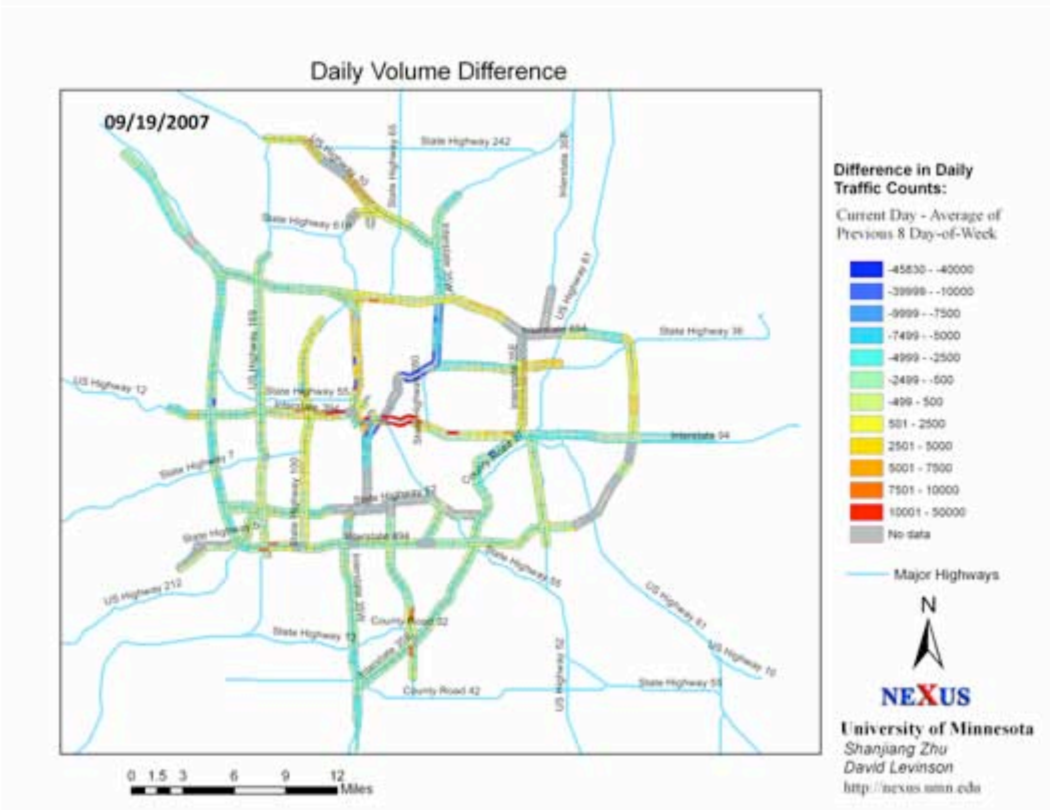
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12
Miles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-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
No data
Major Highways
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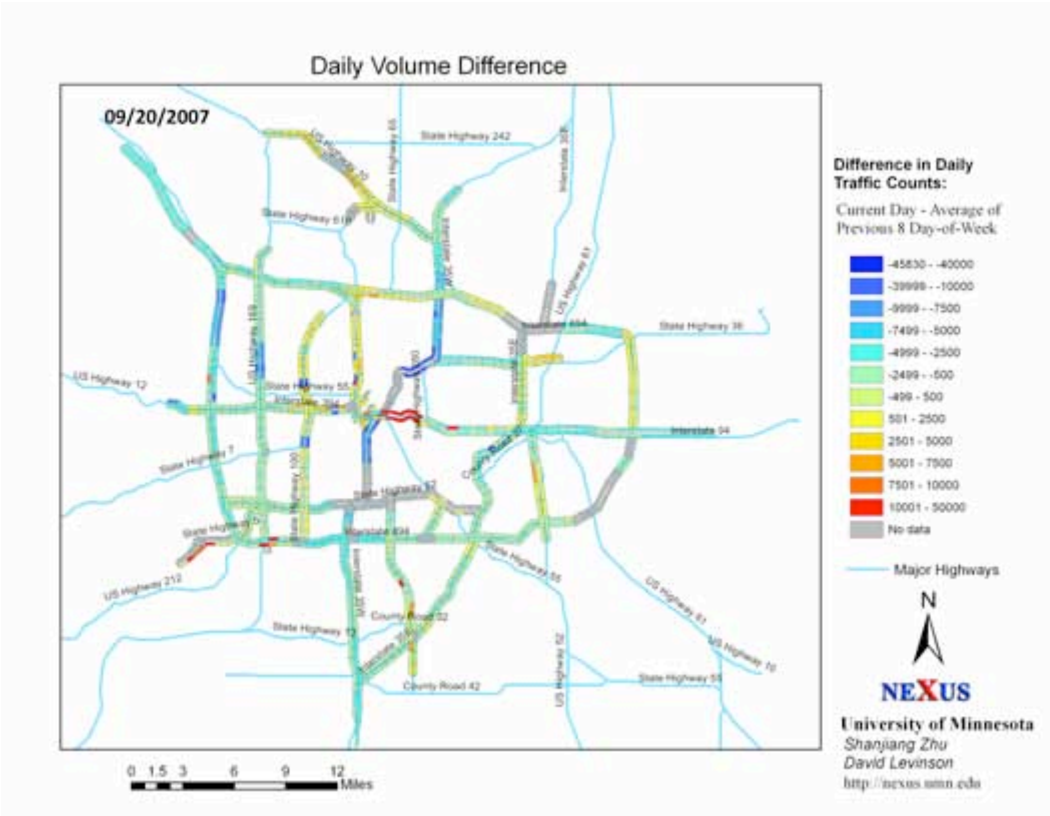
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12
Miles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Difference in Daily Traffic Counts:
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501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
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Major Highways
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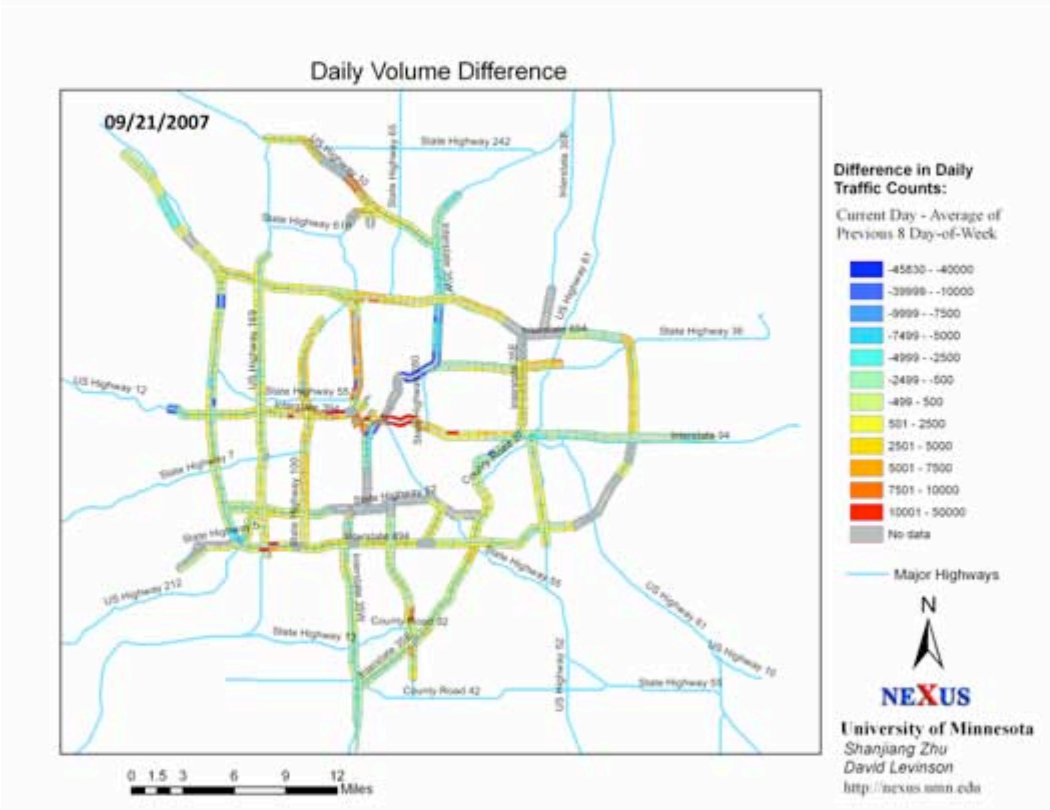
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
No data
Major Highways
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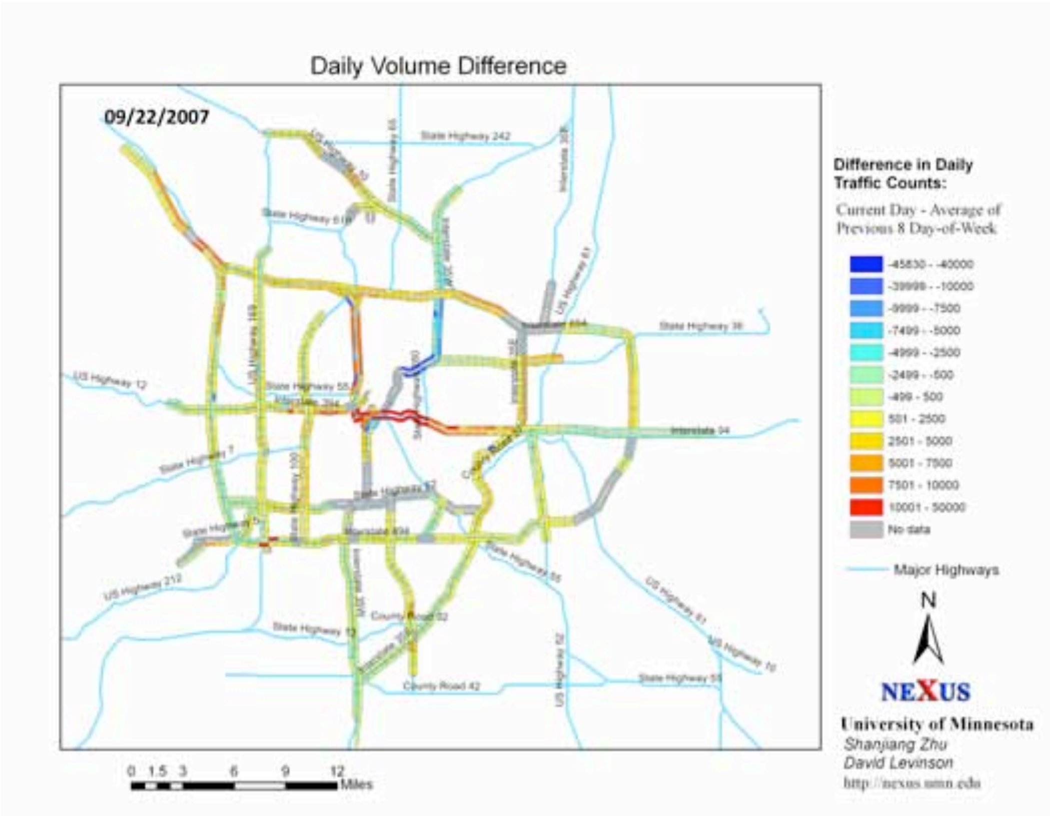
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
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Major Highways
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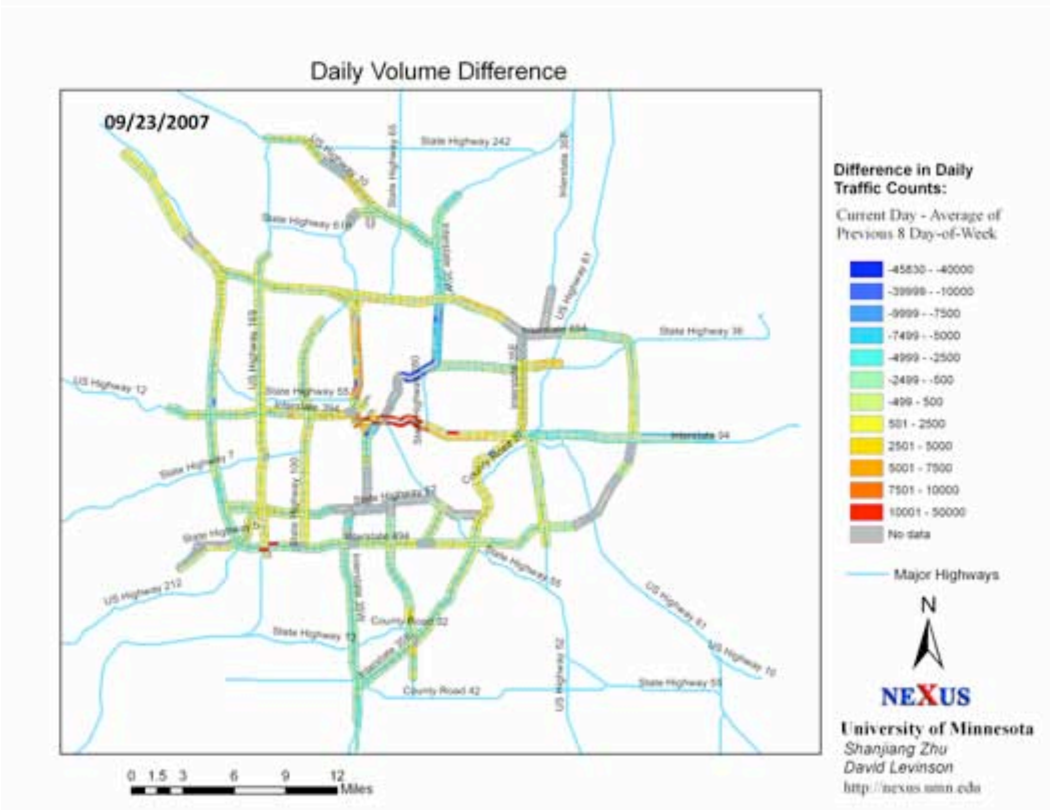
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12
Miles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Difference in Daily Traffic Counts:
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-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
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No data
Major Highways
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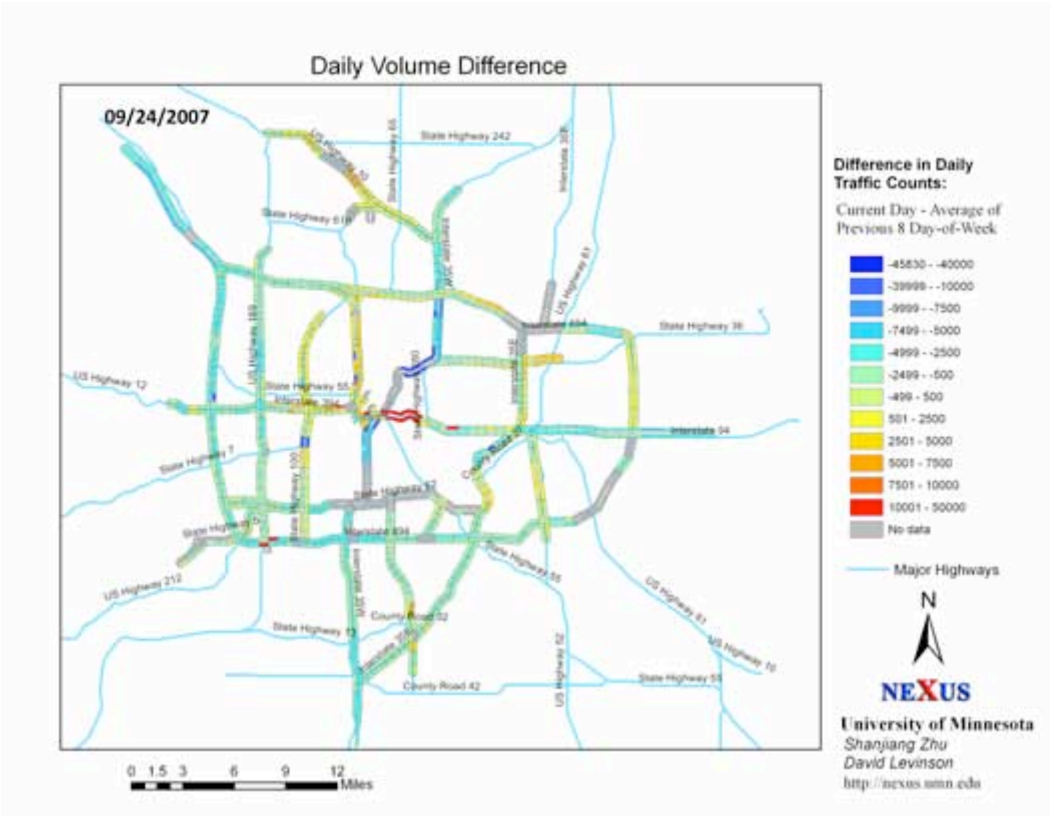
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12
Miles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09/24/2007
Difference in Daily Traffic Counts:
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-2499 - -500
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501 - 2500
2501 - 5000
5001 - 7500
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Major Highways
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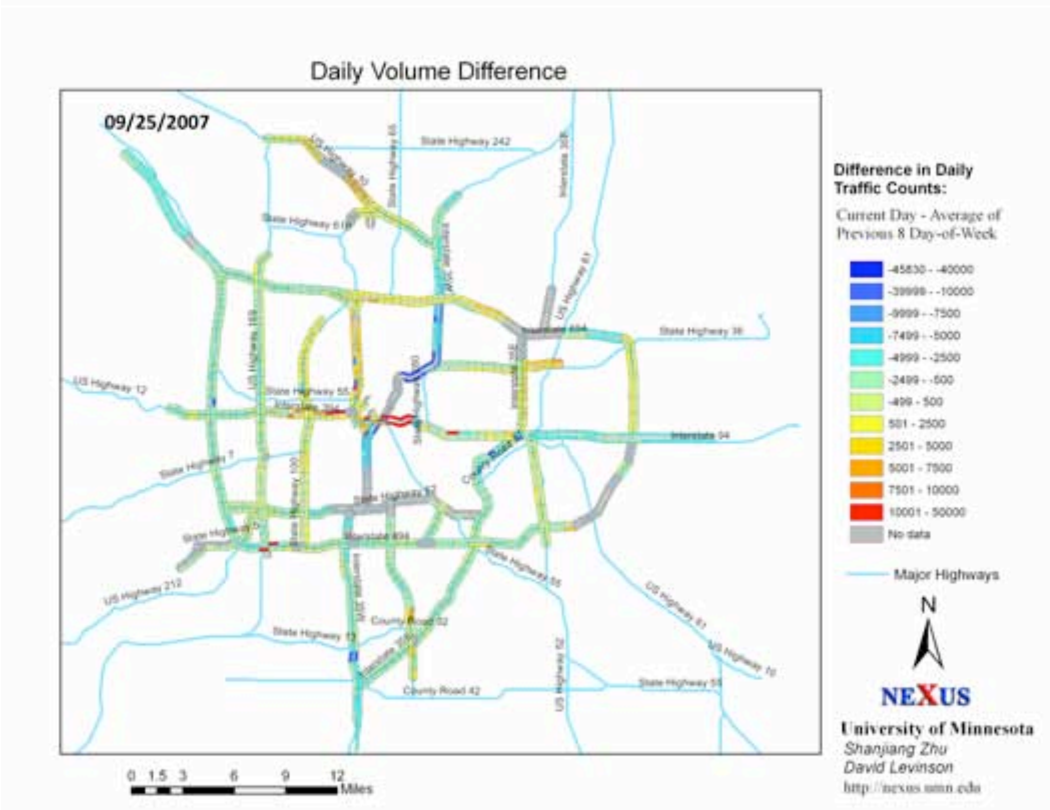
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12
Miles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09/25/2007
Difference in Daily Traffic Counts:
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-499 - 500
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2501 - 5000
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7501 - 10000
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Major Highways
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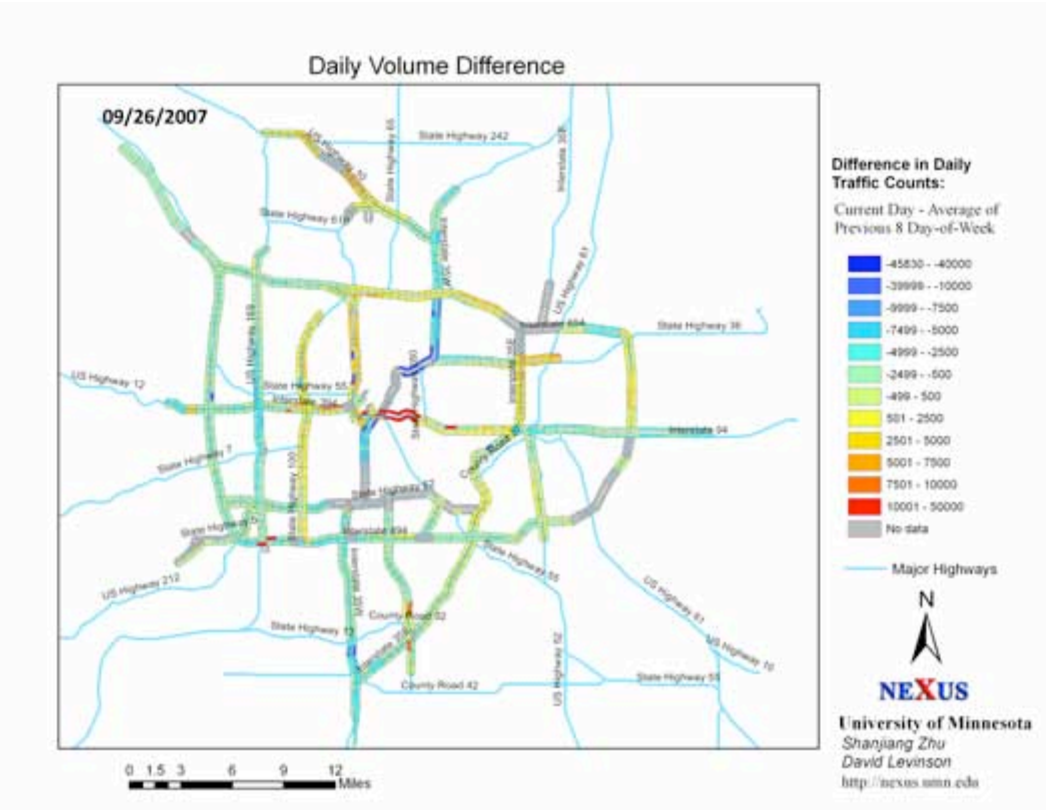
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12
Miles



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5001 - 7500
7501 - 10000
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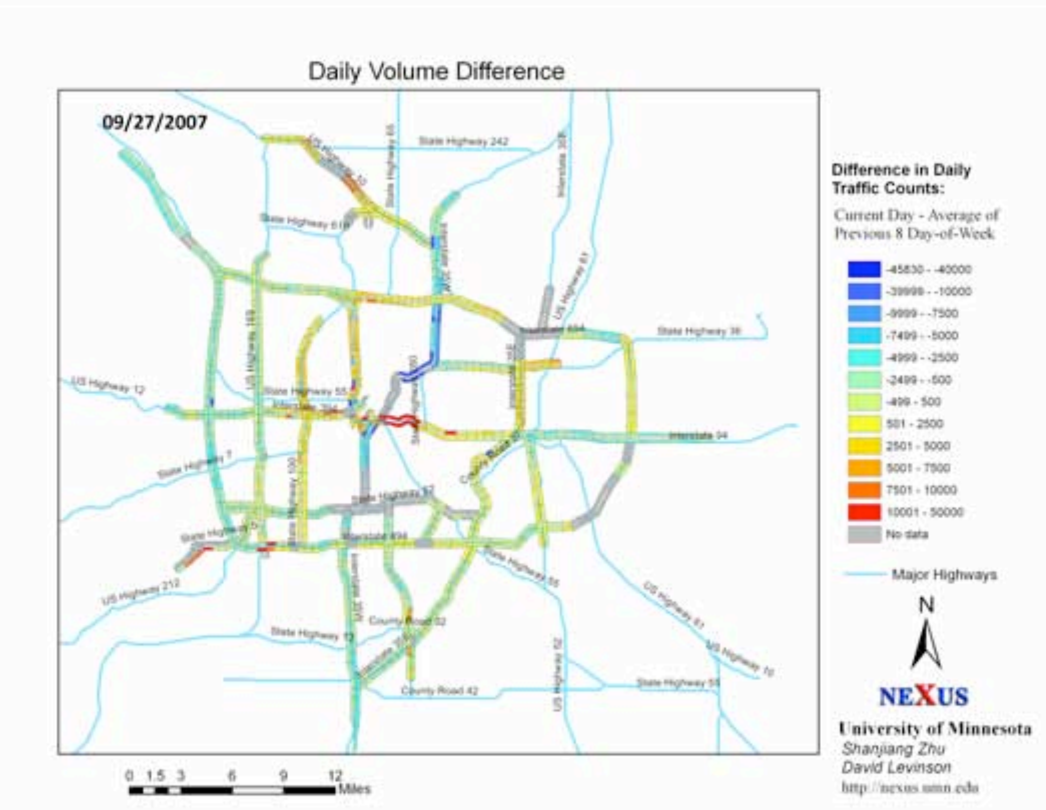
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12
Miles



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-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
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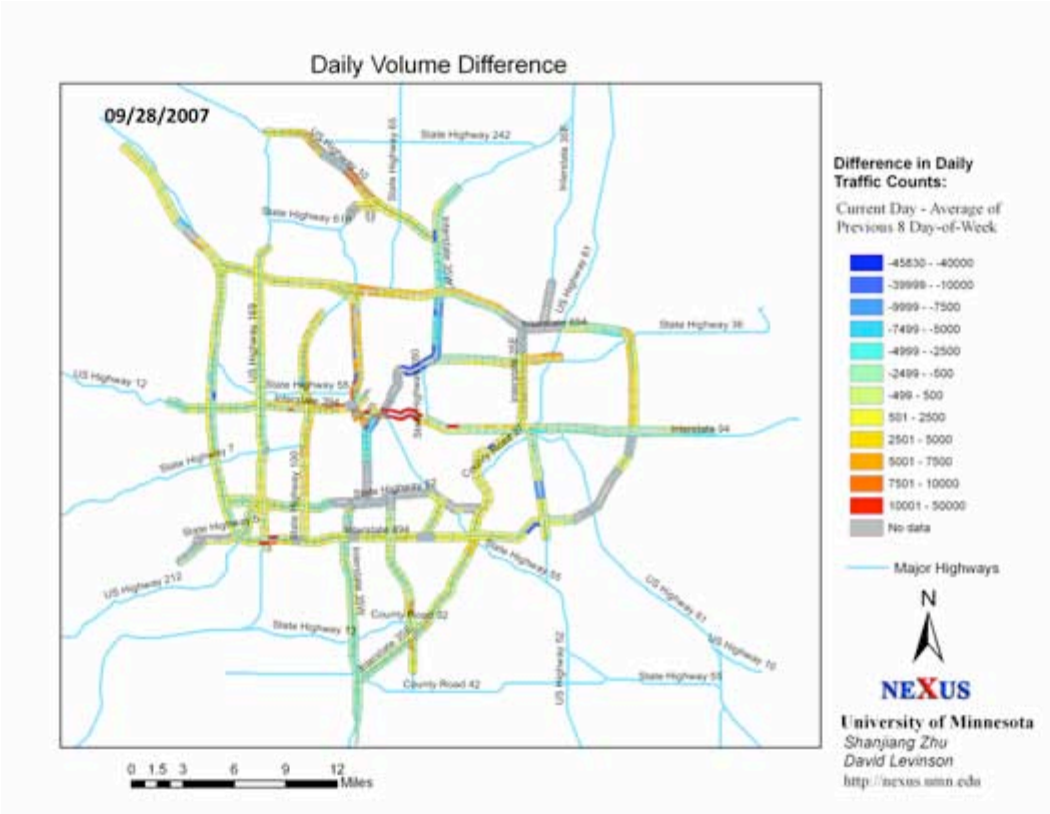
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12
Miles


Daily Volume Difference
09/28/2007
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-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
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Major Highways
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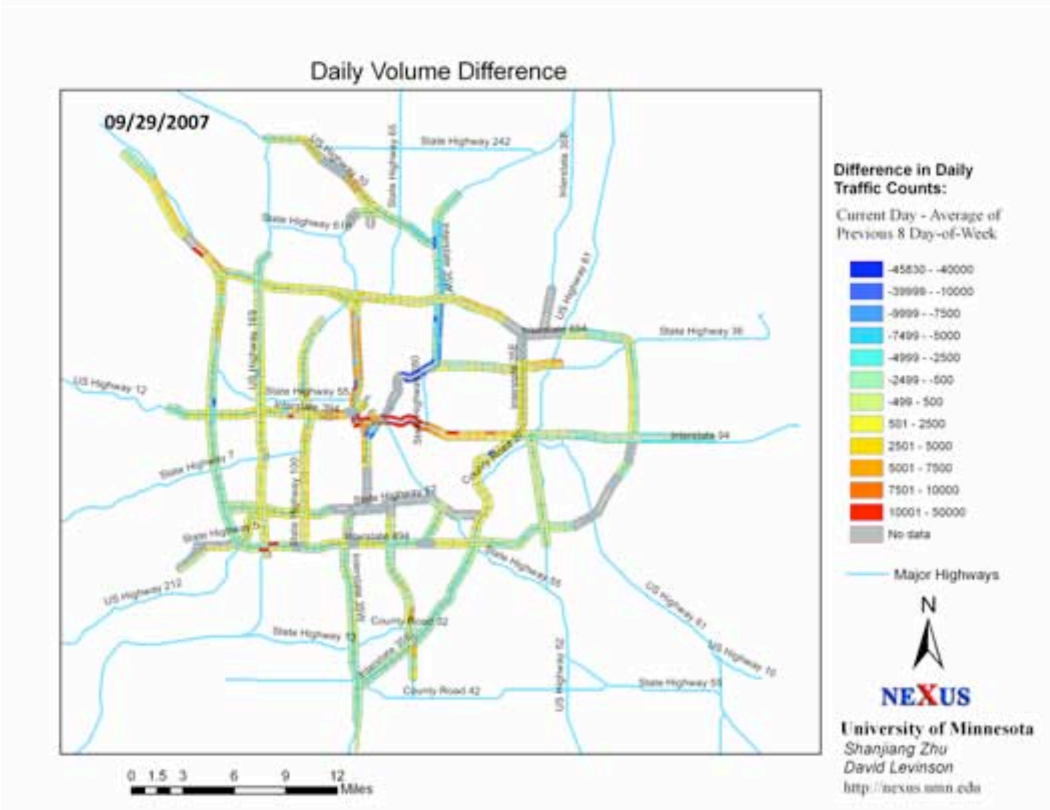
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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-2499 - -500
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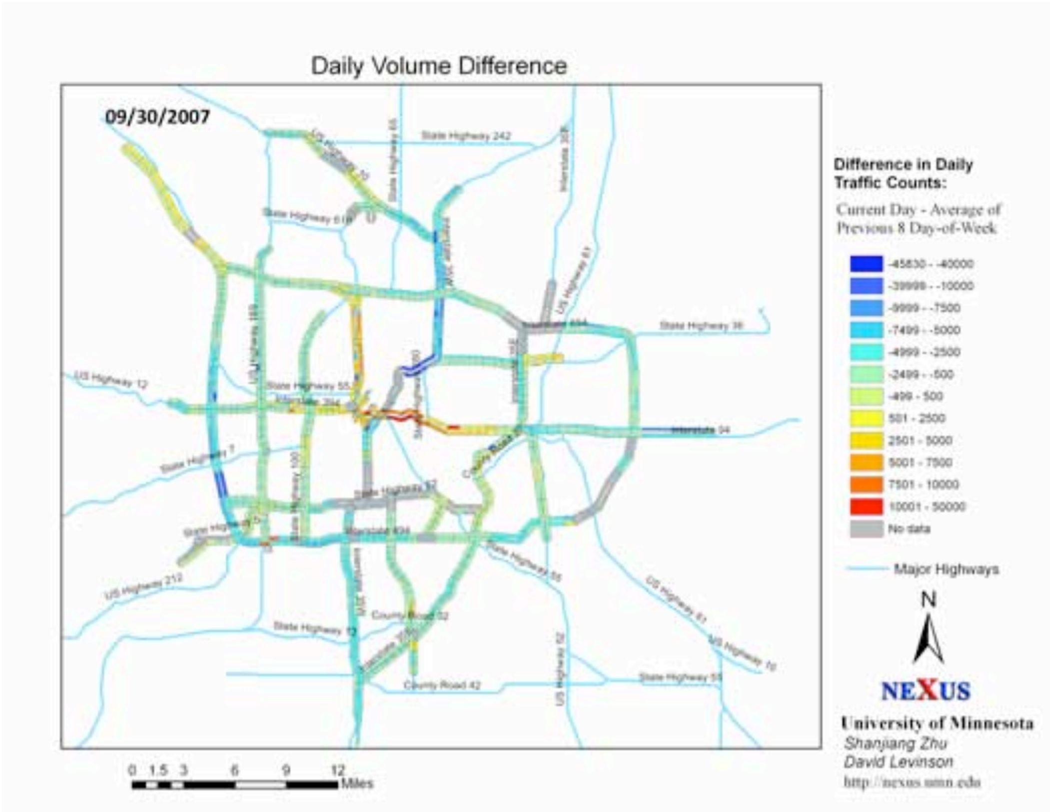
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12 Miles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09/30/2007
Difference in Daily Traffic Counts:
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-2499 - -500
-499 - 500
501 - 2500
2501 - 5000
5001 - 7500
7501 - 10000
10001 - 50000
No data
Major Highways
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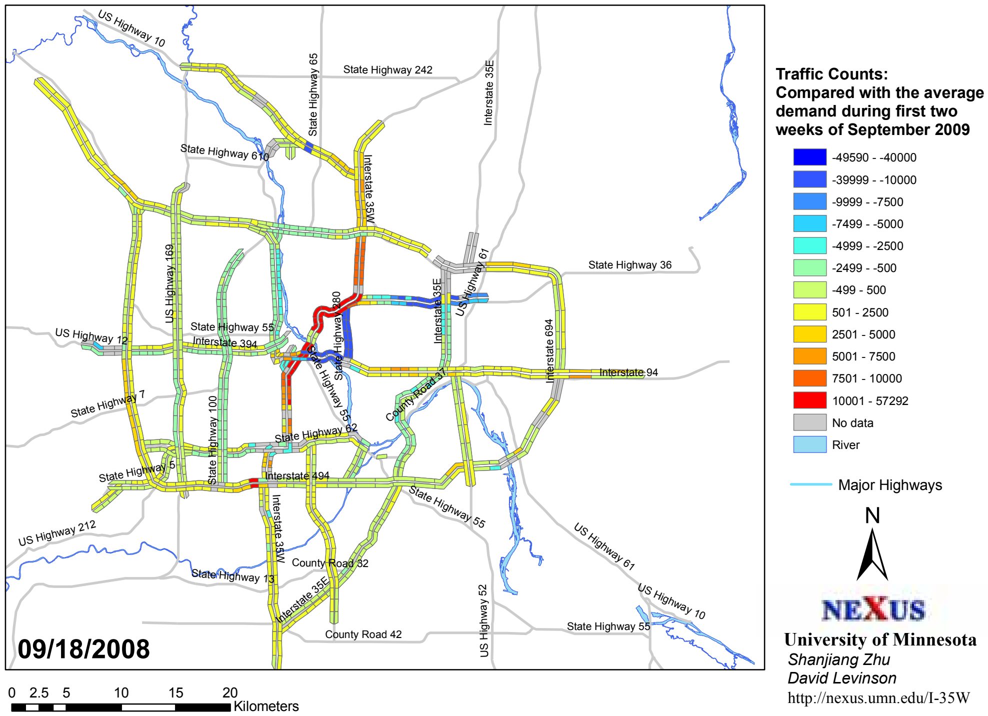
NEXUS
University of Minnesota
Shanjiang Zhu
David Levinson
http://nexus.umn.edu
0 1.5 3 6 9 12
Miles

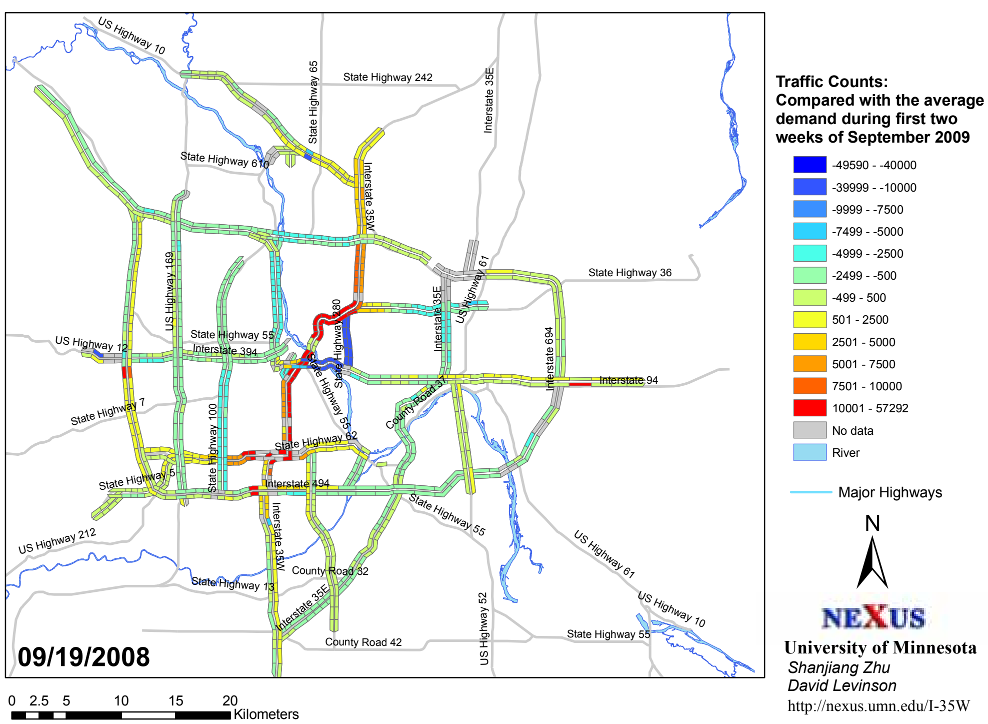
Appendix C

Changes in daily freeway traffic counts after the New I-35W Bridge reopened when compared with the average demand level on the same day during the first two weeks of September 2008.

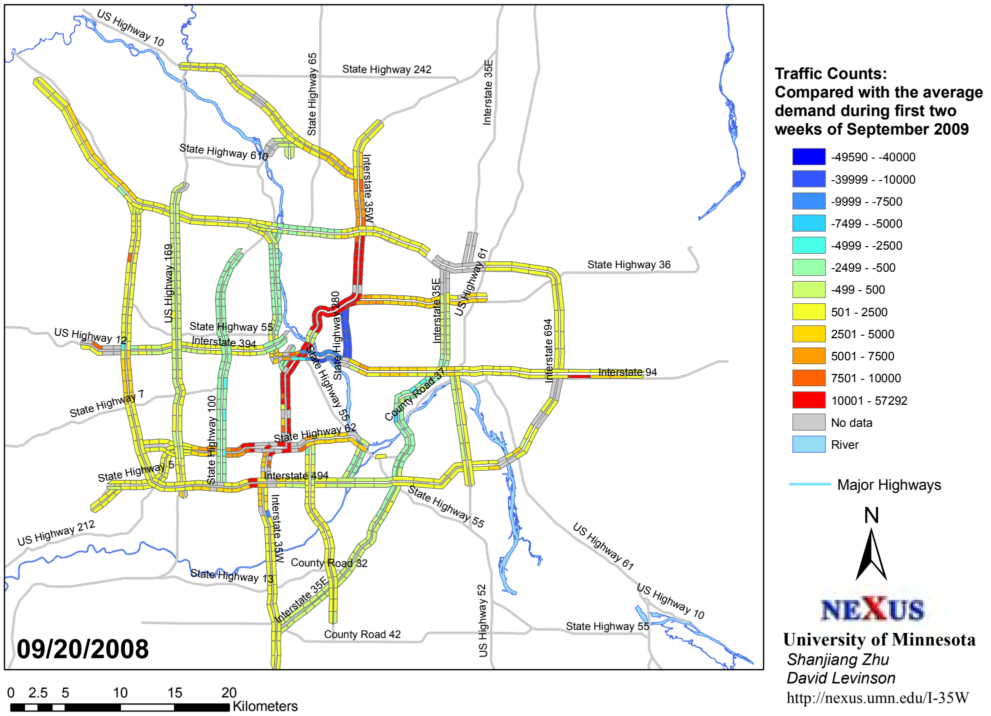
Daily Traffic Volume Variation after the I-35W Bridge Reopening



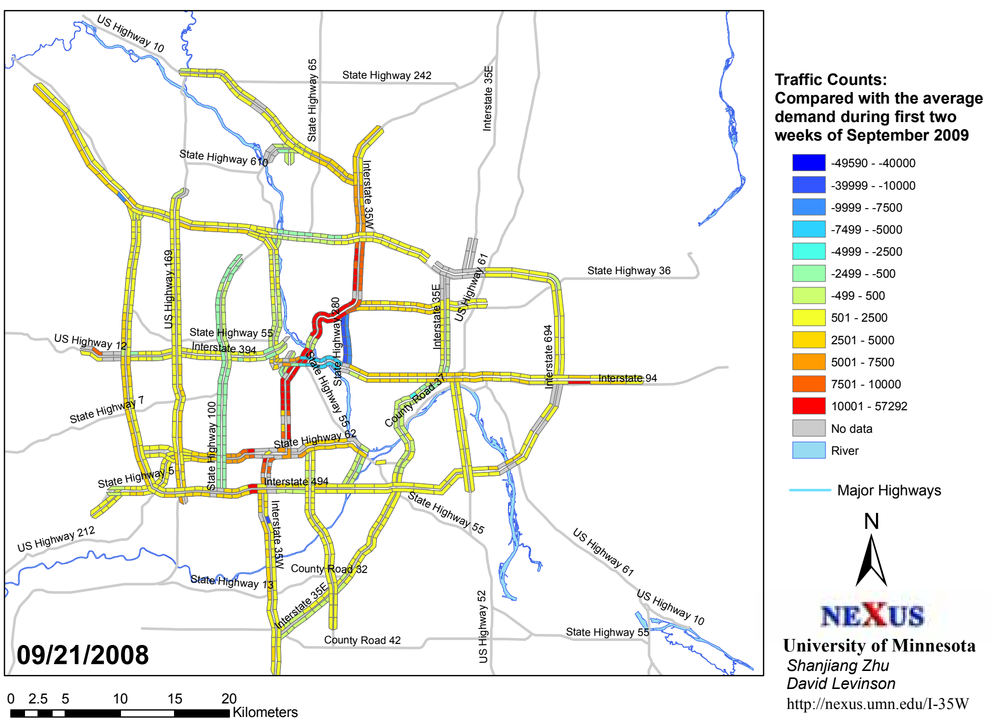
Daily Traffic Volume Variation after the I-35W Bridge Reopening



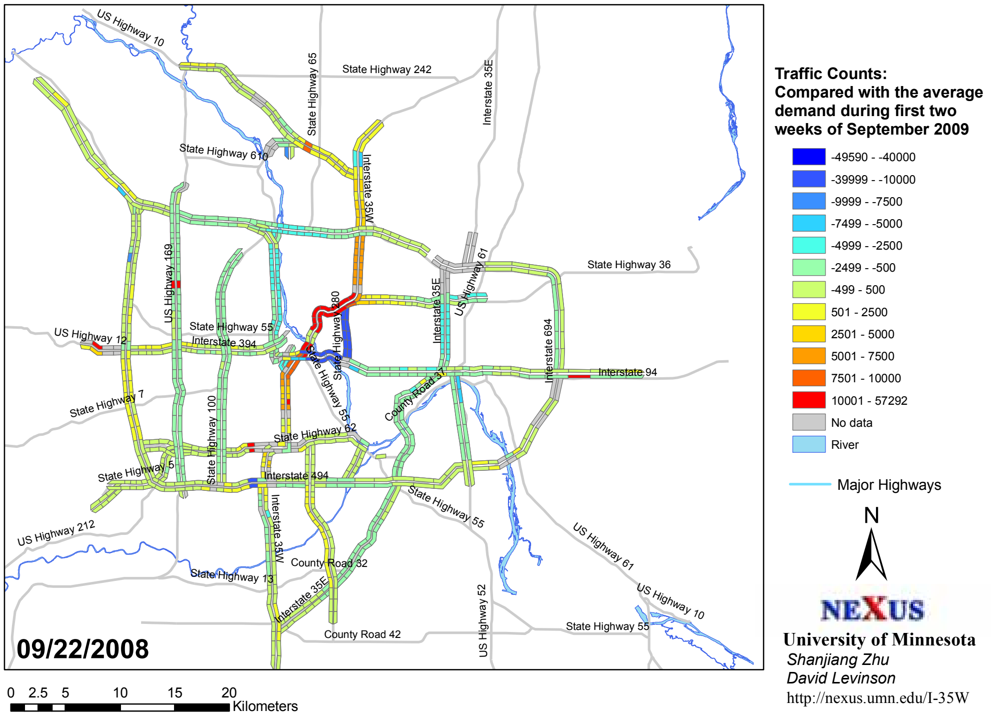
Daily Traffic Volume Variation after the I-35W Bridge Reopening



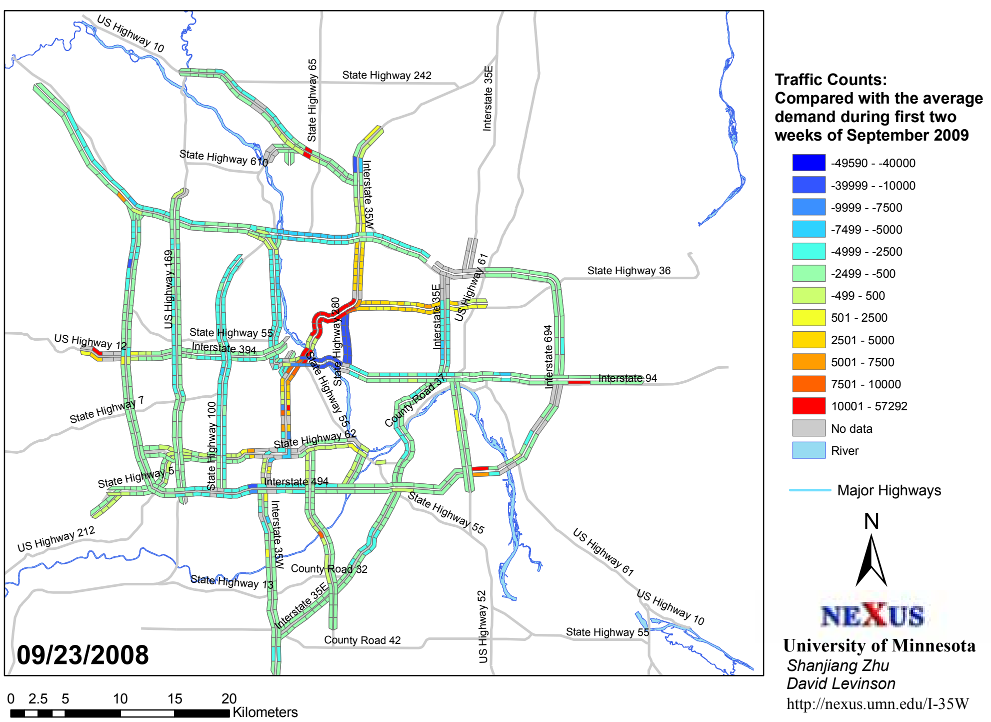
Daily Traffic Volume Variation after the I-35W Bridge Reopening



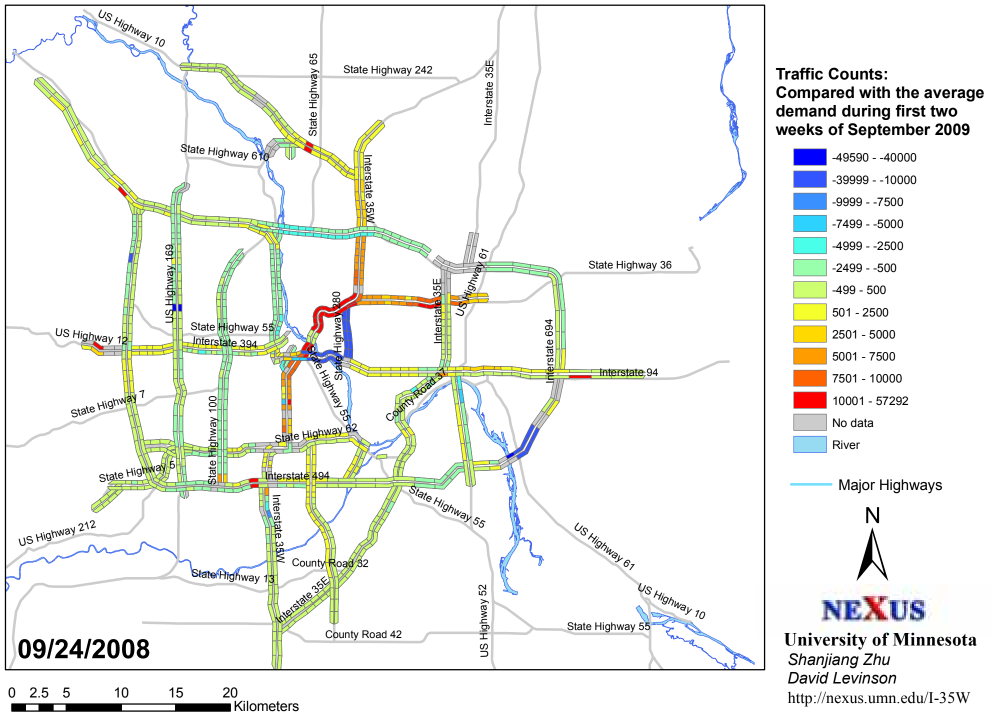
Daily Traffic Volume Variation after the I-35W Bridge Reopening



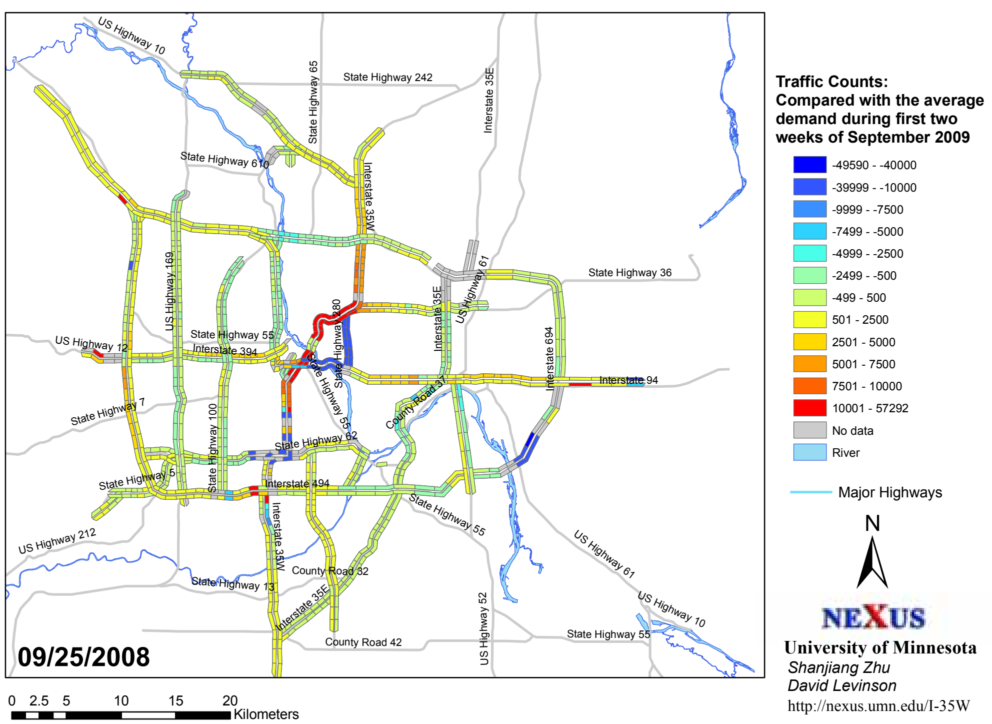
Daily Traffic Volume Variation after the I-35W Bridge Reopening



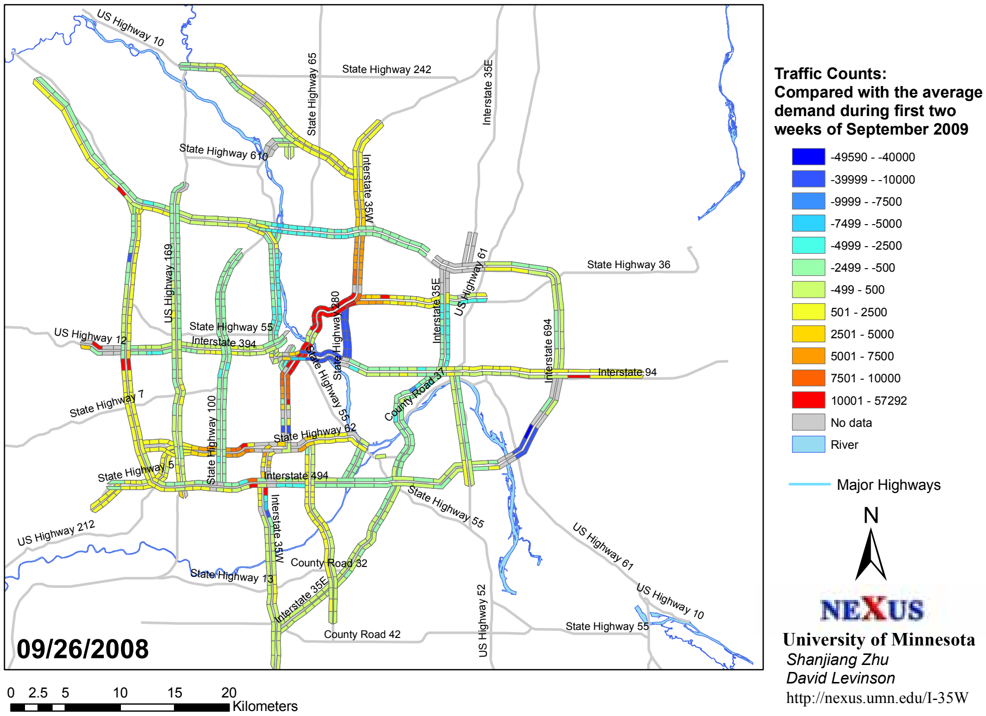
Daily Traffic Volume Variation after the I-35W Bridge Reopening



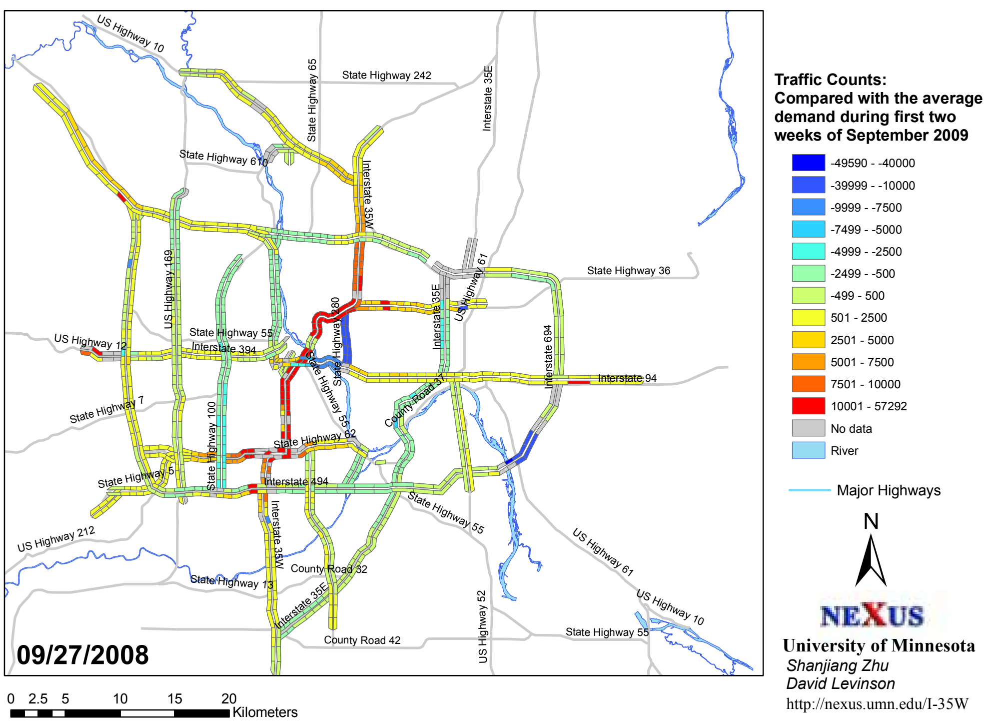
Daily Traffic Volume Variation after the I-35W Bridge Reopening



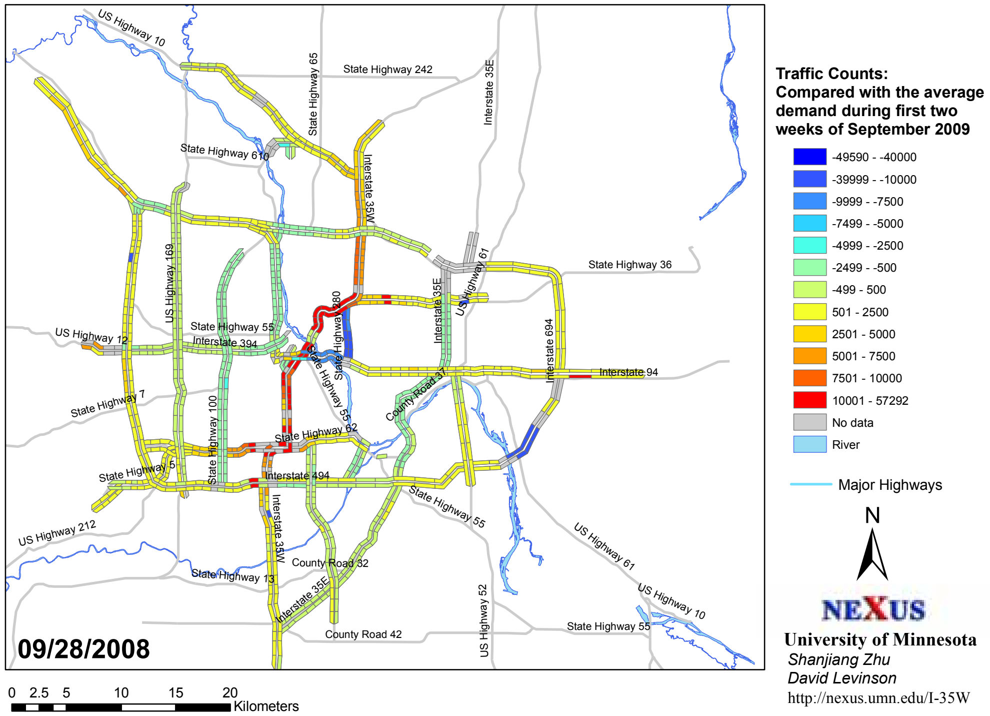
Daily Traffic Volume Variation after the I-35W Bridge Reopening



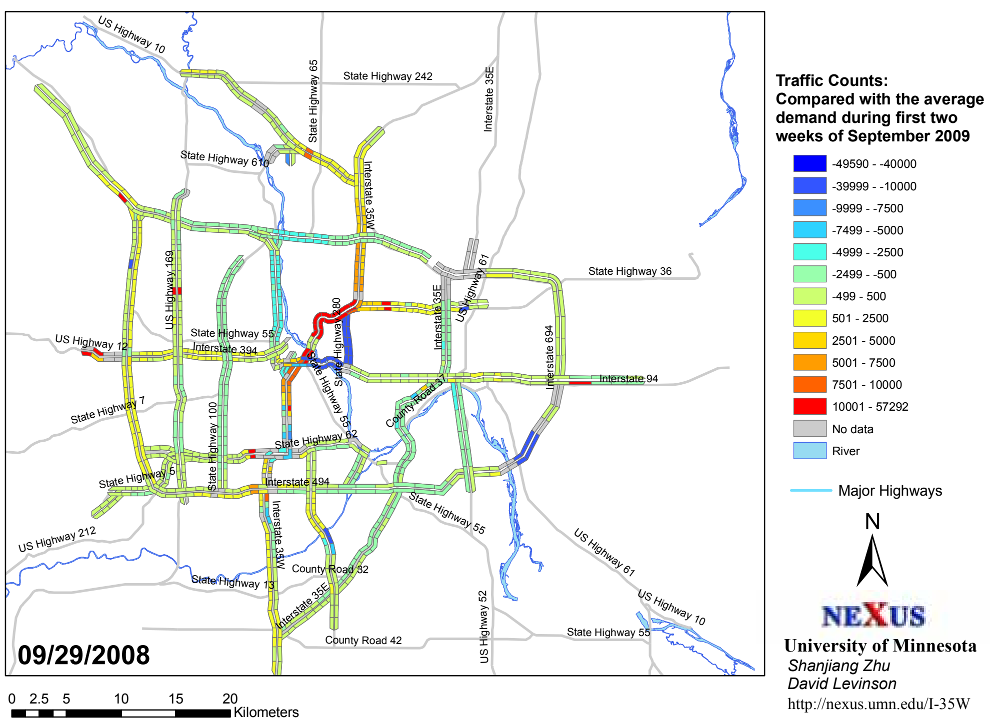
Daily Traffic Volume Variation after the I-35W Bridge Reopening



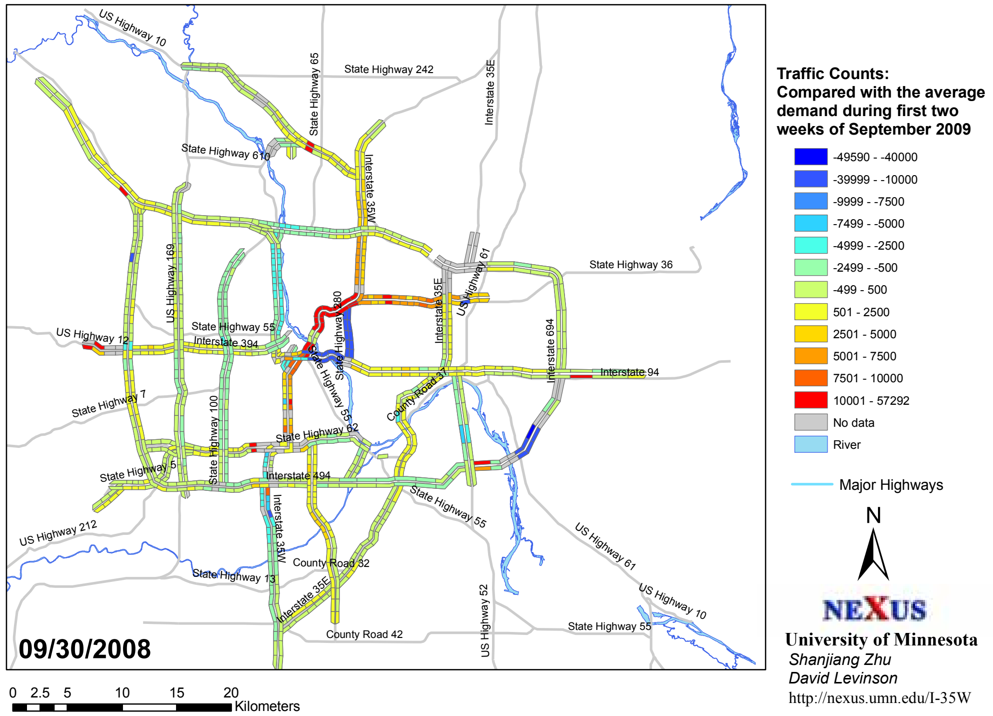
Daily Traffic Volume Variation after the I-35W Bridge Reopening



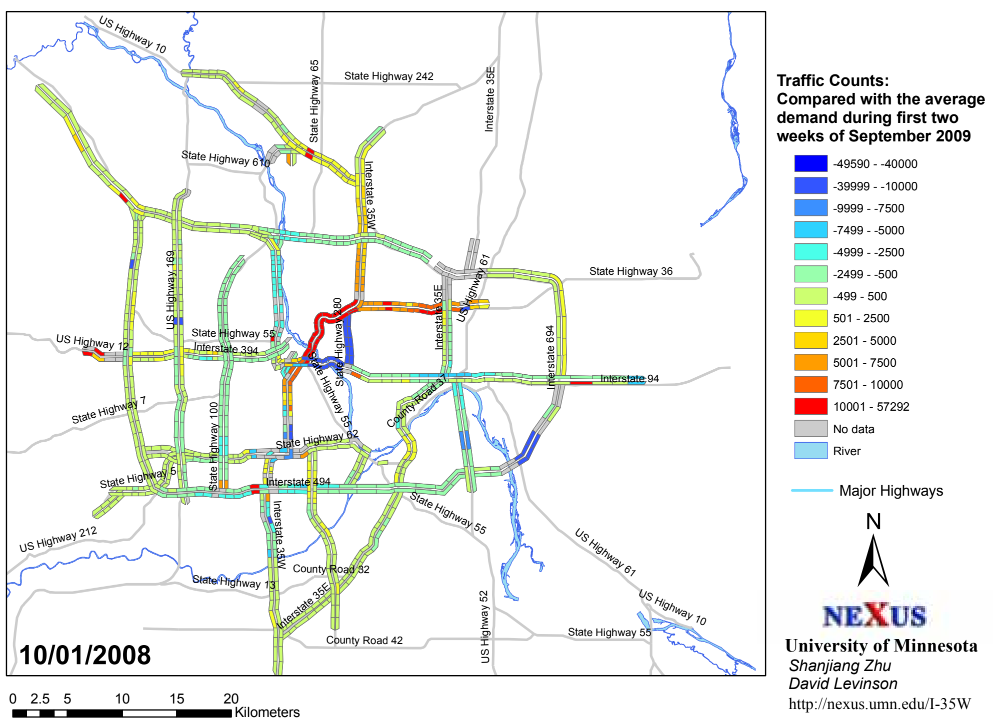
Daily Traffic Volume Variation after the I-35W Bridge Reopening



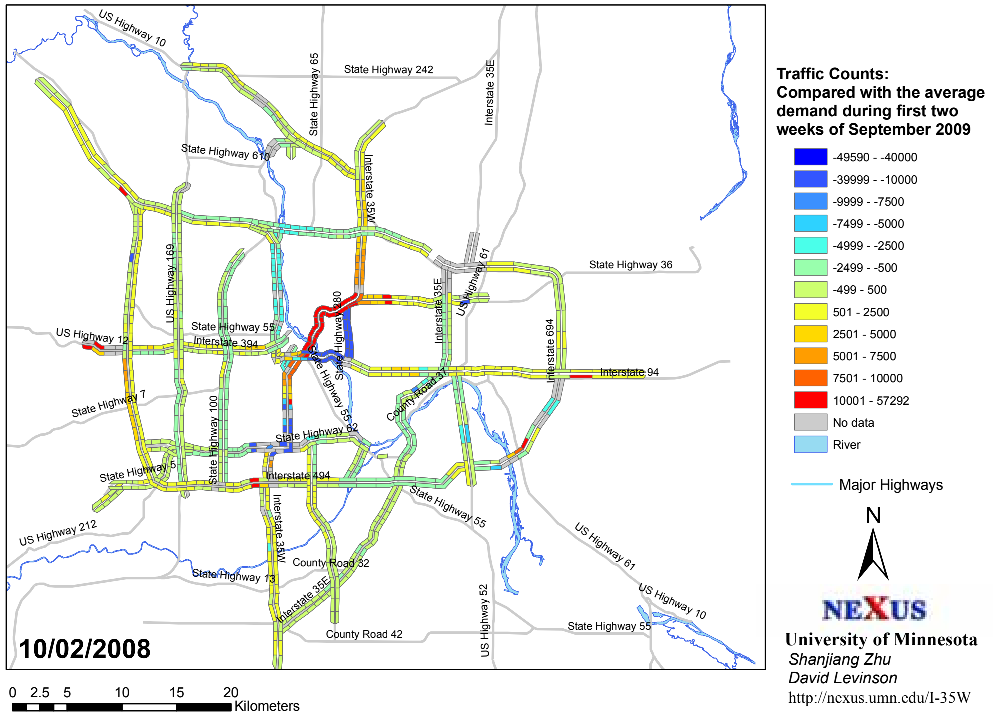
Daily Traffic Volume Variation after the I-35W Bridge Reopening



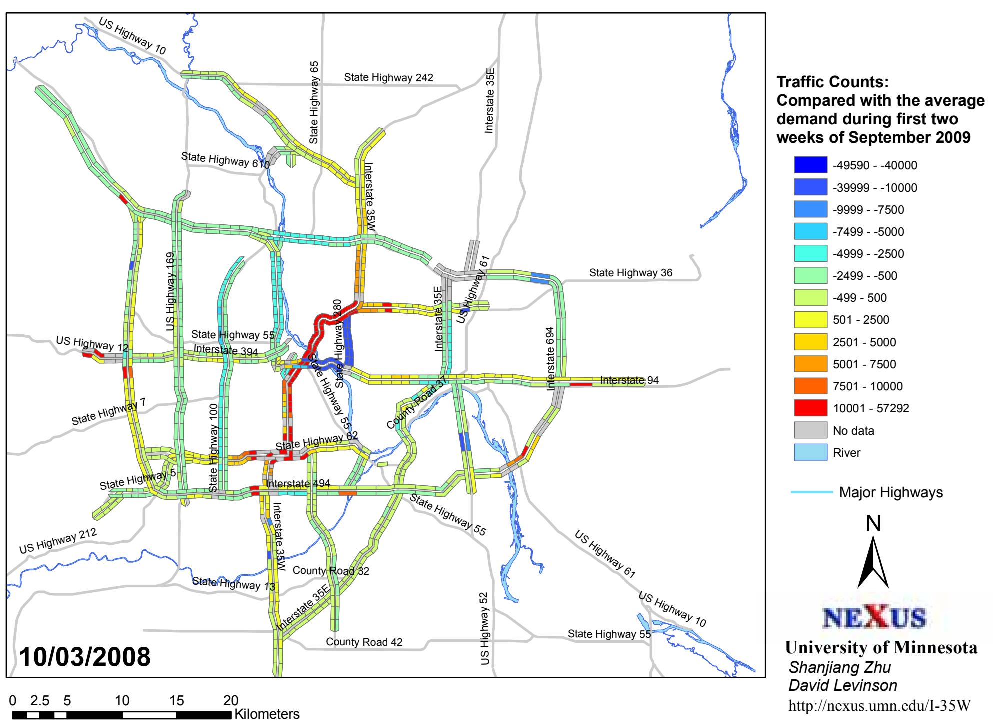
Daily Traffic Volume Variation after the I-35W Bridge Reopening



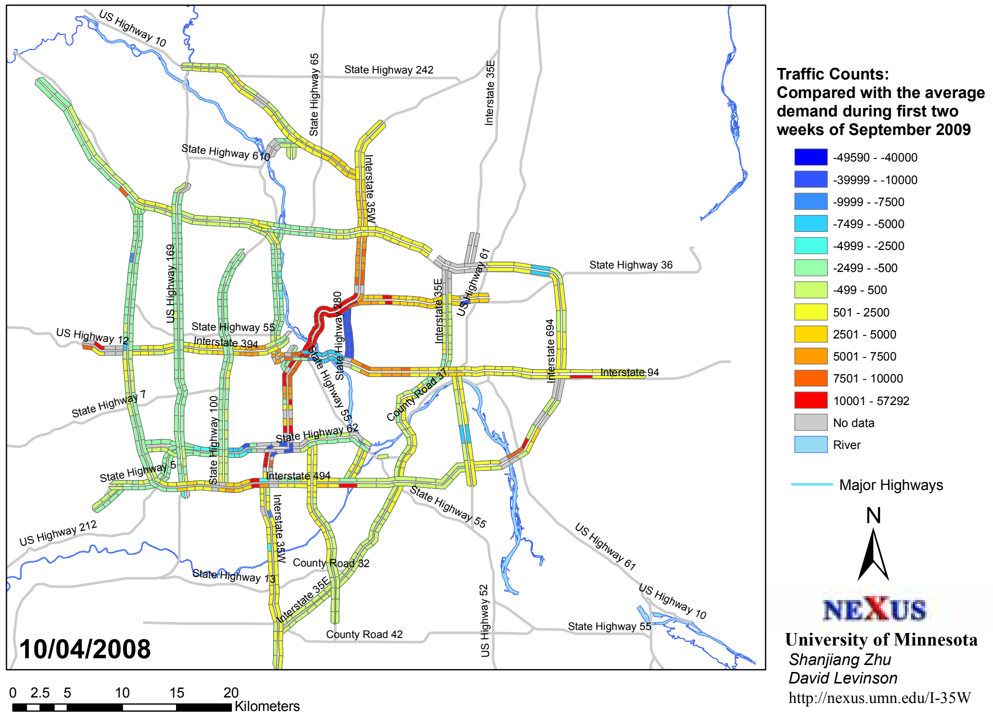
Daily Traffic Volume Variation after the I-35W Bridge Reopening



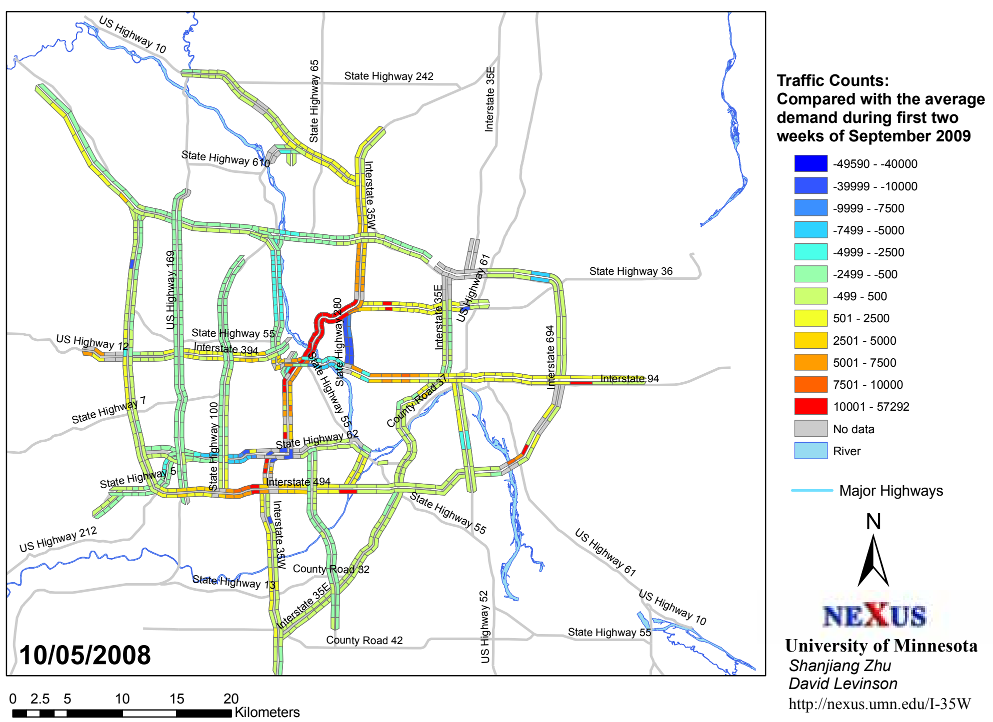
Daily Traffic Volume Variation after the I-35W Bridge Reopening



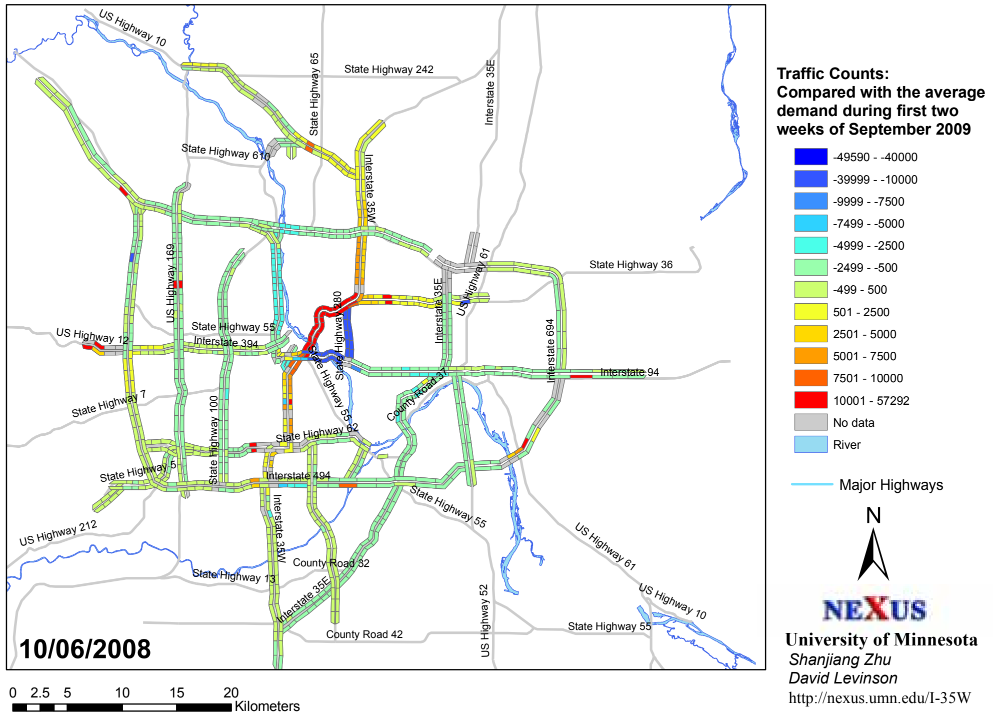
Daily Traffic Volume Variation after the I-35W Bridge Reopening



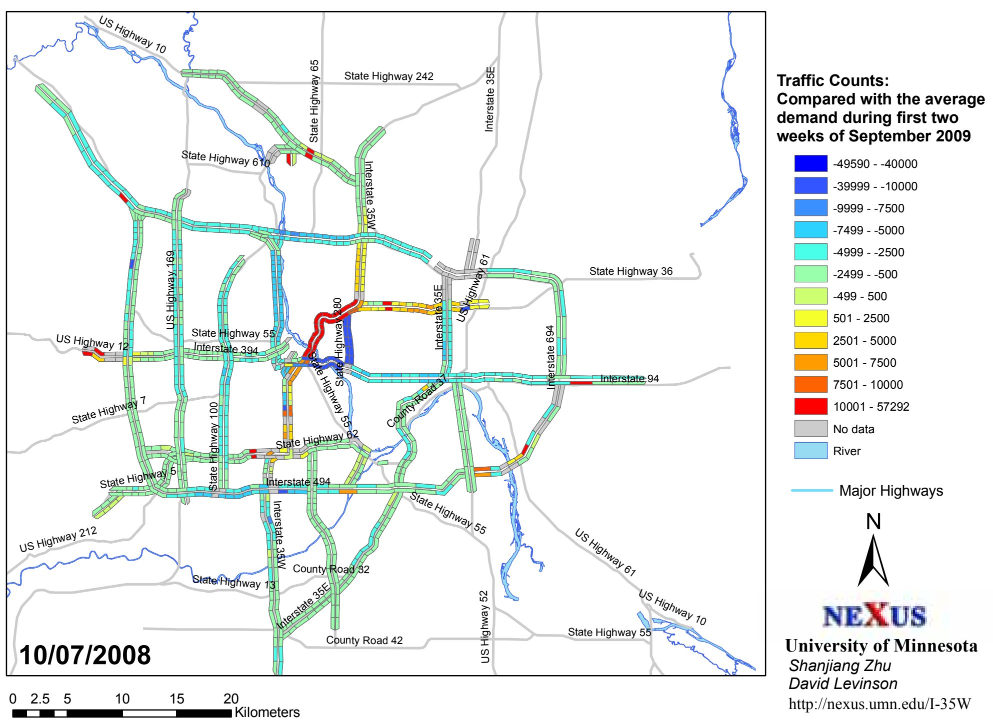
Daily Traffic Volume Variation after the I-35W Bridge Reopening



Daily Traffic Volume Variation after the I-35W Bridge Reopening



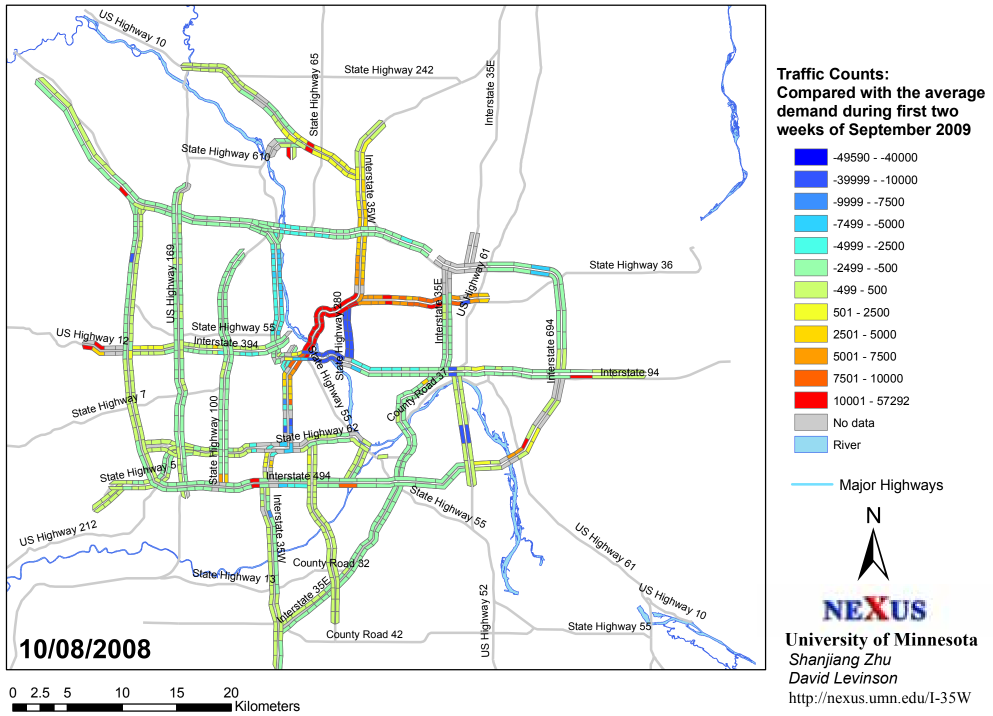
Daily Traffic Volume Variation after the I-35W Bridge Reopening



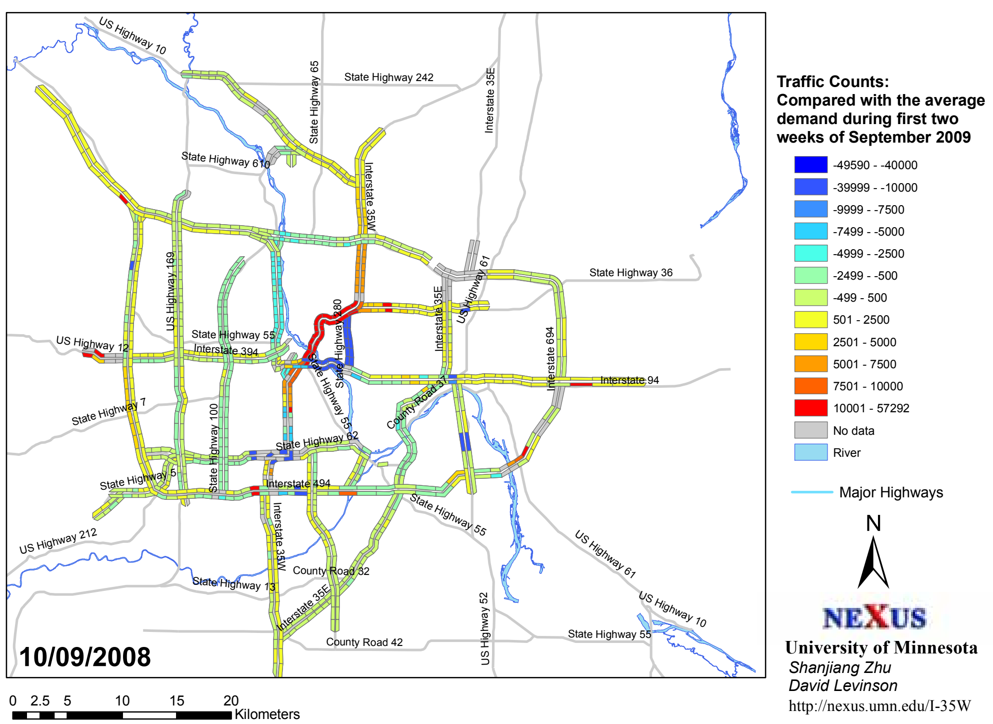
Appendix D

Changes in daily freeway traffic counts after the fourth lane on I-94 Bridge was converted back to bus-only shoulder lane when compared with the average demand level on the same day during the first two weeks of September 2008.

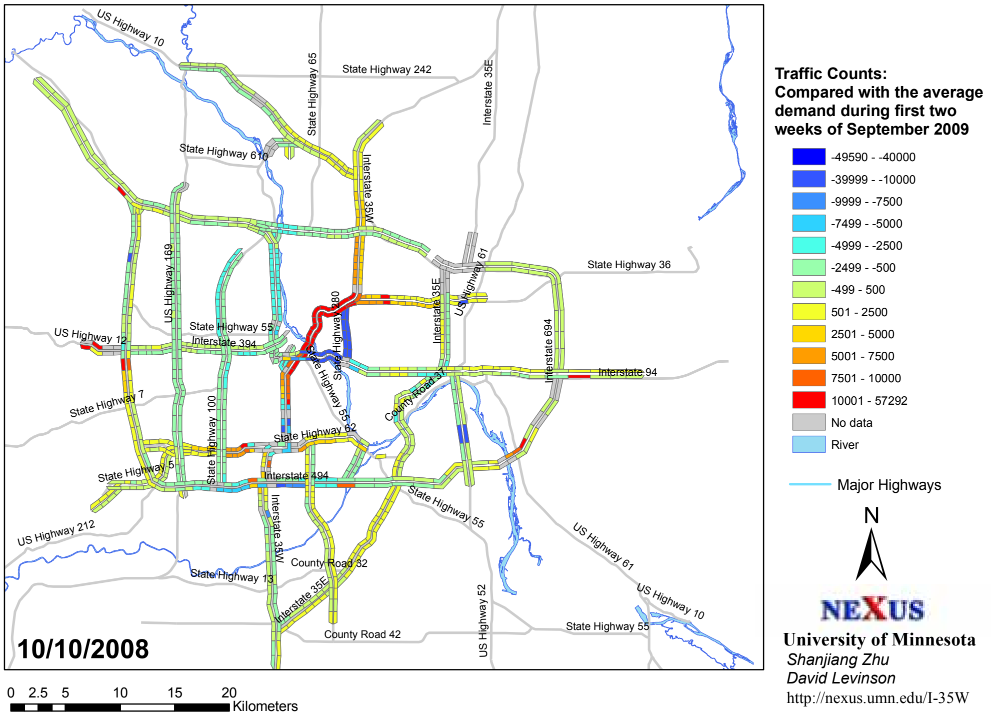
Daily Traffic Volume Variation after the I-35W Bridge Reopening



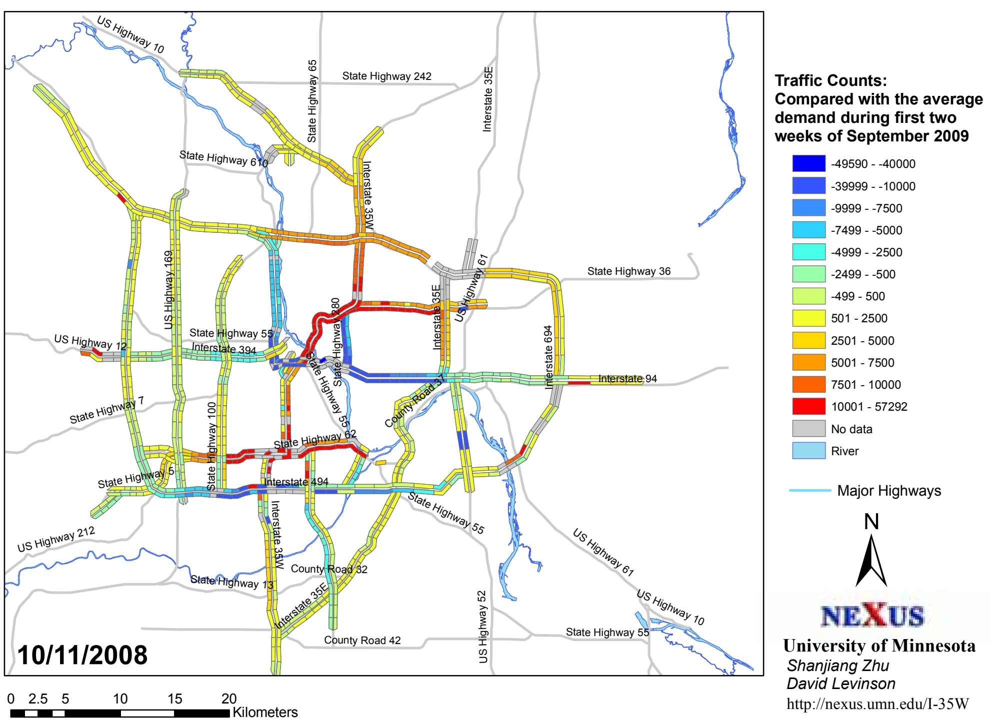
Daily Traffic Volume Variation after the I-35W Bridge Reopening



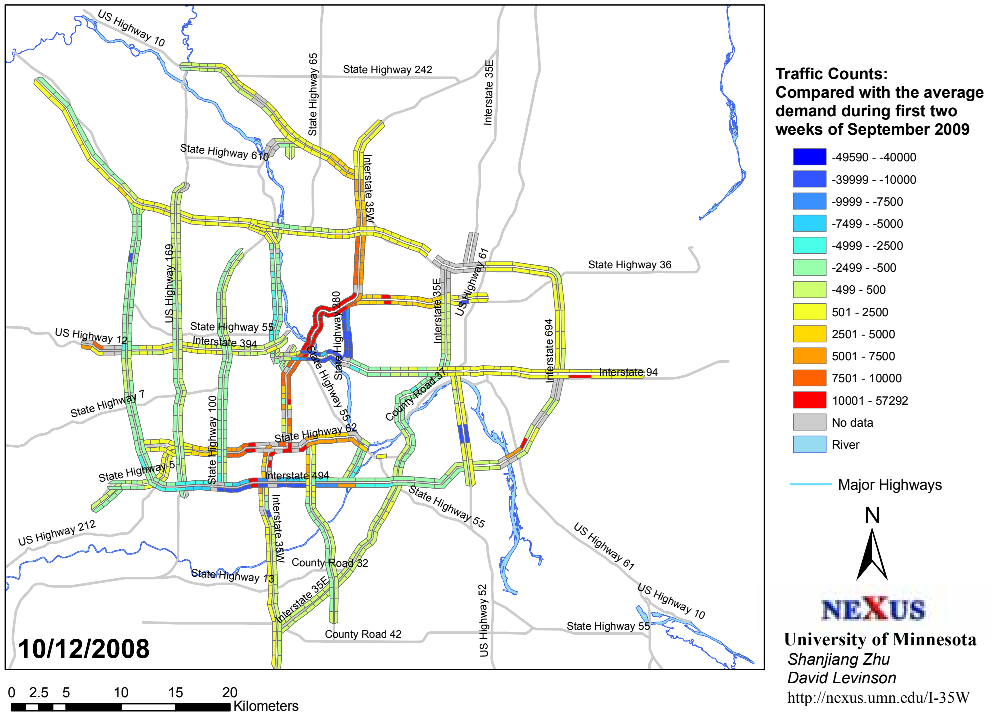
Daily Traffic Volume Variation after the I-35W Bridge Reopening



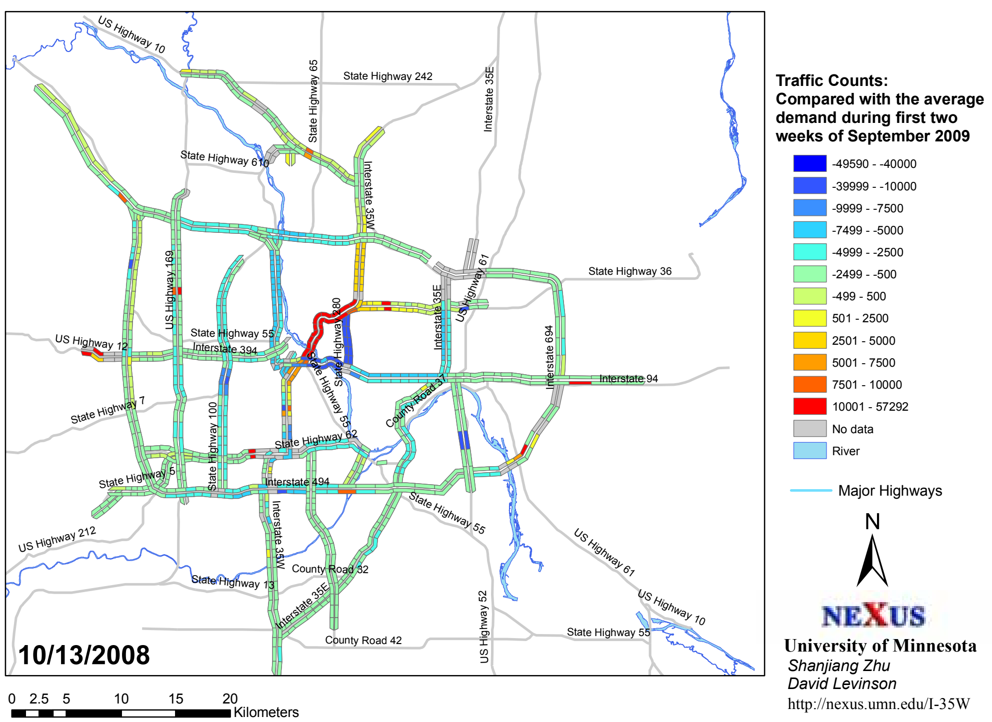
Daily Traffic Volume Variation after the I-35W Bridge Reopening



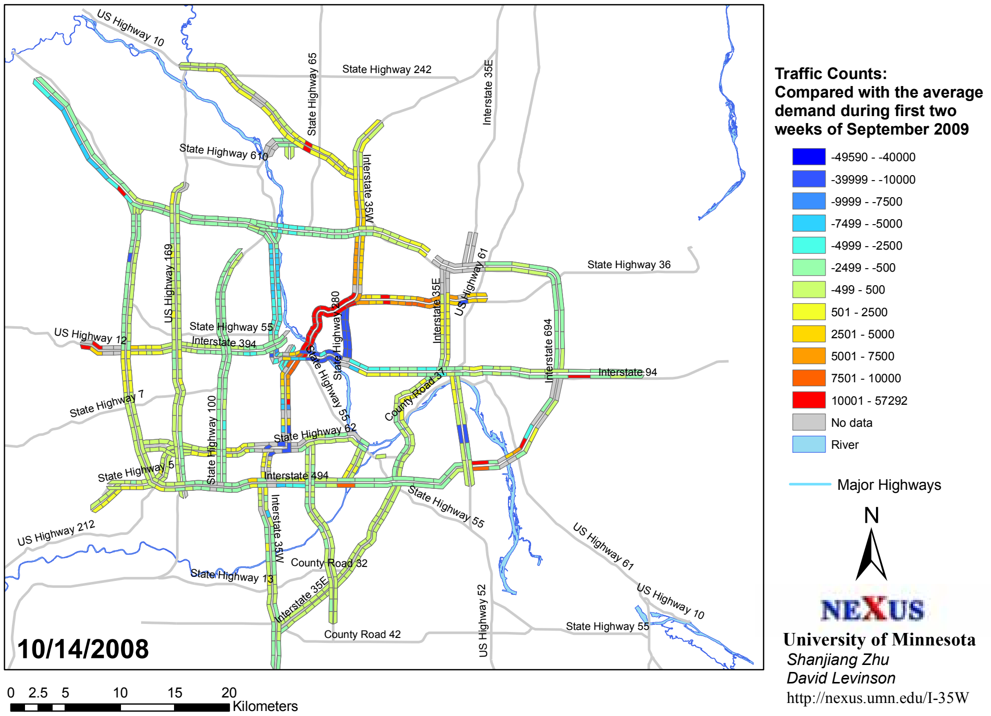
Daily Traffic Volume Variation after the I-35W Bridge Reopening



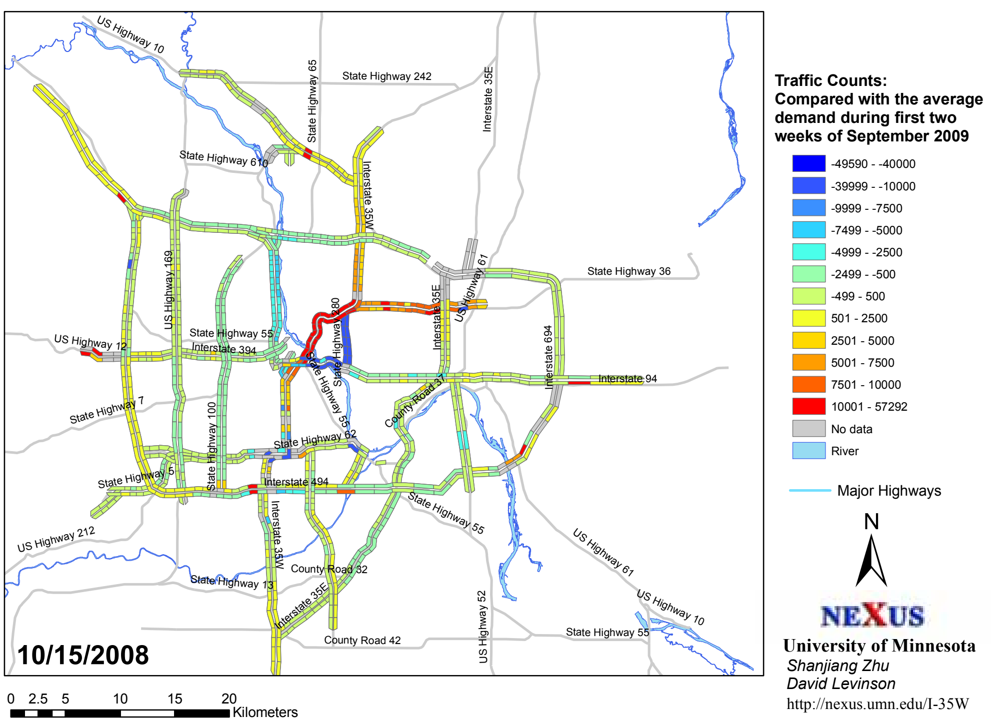
Daily Traffic Volume Variation after the I-35W Bridge Reopening



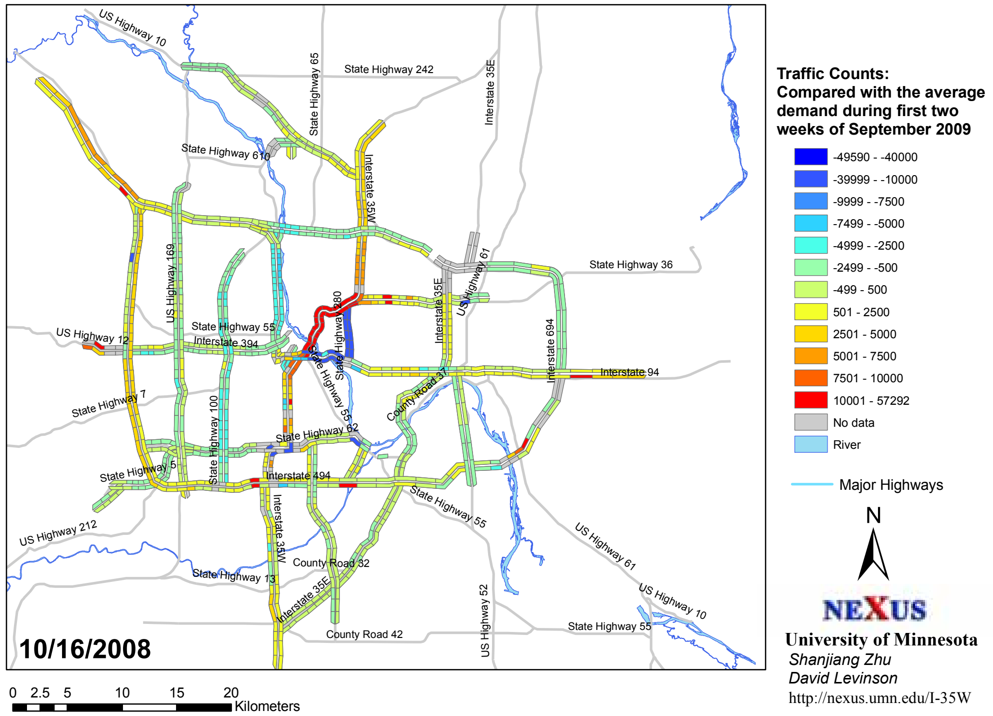
Daily Traffic Volume Variation after the I-35W Bridge Reopening



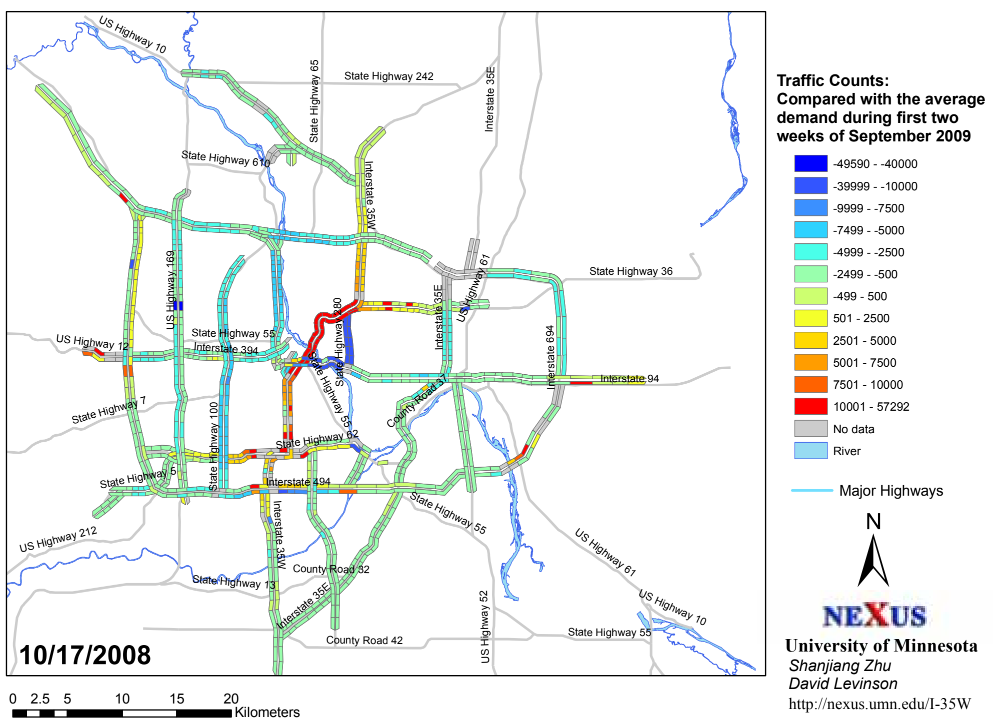
Daily Traffic Volume Variation after the I-35W Bridge Reopening



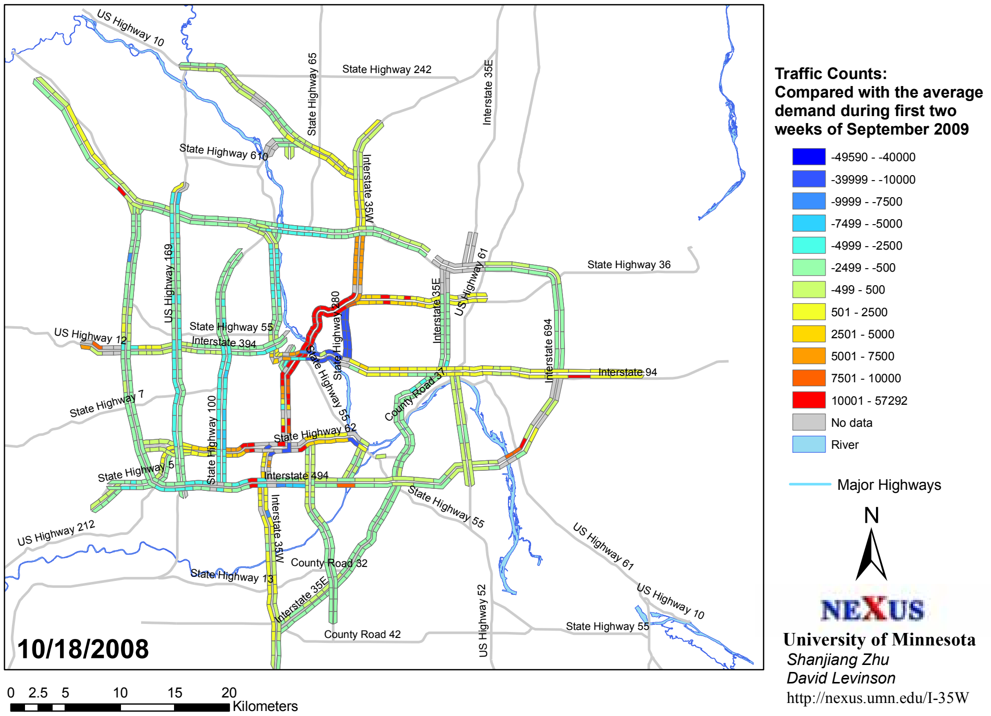
Daily Traffic Volume Variation after the I-35W Bridge Reopening



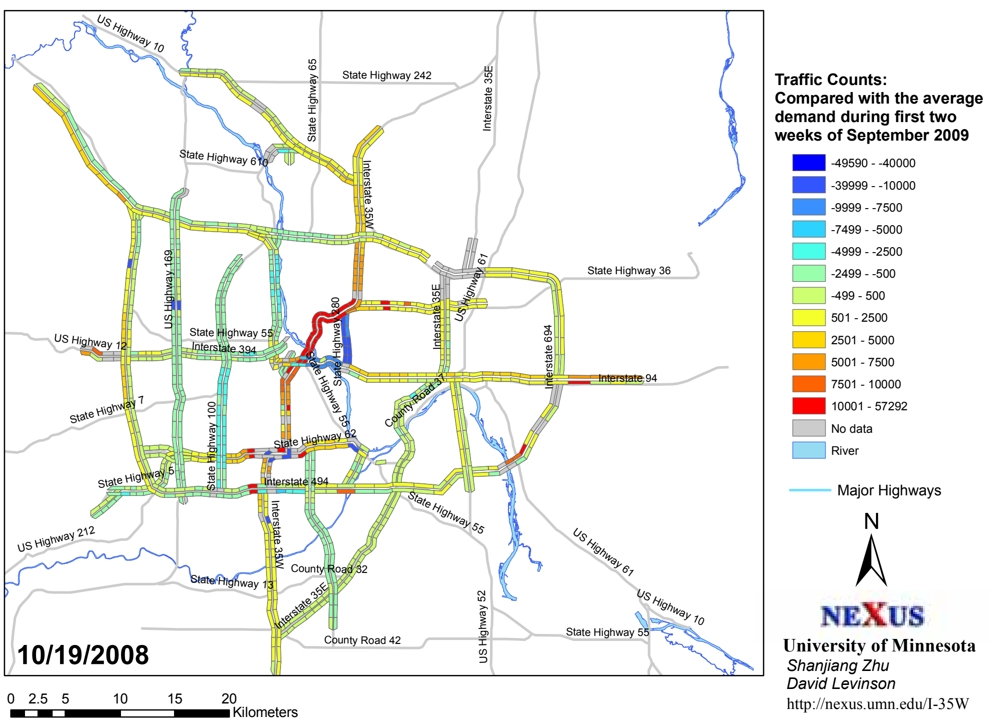
Daily Traffic Volume Variation after the I-35W Bridge Reopening



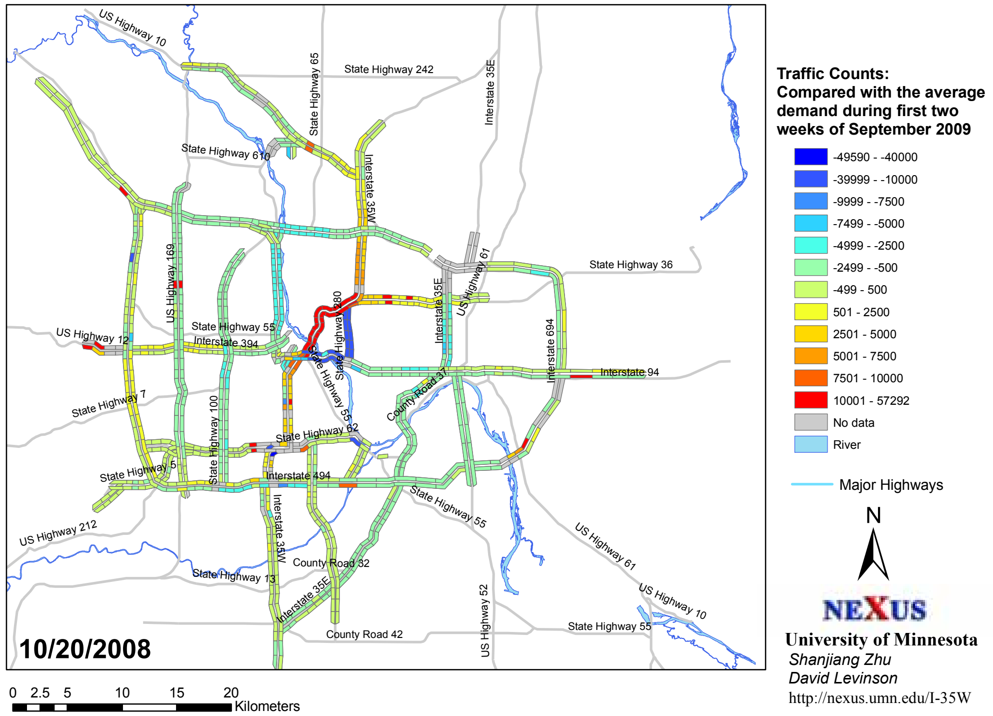
Daily Traffic Volume Variation after the I-35W Bridge Reopening



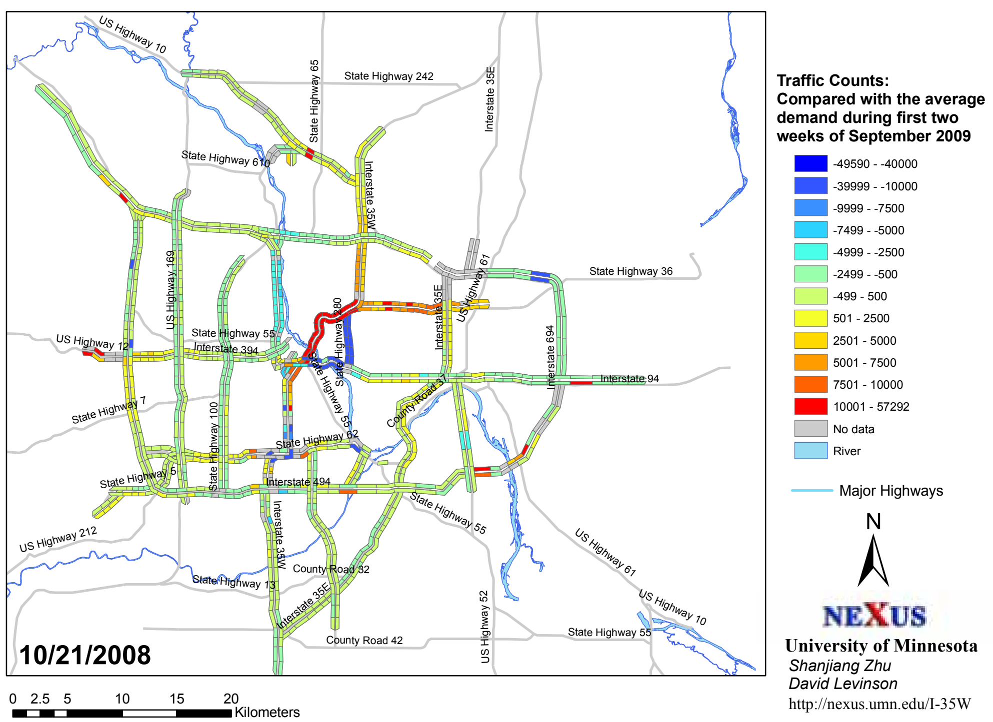
Daily Traffic Volume Variation after the I-35W Bridge Reopening



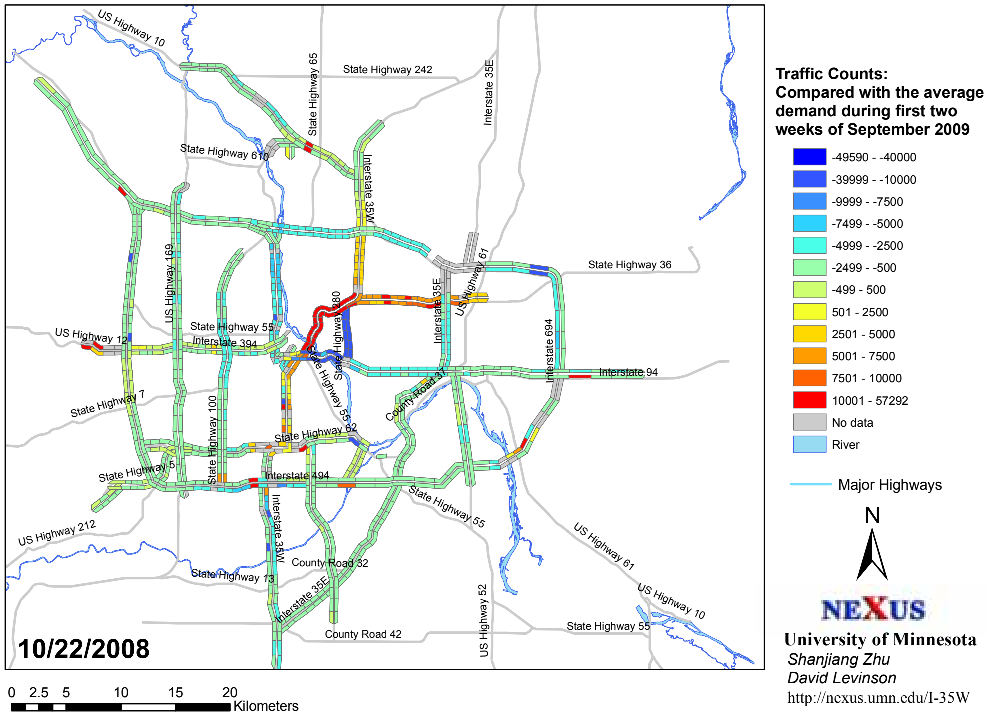
Daily Traffic Volume Variation after the I-35W Bridge Reopening



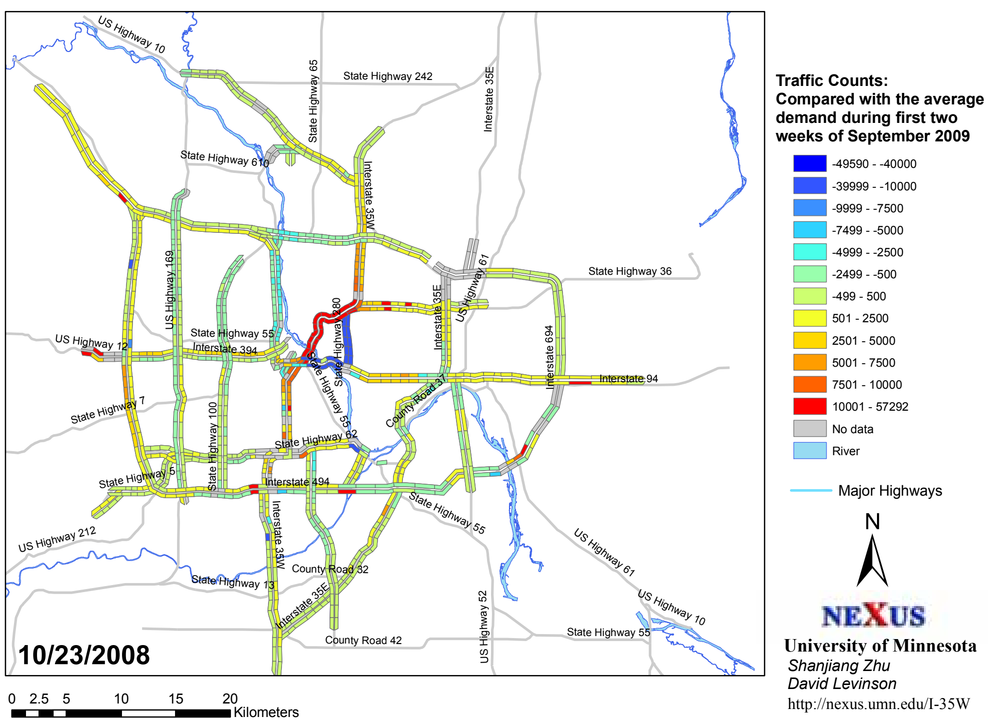
Daily Traffic Volume Variation after the I-35W Bridge Reopening



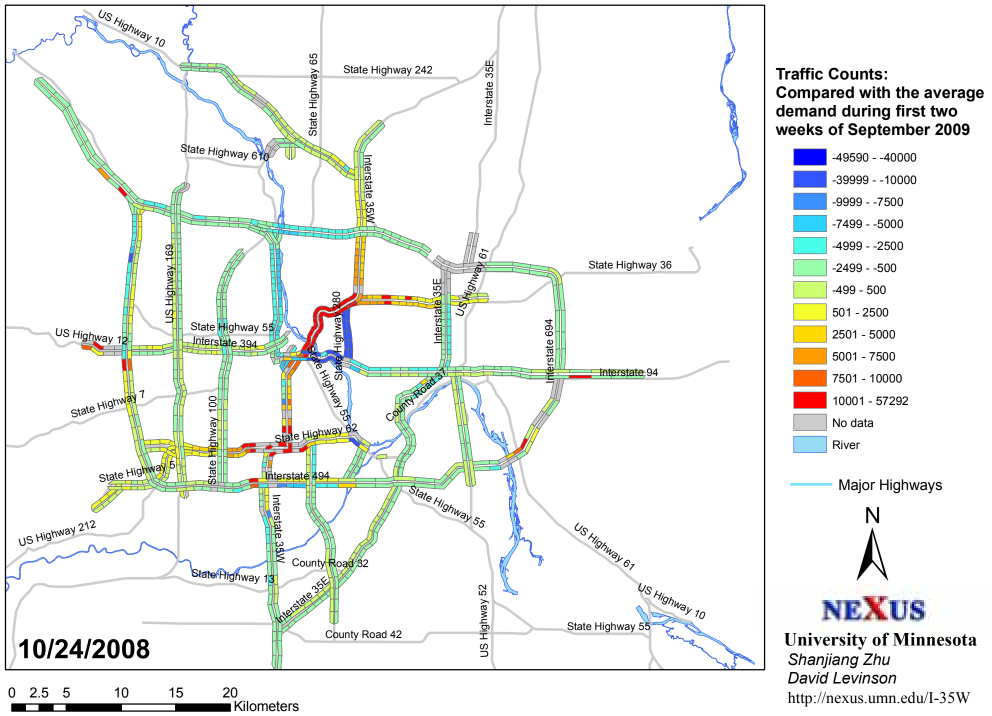
Daily Traffic Volume Variation after the I-35W Bridge Reopening



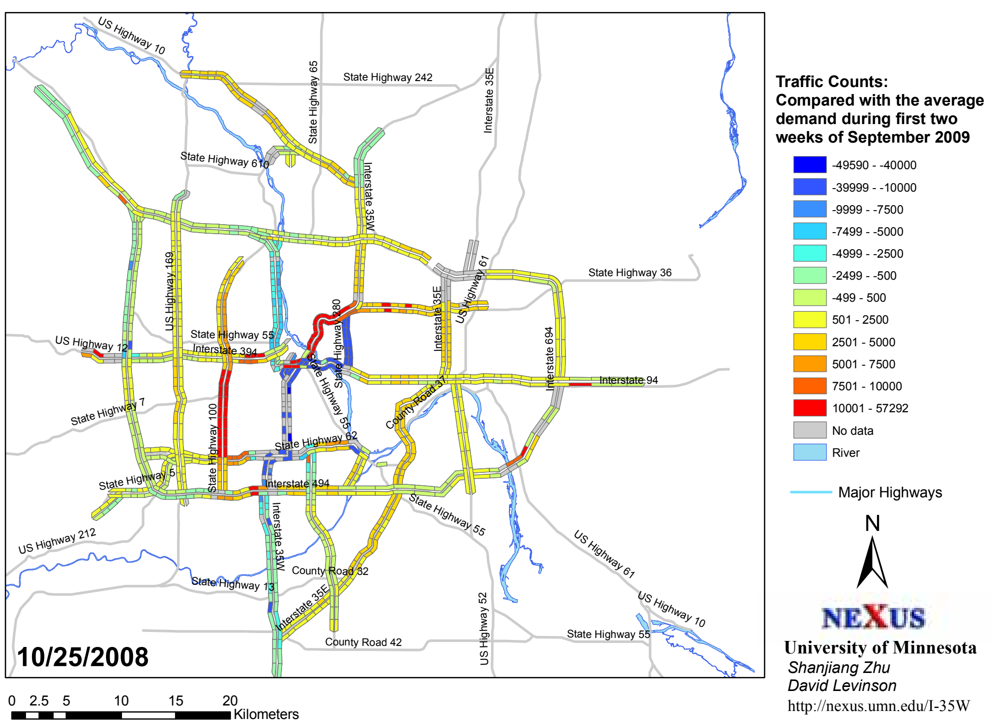
Daily Traffic Volume Variation after the I-35W Bridge Reopening



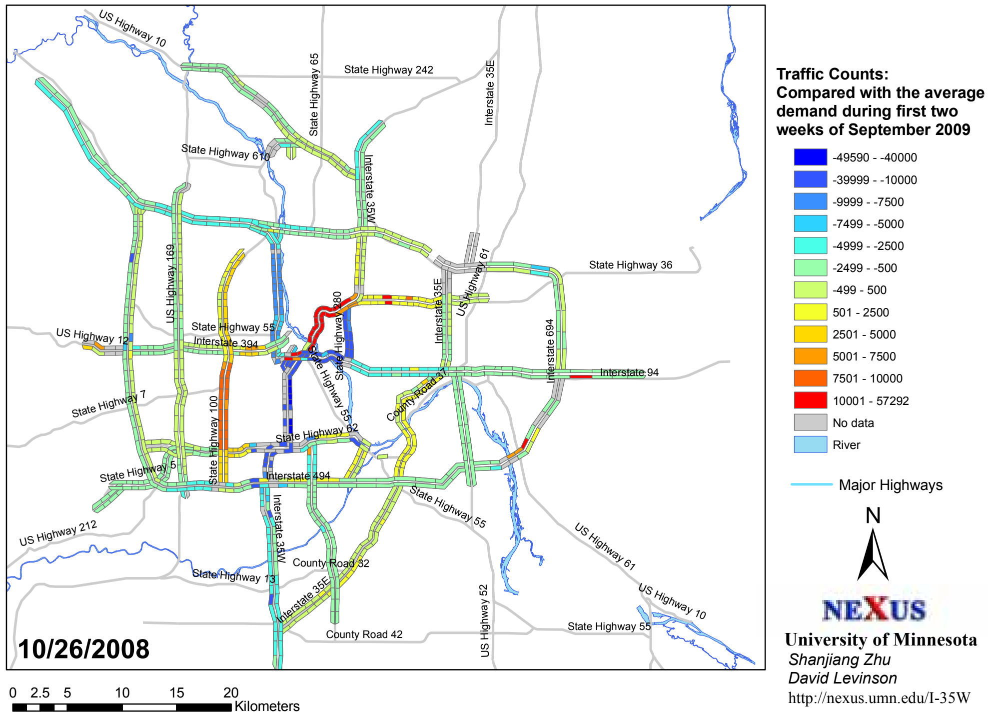
Daily Traffic Volume Variation after the I-35W Bridge Reopening



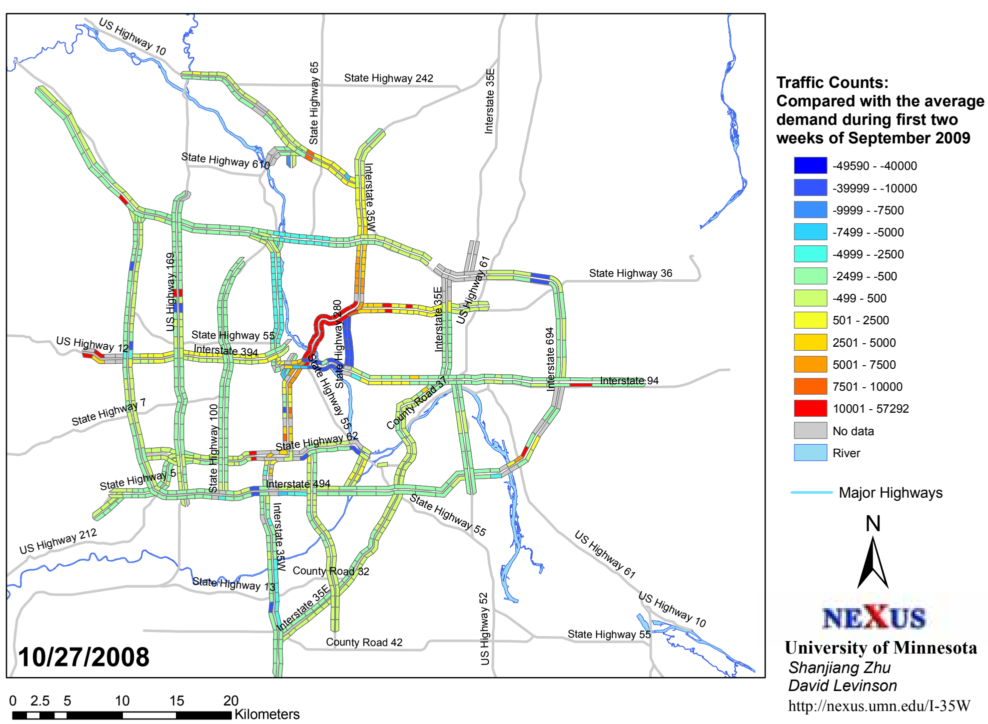
Daily Traffic Volume Variation after the I-35W Bridge Reopening



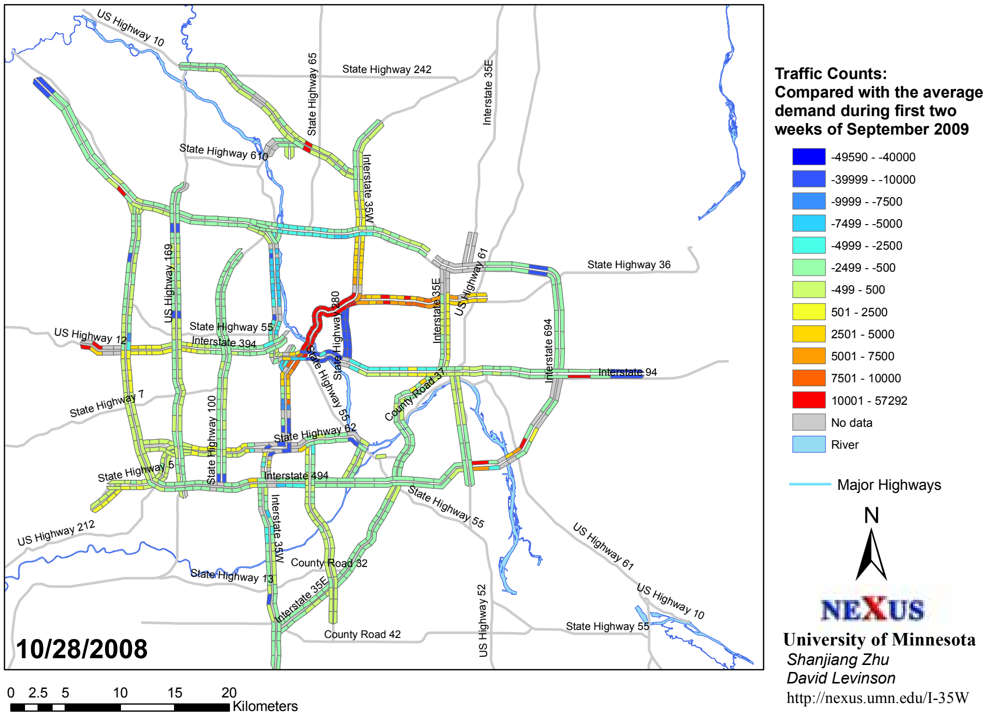
Daily Traffic Volume Variation after the I-35W Bridge Reopening



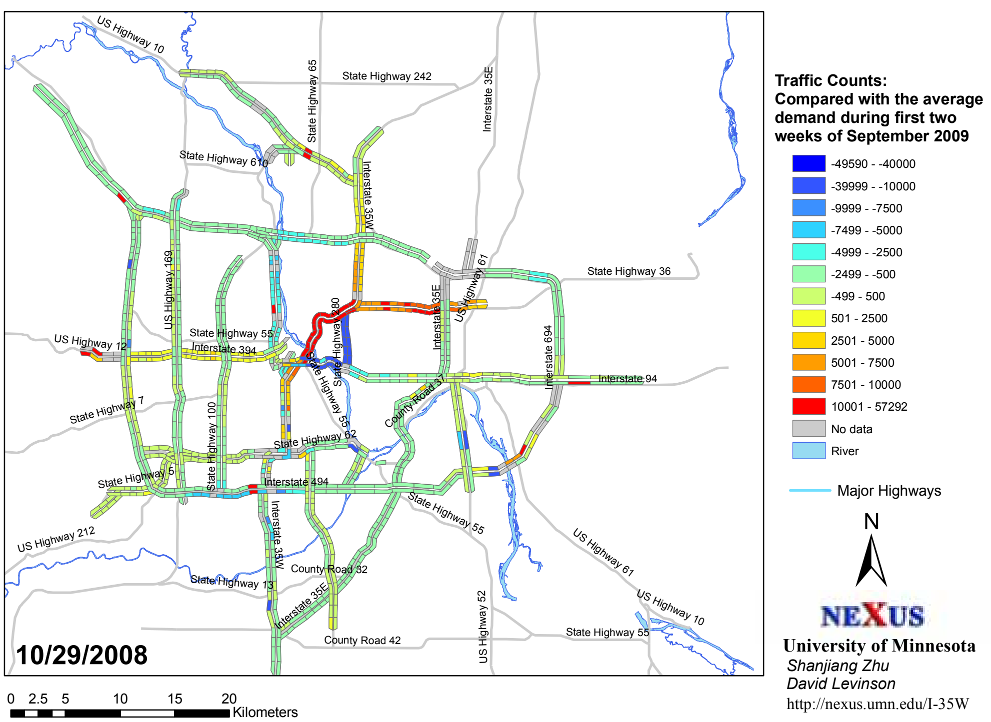
Daily Traffic Volume Variation after the I-35W Bridge Reopening



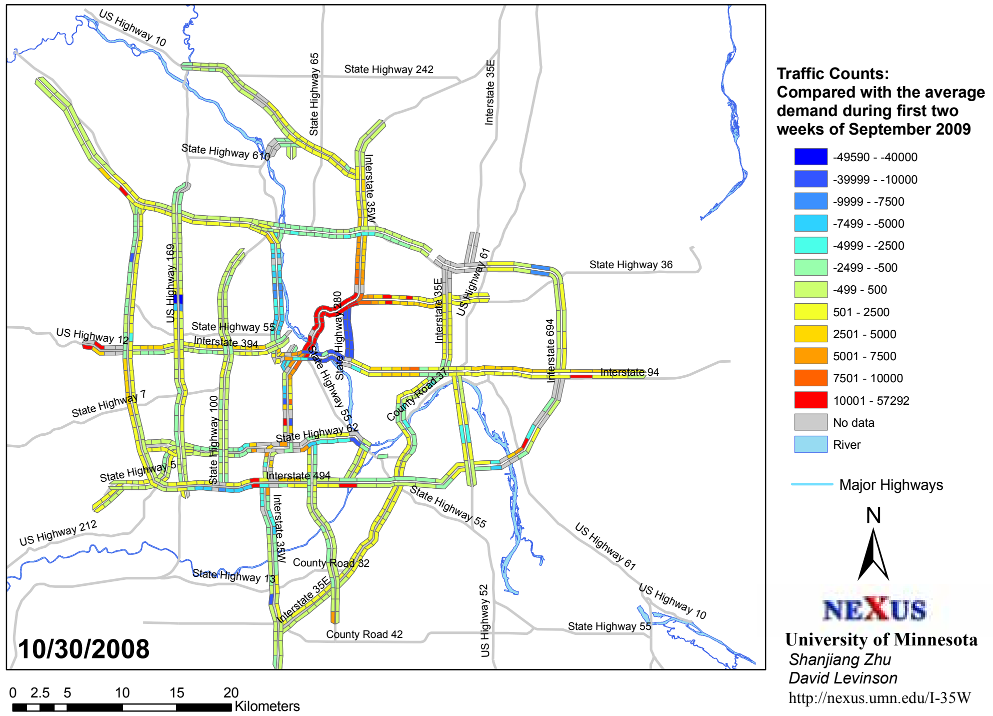
Daily Traffic Volume Variation after the I-35W Bridge Reopening



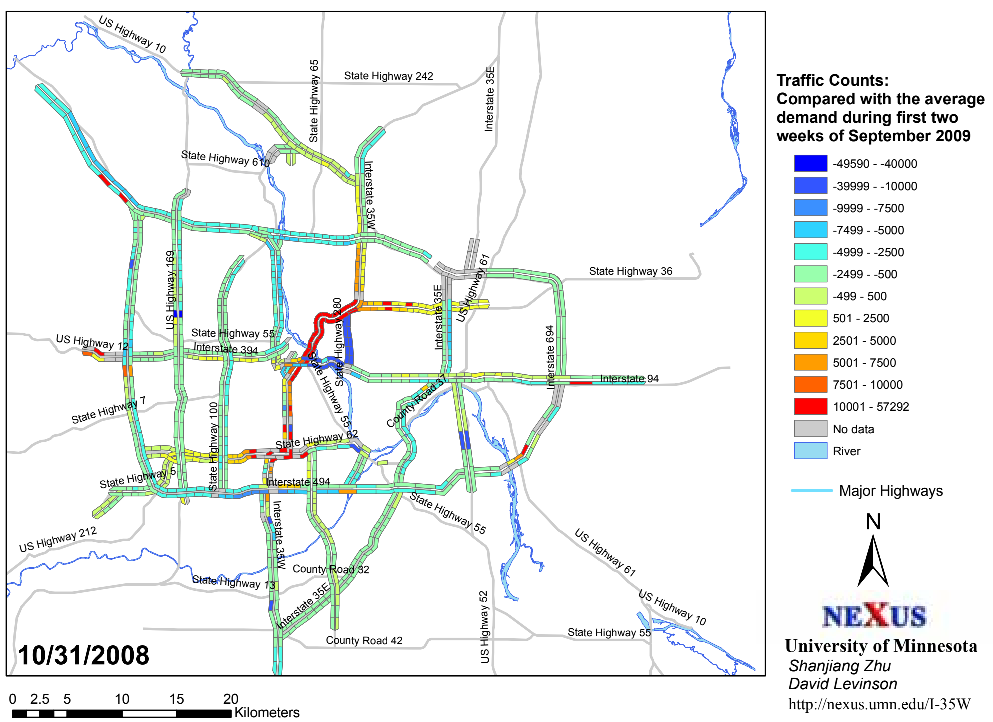
Daily Traffic Volume Variation after the I-35W Bridge Reopening



Daily Traffic Volume Variation after the I-35W Bridge Reopening



Daily Traffic Volume Variation after the I-35W Bridge Reopening



Appendix E

Filtering survey for subject recruitment

Questions about your background, transportation choices and preferences

Do you currently have a valid Minnesota driver's license?

- No
- Yes

Are you between 25 to 65 years of age?

- No
- Yes

What is your gender?

- Female
- Male

How many years have you lived in the Twin Cities area?

________ Years

Are you currently employed?

- No
- Yes

If you are currently employed, what is your main work location?

Address ________

City ________

State ________

Zip ________

On average, how many hours per week do you work at your main job?

Hours

On average, how many days per week do you work at your main job?

Days

How often do you work at home RATHER THAN at your usual workplace?

- Almost everyday
- Several times a week
- Once a week
- Several times a month
- Once a month
- Once or twice a year
- Never

How often do you work at home IN ADDITION TO your usual workplace?

- Almost everyday
- Several times a week
- Once a week
- Several times a month
- Once a month
- Once or twice a year
- Never

Where do you reside?

Address

City

State

Zip

How many vehicles are there in your household?

0 1 2 3 More than 3

How many licensed drivers are there in your household?

○ 0 ○ 1 ○ 2 ○ 3 ○ More than 3

Approximately how many miles did you put on your primary vehicle last year?

[ ] Miles

Which of the following technologies do you own? (Check all that apply)

- ☐ Desktop computer
- ☐ Laptop computer
- ☐ High speed Internet (e.g. DSL, cable modem) or Dial-up Internet
- ☐ Wireless Internet access
- ☐ Mobile phone
- ☐ Personal Digital Assistant (e.g. Palm, Pocket PC)
- ☐ GPS (Global Positioning System)
- ☐ In-vechicle navigation system

Do you have an I-394 MnPASS transponder in your car?

- ○ No
- ○ Yes

Which mode of transportation do you use most often to get to work?

- ○ Drive alone (Automobile, Light truck, etc.)
- ○ Carpool/Vanpool driver
- ○ Carpool/Vanpool passenger
- ○ Bus /Light Rail /Park and ride
- ○ Motorcycle
- ○ Bicycle
- ○ Walk
- ○ Other, Please specify [ ]

Which mode of transportation do you use most often in SUMMER?

- ○ Drive alone (Automobile, Light truck, etc.)
- ○ Carpool/Vanpool driver
- ○ Carpool/Vanpool passenger
- ○ Bus /Light Rail /Park and ride
- ○ Motorcycle
- ○ Bicycle

- Walk
- Other, Please specify ______

How often do you drive to work?

- Every workday
- Several times a week
- Once a week
- Several times a month
- Once a month
- Once or twice a year
- Never

For your commute trip, how often do you use MnPASS (High-Occupancy/Toll) lane on I-394?

- Every workday
- Several times a week
- Once a week
- Several times a month
- Once a month
- Once or twice a year
- Never

For your commute trip, how often do you use the general purpose lane on I-394?

- Every workday
- Several times a week
- Once a week
- Several times a month
- Once a month
- Once or twice a year
- Never

For your commute trip, how often do you use MN-55 (Olsen Memorial Hwy)?

- Every workday
- Several times a week
- Once a week
- Several times a month
- Once a month
- Once or twice a year
- Never

For your commute trip, how often do you use Glenwood Avenue?

- Every workday
- Several times a week
- Once a week
- Several times a month
- Once a month
- Once or twice a year
- Never

For your commute trip, how often do you use MN-7?

- Every workday
- Several times a week
- Once a week
- Several times a month
- Once a month
- Once or twice a year
- Never

For your commute trip, how often do you use MN-3 (Excelsior Blvd)?

- Every workday
- Several times a week
- Once a week
- Several times a month
- Once a month
- Once or twice a year
- Never

For your commute trip, how often do you use MN-5 (Minnetonka Blvd)?

- Every workday
- Several times a week
- Once a week
- Several times a month
- Once a month
- Once or twice a year
- Never

For your commute trip, how often do you use Cedar Lake Road?

- Every workday

- Several times a week
- Once a week
- Several times a month
- Once a month
- Once or twice a year
- Never

Did you use I-35W bridge for your commute before it collapsed?

- No
- Yes

Do you plan to switch back to I-35W bridge for your commute after its reopening?

- No
- Yes

From which resources did you hear about this study?

- On-line advertisement at Craigslist
- On-line advertisement at City Pages
- Newspaper advertisement in City Pages
- Flyer at downtown parking ramp
- Flyer at grocery store
- Flyer at county or city libraries
- From friends, co-workers, or family members
- Email

If you drive a vehicle to work, what is the car you most frequently drive?

Make ________

Model ________

Year ________

Is your commute to work 15 minutes long or longer each way?

- No
- Yes

Are you willing to allow a GPS device to be installed in your vehicle for the duration of the study?

- No
- Yes

Submit

Contact information

Thank you very much for your interest in this study. Please provide your contact information below. We will contact you if you are eligible to participate in this study. Your name and contact information will not be shared with anyone else and they will not be spammed. Your responses to the screening questions will be destroyed after the selection process.

First name: ____________________

Last Name: ____________________

Email: ____________________

Work phone number: ____________________

Home phone number: ____________________

Mobile phone number: ____________________

Submit

Appendix F

The interim email surveys

Questions regarding your travel experience TODAY

Today, we noticed that you changed your route when you drove home from work today. Please tell us why you made this change in your evening commute. Was it because you: (Please choose all that apply.)

- ☐ Discovered there was a problem with your usual route?
- ☐ Had to drop someone off?
- ☐ Had to pick someone up?
- ☐ Engaged in personal activity, like shopping, eating out, or going to the gym?
- ☐ Had to carry out a work-related activity?
- ☐ Felt like going a different way this evening?
- ☐ Others, please specify ______

Did you make this decision:

- ○ Before you departed?
- ○ After you departed?

Submit

Appendix G

The concluding survey

Final survey

1. How would you describe the current condition of the **I-94 Mississippi River Bridge** with regard to the following aspects? (If you are not sure, please choose the option "Not sure" and go directly to the next question)

Congestion level:

	○	○	○	○	○	○	○	
Not at all congested	1	2	3	4	5	6	7	Extremely congested

☐ Not sure

Travel time predictability:

	○	○	○	○	○	○	○	
Not at all predictable	1	2	3	4	5	6	7	Very predictable

☐ Not sure

Ease of driving:

	○	○	○	○	○	○	○	
Very difficult	1	2	3	4	5	6	7	Very easy

☐ Not sure

Pleasantness:

	○	○	○	○	○	○	○	
Very unpleasant	1	2	3	4	5	6	7	Very pleasant

☐ Not sure

2. How does the current condition of the **I-94 Mississippi River Bridge** differ from what it was before the reopening of the I-35W Mississippi River Bridge (two months ago) with regard to the following aspects? (1 = Much better, 4 = No change, 7 = Much worse; if you are not sure, please choose "Not sure.")

Congestion level:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Travel time predictability:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Ease of driving:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Pleasantness:

○ ○ ○ ○ ○ ○ ○

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

3. How would you describe the current condition of the **I-694 Mississippi River Bridge** with regard to the following aspects? (If you are not sure, please choose the option "Not sure" and directly go to the next question)

Congestion level:

Not at all congested 1 2 3 4 5 6 7 Extremely congested

☐ Not sure

Travel time predictability:

Not at all predictable 1 2 3 4 5 6 7 Very predictable

☐ Not sure

Ease of driving:

Very difficult 1 2 3 4 5 6 7 Very easy

☐ Not sure

Pleasantness:

Very unpleasant 1 2 3 4 5 6 7 Very pleasant

☐ Not sure

4. How does the current condition of the **I-694 Mississippi River Bridge** differ from what it was before the reopening of the I-35W Mississippi River Bridge (two months ago) with regard to the following aspects? (1 = Much better, 4 = No change, 7 = Much worse; if you are not sure, please choose "Not sure.")

Congestion level:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

Travel time predictability:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

Ease of driving:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

Pleasantness:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

5. How would you describe the current condition of the **Hennepin Avenue Bridge** crossing the Mississippi River with regard to the following aspects? (If you are not sure, please choose the option "Not sure" and directly go to the next question)

Congestion level:

	○	○	○	○	○	○	○	
Not at all congested	1	2	3	4	5	6	7	Extremely congested

☐ Not sure

Travel time predictability:

	○	○	○	○	○	○	○	
Not at all predictable	1	2	3	4	5	6	7	Very predictable

☐ Not sure

Ease of driving:

	○	○	○	○	○	○	○	
Very difficult	1	2	3	4	5	6	7	Very easy

☐ Not sure

Pleasantness:

	○	○	○	○	○	○	○	
Very unpleasant	1	2	3	4	5	6	7	Very pleasant

☐ Not sure

6. How does the current condition of the **Hennepin Avenue Bridge** differ from what it was before the reopening of the I-35W Mississippi River Bridge (two months ago) with regard to the following aspects? (1 = Much better, 4 = No change, 7 = Much worse; if you are not sure, please choose "Not sure.")

Congestion level:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Travel time predictability:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Ease of driving:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Pleasantness:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

7. How would you describe the current condition of the **3rd Avenue Bridge** crossing the Mississippi River with regard to the following aspects? (If you are not sure, please choose the option "Not sure" and directly go to the next question)

Congestion level:

	○	○	○	○	○	○	○	
Not at all congested	1	2	3	4	5	6	7	Extremely congested

☐ Not sure

Travel time predictability:

	○	○	○	○	○	○	○	
Not at all predictable	1	2	3	4	5	6	7	Very predictable

☐ Not sure

Ease of driving:

	○	○	○	○	○	○	○	
Very difficult	1	2	3	4	5	6	7	Very easy

☐ Not sure

Pleasantness:

	○	○	○	○	○	○	○	
Very unpleasant	1	2	3	4	5	6	7	Very pleasant

☐ Not sure

8. How does the current condition of the **3rd Avenue Bridge** differ from what it was before the reopening of the I-35W Mississippi River Bridge (two months ago) with regard to the following aspects? (1 = Much better, 4 = No change, 7 = Much worse; if you are not sure, please choose "Not sure.")

Congestion level:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Travel time predictability:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Ease of driving:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Pleasantness:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

9. How would you describe the current condition of the **Cedar Avenue Bridge (10th**

Avenue) crossing the Mississippi River with regard to the following aspects? (If you are not sure, please choose the option "Not sure" and directly go to the next question)

Congestion level:

	○	○	○	○	○	○	○	
Not at all congested	1	2	3	4	5	6	7	Extremely congested

☐ Not sure

Travel time predictability:

	○	○	○	○	○	○	○	
Not at all predictable	1	2	3	4	5	6	7	Very predictable

☐ Not sure

Ease of driving:

	○	○	○	○	○	○	○	
Very difficult	1	2	3	4	5	6	7	Very easy

☐ Not sure

Pleasantness:

	○	○	○	○	○	○	○	
Very unpleasant	1	2	3	4	5	6	7	Very pleasant

☐ Not sure

10. How does the current condition of the **Cedar Avenue Bridge (10th Avenue)** differ from what it was before the reopening of the I-35W Mississippi River Bridge (two months ago) with regard to the following aspects? (1 = Much better, 4 = No change, 7 = Much worse; if you are not sure, please choose "Not sure.")

Congestion level:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Travel time predictability:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Ease of driving:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Pleasantness:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

11. How would you describe the current condition of the **Washington Avenue Bridge** crossing the Mississippi River with regard to the following aspects? (If you are not

sure, please choose the option "Not sure" and directly go to the next question)

Congestion level:

	○	○	○	○	○	○	○	
Not at all congested	1	2	3	4	5	6	7	Extremely congested

☐ Not sure

Travel time predictability:

	○	○	○	○	○	○	○	
Not at all predictable	1	2	3	4	5	6	7	Very predictable

☐ Not sure

Ease of driving:

	○	○	○	○	○	○	○	
Very difficult	1	2	3	4	5	6	7	Very easy

☐ Not sure

Pleasantness:

	○	○	○	○	○	○	○	
Very unpleasant	1	2	3	4	5	6	7	Very pleasant

☐ Not sure

12. How does the current condition of the **Washington Avenue Bridge** differ from what it was before the reopening of the I-35W Mississippi River Bridge (two months ago) with regard to the following aspects? (1 = Much better, 4 = No change, 7 = Much worse; if you are not sure, please choose "Not sure.")

Congestion level:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Travel time predictability:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Ease of driving:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

Pleasantness:

	○	○	○	○	○	○	○	
Much better	1	2	3	4	5	6	7	Much worse

☐ Not sure

13. How would you describe the current condition of **Highway 280** with regard to the following aspects? (If you are not sure, please choose the option "Not sure" and directly go to the next question)

Congestion level:

Not at all congested 1 2 3 4 5 6 7 Extremely congested

☐ Not sure

Travel time predictability:

Not at all predictable 1 2 3 4 5 6 7 Very predictable

☐ Not sure

Ease of driving:

Very difficult 1 2 3 4 5 6 7 Very easy

☐ Not sure

Pleasantness:

Very unpleasant 1 2 3 4 5 6 7 Very pleasant

☐ Not sure

14. How does the current condition of **Highway 280** differ from what it was before the reopening of the I-35W Mississippi River Bridge (two months ago) with regard to the following aspects? (1 = Much better, 4 = No change, 7 = Much worse; if you are not sure, please choose "Not sure.")

Congestion level:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

Travel time predictability:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

Ease of driving:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

Pleasantness:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

15. How would you describe the current condition of the **I-35W Mississippi River Bridge** with regard to the following aspects? (If you are not sure, please choose the option "Not sure" and directly go to the next question)

Congestion level:

Not at all congested 1 2 3 4 5 6 7 Extremely congested

☐ Not sure

Travel time predictability:

Not at all predictable 1 2 3 4 5 6 7 Very predictable

☐ Not sure

Ease of driving:

Very difficult 1 2 3 4 5 6 7 Very easy

☐ Not sure

Pleasantness:

Very unpleasant 1 2 3 4 5 6 7 Very pleasant

☐ Not sure

16. How does the current condition of the **I-35W Mississippi River Bridge** differ from what it was **before its collapse** one year ago with regard to the following aspects? (1 = Much better, 4 = No change, 7 = Much worse; if you are not sure, please choose "Not sure.")

Congestion level:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

Travel time predictability:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

Ease of driving:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

Pleasantness:

Much better 1 2 3 4 5 6 7 Much worse

☐ Not sure

Next

Final survey

1. Did you change your usual routes from home to work after the reopening of the I-35W Bridge?

- Yes
- No

If you responded Yes, continue to the next question. If you responded No, please skip the next question.

2. What was the **most** important reason you changed your route after the I-35W Bridge reopened?

- The route I followed before the reopening of I-35W Bridge is more congested now.
- The new route has a shorter travel distance.
- The new route has a shorter travel time.
- The travel time of the new route is more reliable (predictable).
- Others, please specify

3. Did you try alternative routes other than your usual routes after the I-35W Bridge reopened?

- Yes
- No

If you responded No, continue to the next question. If you responded Yes, please skip the next question.

4. What was the most important reason for you to stick to your usual routes without trying alternatives?

- There is no real alternative for my route to work.
- I do not know if there are alternative routes and do not want to bother.
- The alternative routes are not likely to be better off.
- The time and effort of trying alternatives outweighs possible time savings.
- Others, please specify

5. Please rank your route preferences for driving to WORK.

Most preferred	1	2	3	Least preferred
I-35W Mississippi Bridge	○	○	○	
I-94 Mississippi Bridge	○	○	○	
I-694 Mississippi Bridge	○	○	○	
Hennepin Avenue Bridge	○	○	○	
3rd Avenue Bridge	○	○	○	
Cedar Avenue Bridge				

Cedar Avenue Bridge (10th Avenue)	○	○	○
Washington Avenue Bridge	○	○	○
Franklin Avenue Bridge	○	○	○
Others	○	○	○

If you chose others, please specify

6. Please rank the importance of the following factors (top three) when you choose a route to WORK.

Most important	1	2	3	Least important
Travel time	○	○	○	
Distance	○	○	○	
Travel time predictability	○	○	○	
Cost (including tolls)	○	○	○	
Convenience for shopping	○	○	○	
Drop off spouse	○	○	○	
Drop off children	○	○	○	
Aesthetics of route	○	○	○	
Others	○	○	○	

If you chose others, please specify

7. Please rank your route preferences for driving HOME.

Most preferred	1	2	3	Least preferred
I-35W Mississippi Bridge	○	○	○	
I-94 Mississippi Bridge	○	○	○	
I-694 Mississippi Bridge	○	○	○	
Hennepin Avenue Bridge	○	○	○	
3rd Avenue Bridge	○	○	○	
Cedar Avnuee Bridge (10th Avenue)	○	○	○	
Washington Avenue Bridge	○	○	○	
Franklin Avenue Bridge	○	○	○	
Others	○	○	○	

If you chose others, please specify

8. Please rank the importance of the following factors (top three) when you choose a

route HOME.

Most important	1	2	3	Least important
Travel time	○	○	○	
Distance	○	○	○	
Travel time predictability	○	○	○	
Cost (including tolls)	○	○	○	
Convenience for shopping	○	○	○	
Drop off spouse	○	○	○	
Drop off children	○	○	○	
Aesthetics of route	○	○	○	
Others	○	○	○	

If you chose others, please specify

9. What other activities do you engage in which require you to make trips that cross the Mississippi River? (Choose all that apply.)

- ☐ Childcare
- ☐ Quick stop
- ☐ Shopping
- ☐ Visit friends/Relatives
- ☐ Personal business
- ☐ Eat meal outside of home
- ☐ Entertainment/Recreational/Fitness
- ☐ Civic/Religious
- ☐ Pick up/Drop off
- ☐ With another person at their activity
- ☐ Others, please specify

10. Which of those activities affects your route choice the most?

- ○ Childcare
- ○ Quick stop
- ○ Shopping
- ○ Visit friends/Relatives
- ○ Personal business
- ○ Eat meal outside of home
- ○ Entertainment/Recreational/Fitness
- ○ Civic/Religious
- ○ Pick up/Drop off
- ○ With another person at their activity

○ Others, please specify [ ]

11. Please rank your route preferences for that purpose.

Most preferred	1	2	3	Least preferred
I-35W Mississippi Bridge	○	○	○	
I-94 Mississippi Bridge	○	○	○	
I-694 Mississippi Bridge	○	○	○	
Hennepin Avenue Bridge	○	○	○	
3rd Avenue Bridge	○	○	○	
Cedar Avenue Bridge (10th Ave)	○	○	○	
Washington Avenue Bridge	○	○	○	
Franklin Avenue Bridge	○	○	○	
Others	○	○	○	

If you chose others, please specify

[ ]

12. Please rank the importance of the following factors (top three) when you choose a route for that purpose?

Most important	1	2	3	Least important
Travel time	○	○	○	
Distance	○	○	○	
Travel time predictability	○	○	○	
Cost (including tolls)	○	○	○	
Convenience for shopping	○	○	○	
Drop off spouse	○	○	○	
Drop off children	○	○	○	
Aesthetics of route	○	○	○	
Others	○	○	○	

If you chose others, please specify

[ ]

The following questions are about your travel preferences after the I-35W Bridge collapse

13. Did you change your usual routes from home to work after the I-35W Bridge Collapse one year ago?

○ Yes

○ No

If you responded Yes, continue to the next question. If you responded No, please skip the next question.

14. What was the **most** important reason you changed your route after the I-35W Bridge Collapse?

- Routes or ramp closed because of the bridge collapse.
- The traffic condition on the usual route before the bridge collapse was much worse.
- The traffic condition on new route was better than the usual route before the bridge collapse.
- The travel time of the new route was more reliable (predictable).
- Others, please specify

15. Did you try alternative routes other than your usual route after the bridge collapse?

- Yes
- No

If you responded No, continue to the next question. If you responded Yes, please skip the next question.

16. What is the **most** important reason for you to stick to your usual route without trying alternatives after the bridge collaspe?

- There is no real alternative for my route to work.
- I do not know if there are alternative routes and do not want to bother.
- The alternative routes are not likely to be better off.
- The time and efforts for trying alternatives outweight possible time savings.
- Others, please specify

17. Did you make fewer crossing-river trips after the bridge collapse?

- Yes
- No

If you responded Yes, continue to the next question. If you responded No, please skip the next question.

18. If yes, how many trips did you cancel or consolidate with other trips?

- Several trips per day
- Several trips a week
- Once a week
- Once a month
- Less than once a month

19. Did you change your departure time from home to work after the bridge collapse?

- Yes
- No

If Yes, by how much?

minutes

- earlier
- later

20. Could you please comment on the impacts of the I-35W Bridge collapse regarding your travel pattern?

Next

Please answer the following question

The following scenario pertains to your drive to **WORK** on a typical day.

If you were to use the Toll-free lanes on I-394, your trip would take 30 minutes and be free. If you used the MnPASS lane you would pay $2.50 and your trip would take 20 minutes. Now under these conditions, which would you choose to go to work on a typical day, would you:

- ◯ Use the MnPASS lane, pay $2.50 and save 10 minutes
- ◯ Use the toll-free lanes for free

Next

Please answer the following question

The following scenario pertains to a trips you make to destinations **other than work or home (e.g. shopping)** on a typical day?

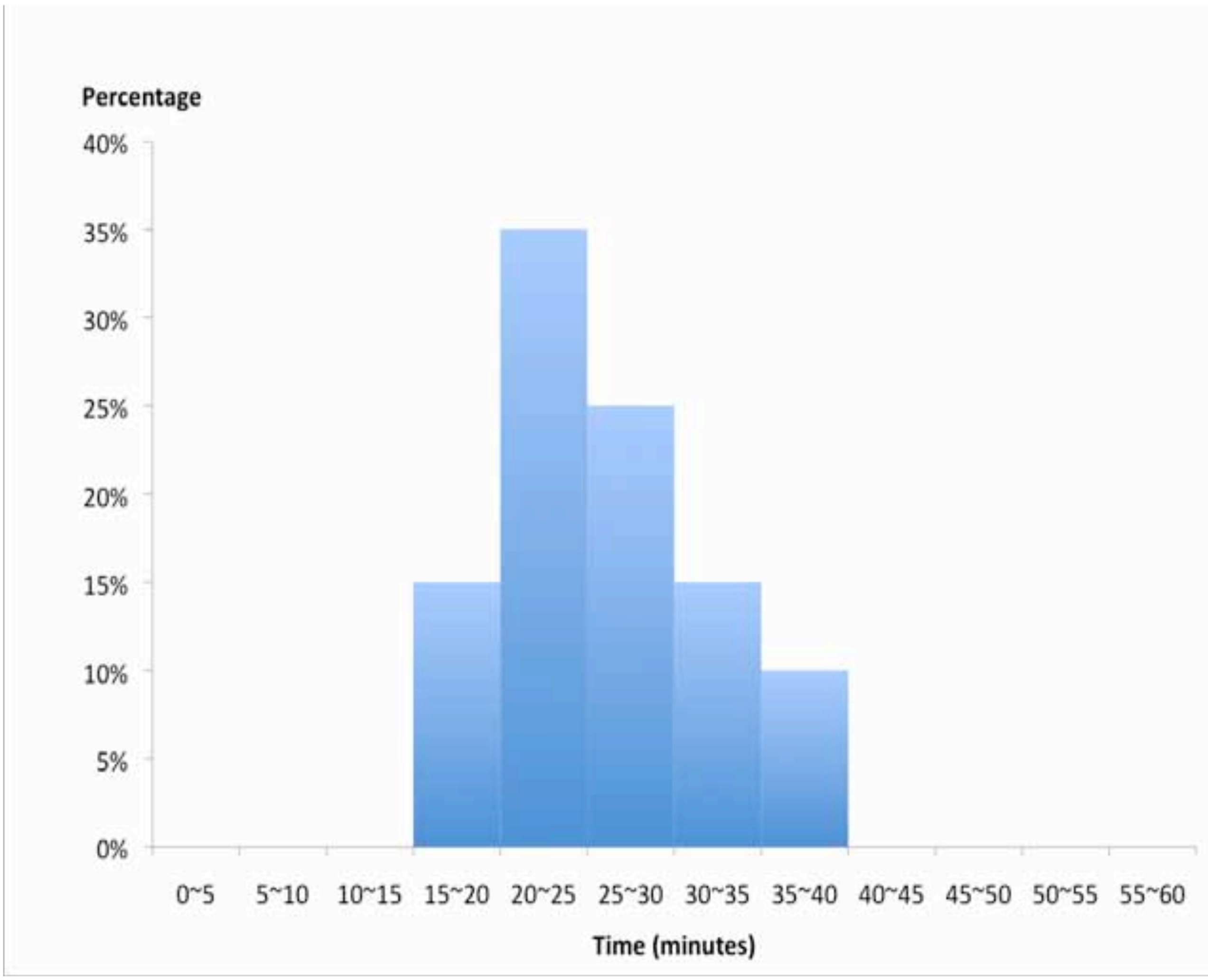
If you were to use the toll-free lanes on I-394, your trip would take 30 minutes and be free. If you used the MnPASS lane you would pay $2.50 and your trip would take 20 minutes. Now under these conditions, which would you choose for a trip to destinations **other than work or home** (e.g. shopping) on a typical day? Would you:

- ○ Use the MnPASS lane, pay $2.50 and save 10 minutes
- ○ Use the toll-free lanes for free

Next

Some information about travel time

---Suppose I asked you what your travel time was on your way to work and you answered it is about 26 minutes. However, you sometimes travel faster, and sometimes slower because of the different congestion level from day to day. For example, 15% of the time, your travel time is between 15 to 20 minutes. And 35% of the time, your travel time is between 20 to 25 minutes. This situation can be represented by the following graph where each bar represents the likelihood of a particular outcome. The average or expected travel time is 26 minutes.

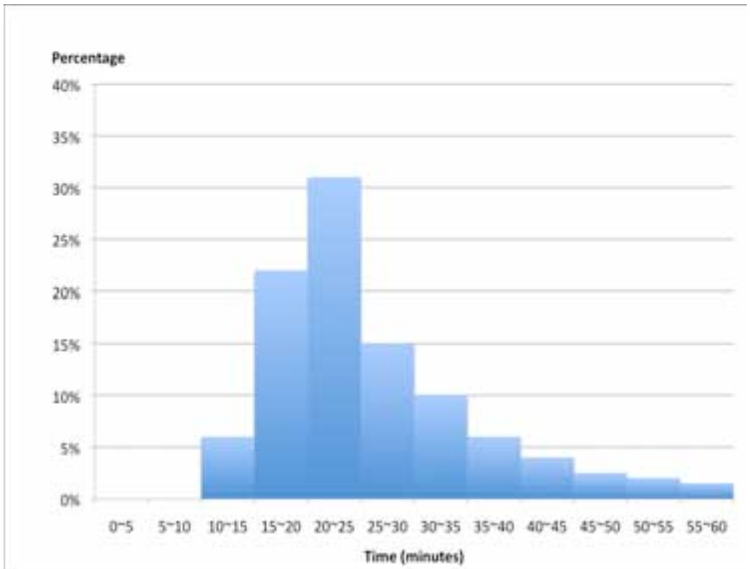


Average Travel Time: 26 minutes

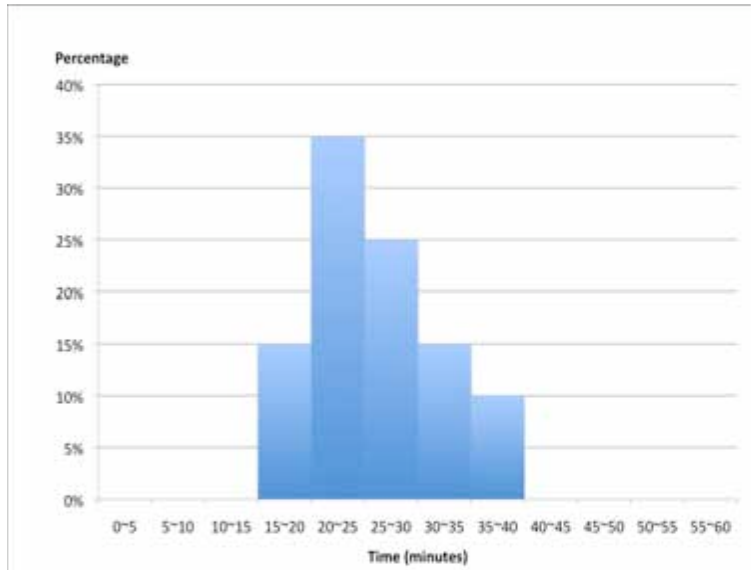
Next

Please choose the scenario you prefer

If you were to use one of the following two routes, with a different travel time distribution, average travel time, and tolls, which one would you prefer as your commute route?



Average Travel Time: 26 minutes



Average Travel Time: 26 minutes

Toll: $1.00

Next

Final Questions

For the following questions please choose a number from 1 – 7 that represents your response. For example, an answer of 1 means that you never worry and an answer of 7 means that you always worry.

1. Do you sometimes worry about driving on bridges or overpasses?

- Yes
- No

If yes, please answer the following question. If no, continue to Question 2.

How often do you worry?

	○	○	○	○	○	○	○	
Never	1	2	3	4	5	6	7	Always

2. Do you sometimes worry about driving under a bridge or overpass?

- Yes
- No

If yes, please answer the following question. If no, continue to Question 3.

How often do you worry?

	○	○	○	○	○	○	○	
Never	1	2	3	4	5	6	7	Always

3. Do you sometimes worry that a bridge or overpass might collapse when you are driving on it?

- Yes
- No

If yes, please answer the following question. If no, continue to Question 4.

How often do you worry?

	○	○	○	○	○	○	○	
Never	1	2	3	4	5	6	7	Always

4. Do you sometimes worry that a bridge or overpass might collapse when you are driving under it?

- Yes
- No

If yes, please answer the following question. If no, continue to Question 5.

How often do you worry?

	○	○	○	○	○	○	○	
Never	1	2	3	4	5	6	7	Always

5. Before the I-35W Bridge collapsed, did you sometimes worry that a bridge or overpass might collapse while you were driving on it?

○ Yes
○ No

If yes, please answer the following question. If no, continue to Question 6.
How often do you worry?

	○	○	○	○	○	○	○	
Never	1	2	3	4	5	6	7	Always

6. Before the I-35W Bridge collapsed, did you sometimes worry that a bridge or overpass might collapse while you were driving under it?

○ Yes
○ No

If yes, please answer the following question. If no, continue to Question 7.
How often do you worry?

	○	○	○	○	○	○	○	
Never	1	2	3	4	5	6	7	Always

7. If you worry about driving on bridges and overpasses, or under them, does this affect how you drive or where you drive?

○ Yes
○ No

If yes, please comment below:

8. What is the highest grade or year of school that you have completed?

○ 11th grade or less

- High school graduate
- Associate degree
- Bachelors degree
- Masters degree
- Doctoral degree

9. What is your age?

- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65+

10. What is the total annual income for your household, when you consider the income of all employed individuals?

- $30,000 or less
- $30,000 to $49,999
- $50,000 to $74,999
- $75,000 to $99,999
- $100,000 to $124,999
- $125,000 to $149,999
- $150,000 or above

11. Which of the following categories best describes your race or ethnic background?

- White or Caucasian
- Black/African American
- Native American
- Hispanic
- Asian
- Mixed race
- Others

12. How long have you worked at your current work location?

[ ] Years
[ ] Months

13. How long have you lived in your current house/apartment?

[ ] Years

[ ] Months

14. Where would you like the check and gas card you will receive for participating in this study to be mailed?

Payee [ ]

Address [ ]

City [ ]

State [ ]

Zip [ ]

Next

Appendix H

Questionnaire of the mail-in survey

UNIVERSITY OF MINNESOTA

Prof. Henry Liu
Dept. of Civil Engineering
122 Civil Engineering Building
500 Pillsbury Dr. S.E.
Minneapolis, MN 55455

October 30, 2008

RE: Survey of Travel Behavior Impacts of I-35W Bridge Reopening

Dear participants:

We ask your help to participate in a survey on the travel behavior impacts of the I-35W Bridge reopening. The purpose of this survey is to advance our understanding of travel behavior. Participation in this study is voluntary. All information collected will only be used at a statistical level and for research purposes.

The survey is being conducted by the Department of Civil Engineering of the University of Minnesota. Please complete the questionnaire; then draw travel routes on the maps, following the instructions provided. Please place your survey responses and the maps in the prepaid envelope and drop the envelope in the mailbox. If you have any questions, please contact the principal investigator of this project, Prof. Henry Liu, at 1-651-314-4586. Thank you again for your participation.

Survey of Travel Behavior Impacts of I-35W Bridge Reopening

*Please complete the table, indicating the choice best describing your **MORNING COMMUTE** trip in the following time periods, and draw your route(s) on the attached maps.*

	Before Bridge Collapse *(e.g., in July 2007)*	**Before Bridge Reopening** *(e.g., Sept 17th, 2008)*	**After Bridge Reopening** *(September 18th, 2008)*	**Following Weeks** *(Sept. 19th to Oct. 23th)*	**Current Status**
Departure Time: (Typical departure time from home, to the nearest minute)					
Arrival Time: (Typical arrival time at work, to the nearest minute)					
Travel Mode: (The primary mode of travel) a) Drive alone b) Carpool driver c) Carpool passenger d) Bus/Light rail e) Bicycle f) Walk g) Other (Please specify)					
Route Choice: (Please draw your routes on the attached maps.)	Please mark line(s) on **MAP 1**	Please mark line(s) on **MAP 2**	Please mark line(s) on **MAP 3**	Please mark line(s) on **MAP 4**	Please mark line(s) on **MAP 5**
If you did not change route, please draw your route on at least one map.	*If you used more than one route at that time period, please indicate **ALL** of them in the same map.* (Please indicate the **Transit Route Number** if you chose Bus/Light rail)				
Route Familiarity: (How familiar are you with the routes you used)	*Please circle how familiar you are with each route on a scale of* 1-7, *with* 1 *representing not at all familiar and* 7 *representing very familiar*				
	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7	1 2 3 4 5 6 7
Motivation for Changes in Travel Choices: Why did you change your route(s)? Please specify.					

Please answer the following questions.

Did the bridge collapse affect your travel? ☐ Y / ☐ N

If so, did you: cancel trip(s) ☐ Y/ ☐ N avoid certain destinations ☐ Y/ ☐ N
change departure time ☐ Y/ ☐ N change mode ☐ Y/ ☐ N
change route ☐ Y/ ☐ N work at home more frequently ☐ Y/ ☐ N

Did the bridge reopening affect your travel? ☐ Y/ ☐ N

If so, did you: avoid certain destinations ☐ Y/ ☐ N change departure time ☐ Y/ ☐ N
change mode ☐ Y/ ☐ N change route ☐ Y/ ☐ N

How much time savings would be required for you to change routes: .... Minutes

How much time savings would be required for you to change travel modes: .... Minutes

How did you find out about the I-35W Bridge reopening? ....

-- **OVER** --

Are you: □ Male □ Female

Do you have a flexible work schedule: □ Y/ □ N

Do you reside at the same location as you did in July 2007? □ Y/ □ N

Do you work at the same location as you did in July 2007? □ Y/ □ N

Where do you reside? (Please provide nearest cross streets) ....

Where do you work? (Please provide nearest cross streets) ....

How many people live in your household: ....

How many children: age 0-5 .... age 6-16 ....

What is your age group?

- □ 0 – 20 years
- □ 20 – 25 years
- □ 25 – 30 years
- □ 30 – 35 years
- □ 35 – 40 years
- □ 40 – 45 years
- □ 45 – 50 years
- □ 50 – 55 years
- □ 55 – 60 years
- □ 60+ years

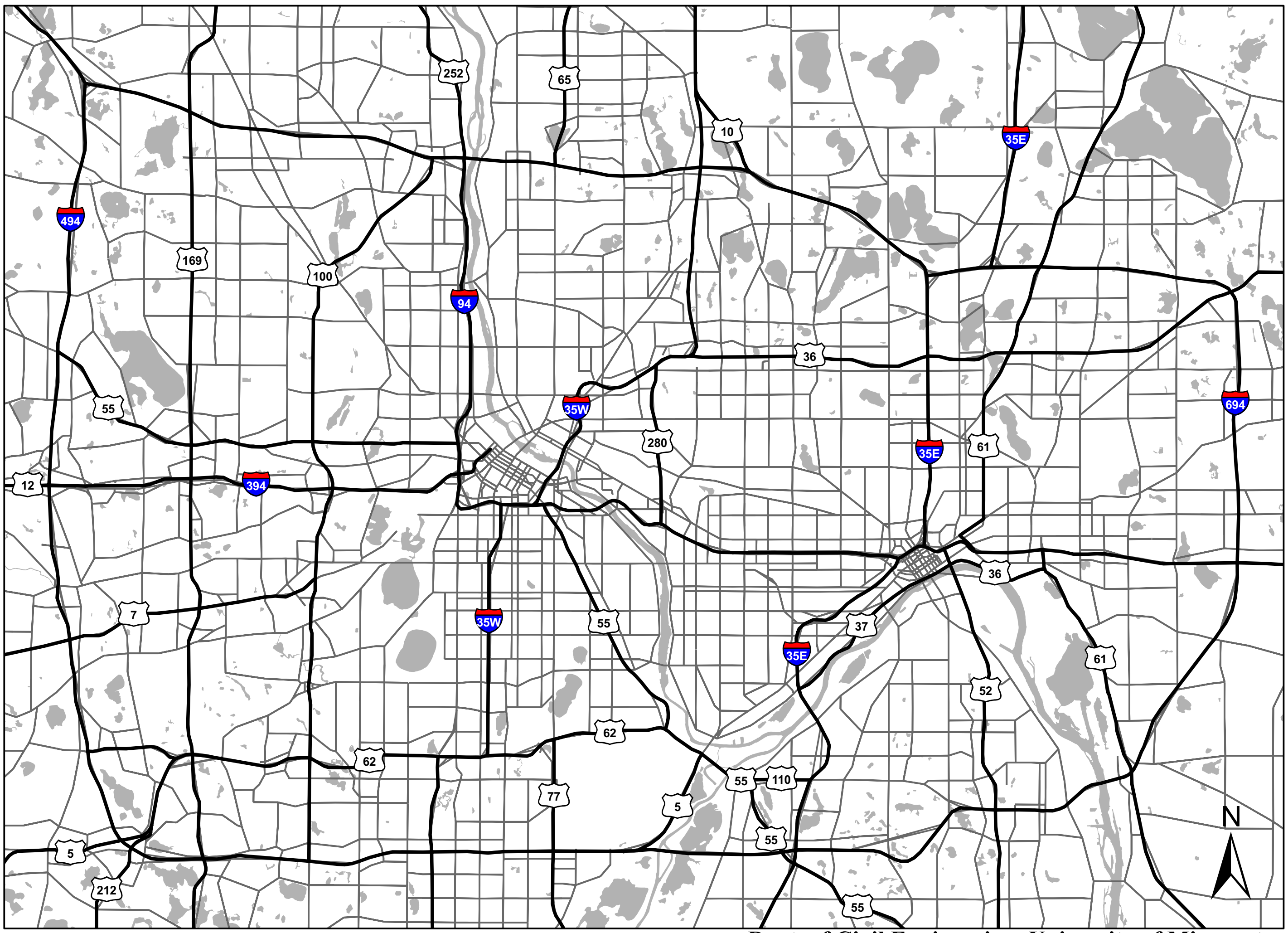
What is your annual household income group?

- □ $0 - $10,000
- □ $10,000 - $25,000
- □ $25,000 - $40,000
- □ $40,000 - $60,000
- □ $60,000 - $80,000
- □ $80,000 - $100,000
- □ $100,000 - $150,000
- □ $150,000+

. . . .

Please comment about how you changed your travel behavior in response to the I-35W Bridge reopening:

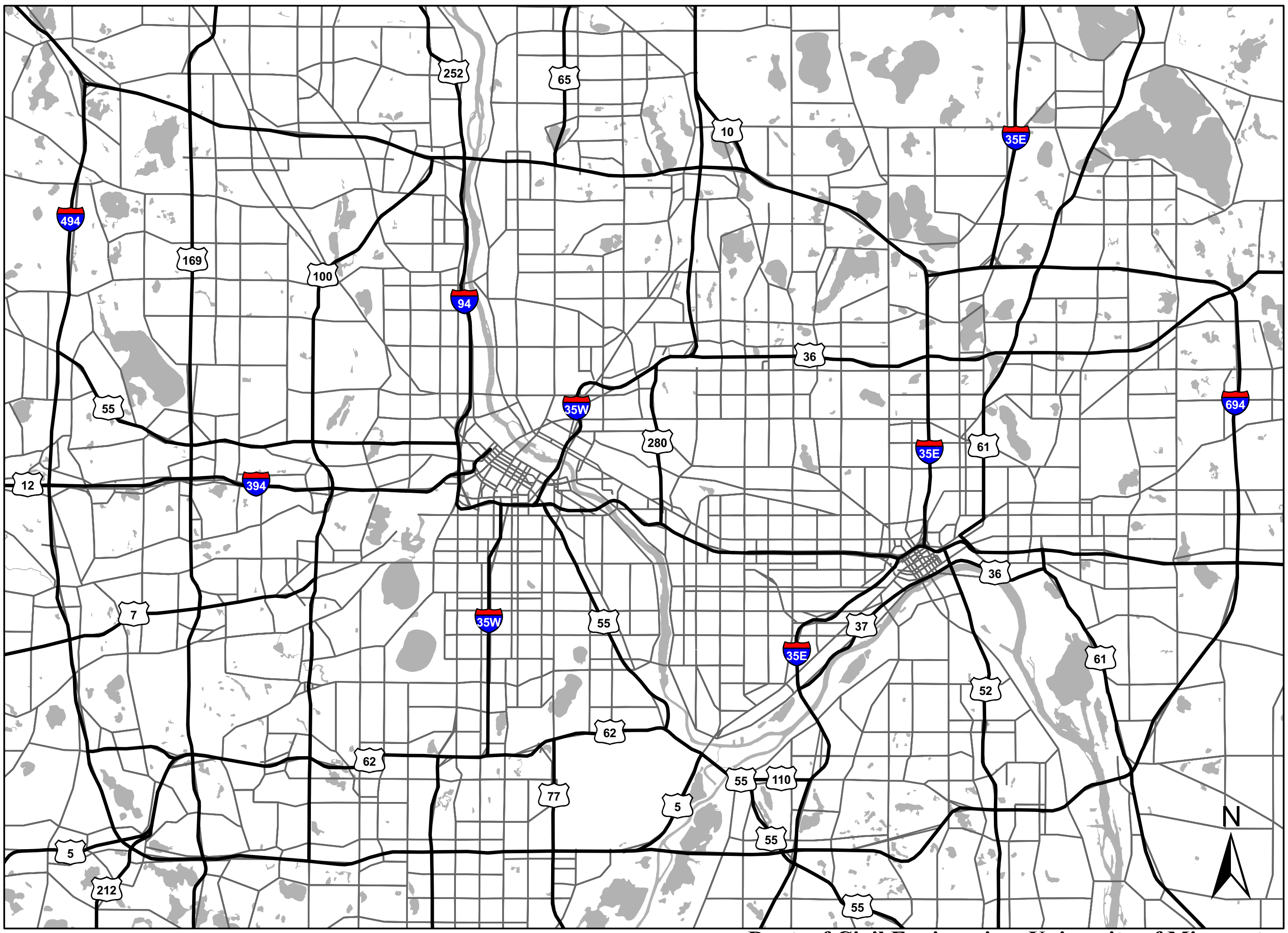
MAP 1: Please indicate your commute route BEFORE the I-35W Bridge COLLAPSE. THANK YOU!



Dept. of Civil Engineering, University of Minnesota

-- OVER --

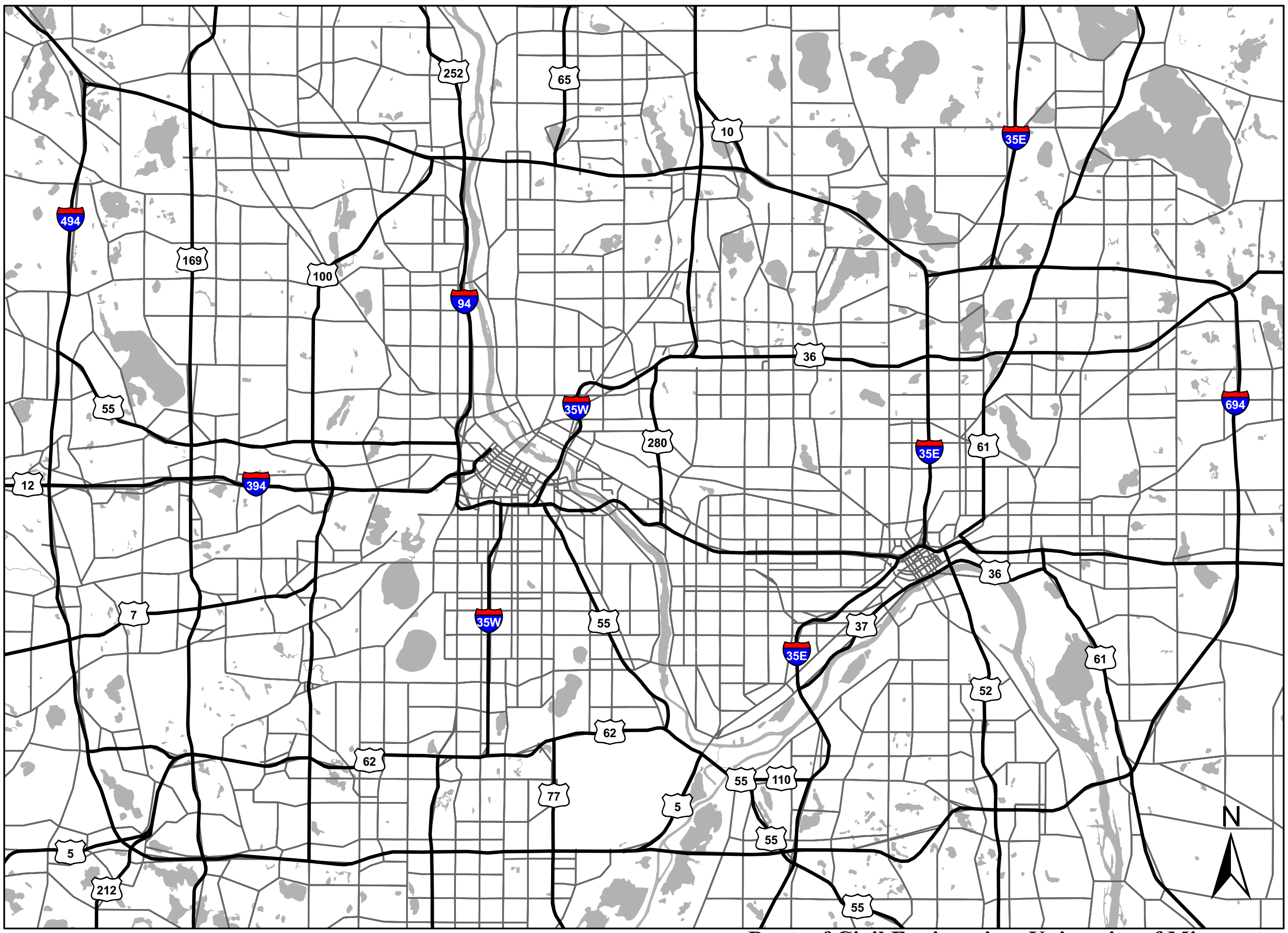
MAP 2: Please indicate your commute route BEFORE the I-35W Bridge REOPENING. THANK YOU!



Dept. of Civil Engineering, University of Minnesota

-- OVER --

MAP 3: Please indicate your commute route ON THE DAY of the I-35W Bridge REOPENING (September 18). THANK YOU!



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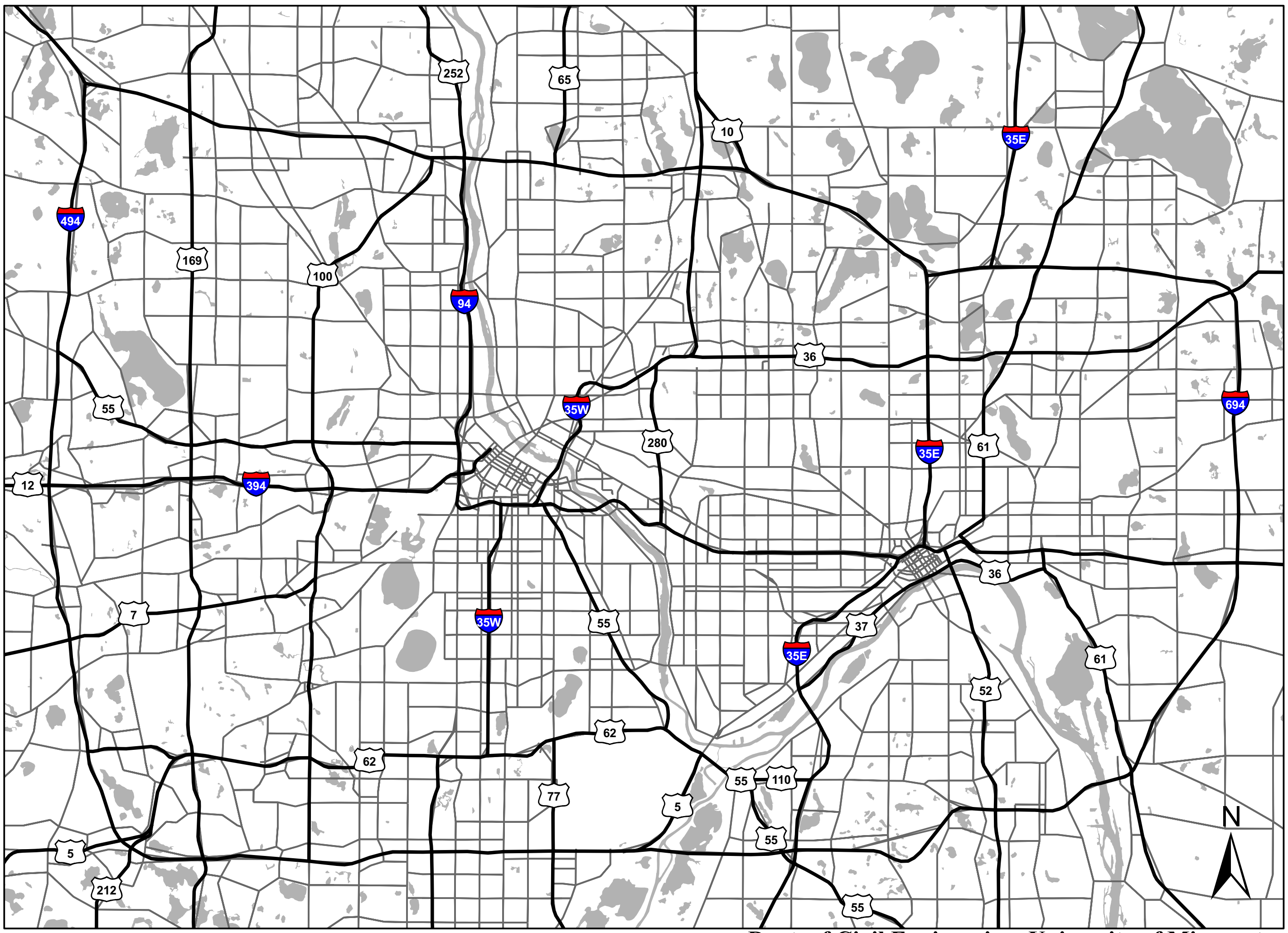
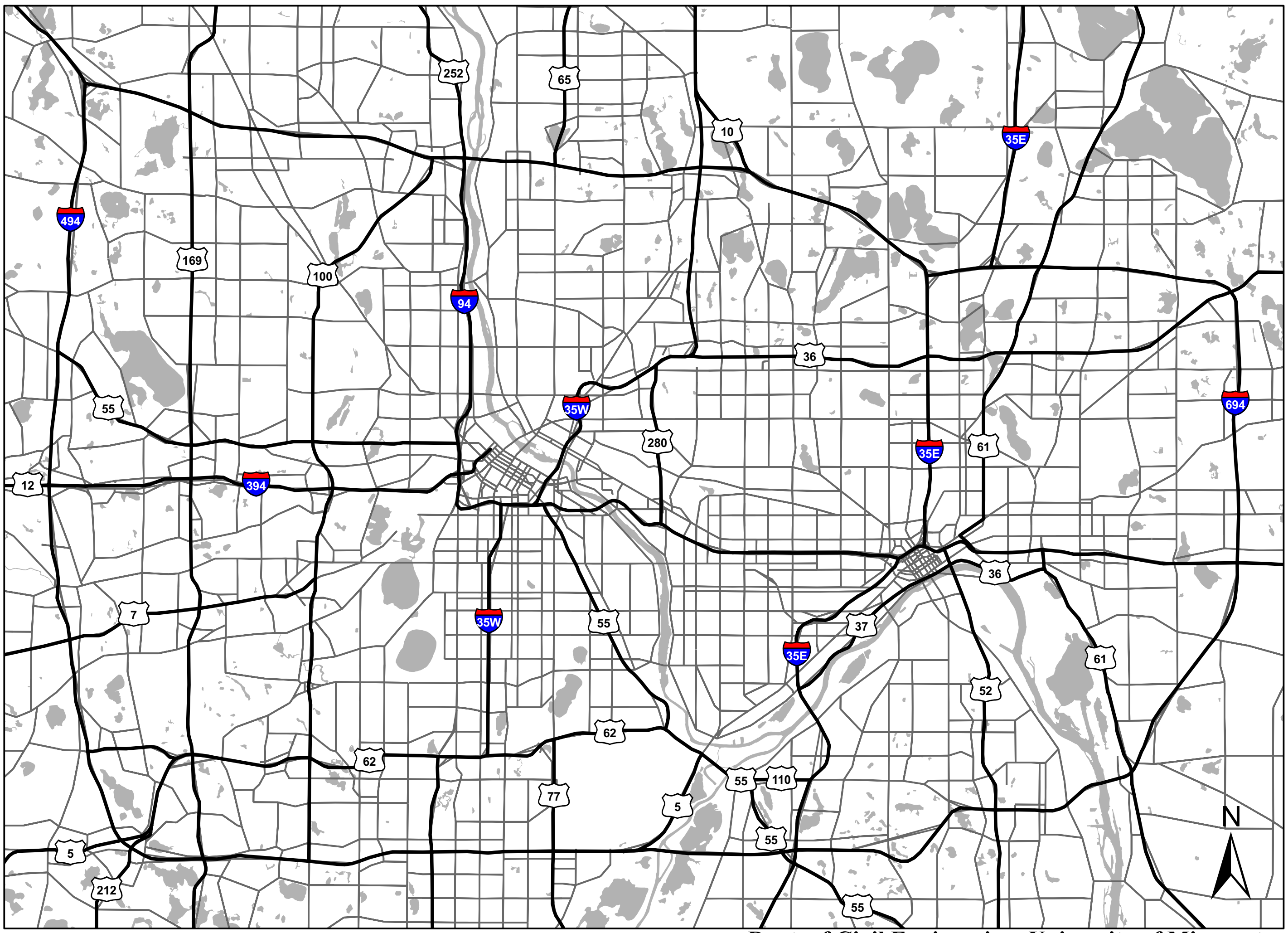
MAP 4: Please indicate your commute route in the WEEKS FOLLOWING the I-35W Bridge REOPENING. THANK YOU!



Dept. of Civil Engineering, University of Minnesota

MAP 5: Please indicate your CURRENT commute route. THANK YOU!



Dept. of Civil Engineering, University of Minnesota

-- OVER --

You have completed the survey. Thank you very much for your participation!

Please return the questionnaire in the accompanying prepaid envelope to:

I-35W Travel Behavior Survey
University of Minnesota, Twin Cities
Department of Civil Engineering
500 Pillsbury Dr. S.E.
Minneapolis, MN 55455

Appendix I

Questionnaire of the web-based survey

Questions Regarding Your Travel Experiences and Choices Surrounding the I-35W Bridge Collapse and Reopening

*On August 1st, 2007, the I-35W Bridge over the Mississippi River in Minneapolis, Minnesota, collapsed unexpectedly. This event resulted in the closure of a half-mile strip of I-35W near downtown Minneapolis and the University of Minnesota. The following questions pertain to choices made immediately **BEFORE** the collapse.*

Before the collapse, did you use the I-35W Bridge as part of your daily commute?

- Yes
- No

Please list the roads that you used as part of your daily commute **BEFORE** the collapse of the I-35W Bridge, from the intersection nearest your RESIDENCE to the intersection nearest your WORKPLACE or SCHOOL:

Please list the roads that you used as part of your daily commute **BEFORE** the collapse of the I-35W Bridge, from the intersection nearest your WORKPLACE or SCHOOL to the intersection nearest your RESIDENCE (if same as above, but in reverse order, write SAME):

Questions Regarding Your Travel Experiences and Choices Surrounding the I-35W Bridge Collapse and Reopening

*The following questions pertain to choices made immediately **AFTER** the collapse.*

Through which sources did you learn or receive coverage of the bridge collapse? (Check all that apply):

- ☐ National or International Media Outlets (CNN, MSNBC, FOX News Network, etc.)
- ☐ Local Media Outlets (FOX 9, KARE 11, WCCO 4, etc.)
- ☐ News Radio or other Radio Services (e.g. MPR, NPR, etc.)
- ☐ Newspapers (Star Tribune, Pioneer Press, etc.)
- ☐ Internet Websites (cnn.com, wcco.com, startribune.com, etc.)
- ☐ Word of Mouth (family, friends, coworkers, neighbors, etc.)
- ☐ Other. Please specify:

In the **DAYS FOLLOWING** the I-35W bridge collapse, how did the amount of media coverage you read or watched (through television, radio, newspaper, internet, or others) compare with a typical day?

No Change

Significant Decrease ○1 ○2 ○3 ○4 ○5 ○6 ○7 Significant Increase

Because of information received about the bridge collapse, regardless of source, did you believe traffic would be worse the next day on your commuting route?

- ○ Yes
- ○ No

Because of information received about the bridge collapse, regardless of source, did you change your normal route on the day **IMMEDIATELY AFTER** the bridge collapse (August 2nd, 2007)?

- ○ Yes
- ○ No

If you changed your normal route on the day **IMMEDIATELY AFTER** the bridge collapse, what motivated you to make the change? (Check all that apply):

- ☐ My old route used the I-35W Bridge.
- ☐ My route was closed for other reasons (i.e. ramp closure because of collapse).
- ☐ I anticipated worse traffic conditions.
- ☐ The media coverage led me to believe that I should change routes.
- ☐ I followed recommendations from family members and/or friends and/or government
- ☐ I decided against traveling that day (e.g. took a day off work, telecommuted, etc.).
- ☐ I had reasons unrelated to the bridge collapse (i.e. changed workplace, switched daycare, etc.).
- ☐ Other. Please specify: ____________

If you changed your normal route on the day **IMMEDIATELY AFTER** the bridge collapse, were you familiar with your new route?

- ○ Yes
- ○ No
- ○ Not Applicable

If you did **NOT** change your normal route on the day **IMMEDIATELY AFTER** the bridge collapse, did you experience congestion?

- ○ Yes
- ○ No
- ○ Not Applicable

If you did **NOT** change your normal route on the day **IMMEDIATELY AFTER** the bridge collapse, did you change routes after that?

- ○ Yes
- ○ No
- ○ Not Applicable

How did your commute after the bridge collapse compare to your commute before the collapse?

- ○ Worse than before
- ○ No change
- ○ Better than before

If your commute after the bridge collapse was **WORSE** than before, how did your commute worsen? (Check all that apply):

- ☐ My travel time increased.
- ☐ I had to make more stops (e.g. at intersections, traffic lights, ramp meters, etc.).
- ☐ There were more cars on the road.
- ☐ I had to use an unfamiliar route.
- ☐ Other. Please specify:

If your commute after the bridge collapse was **BETTER** than before, how did your commute improve? (Check all that apply):

- ☐ My travel time decreased.
- ☐ I had to make fewer stops (e.g. at intersections, traffic lights, ramp meters, etc.).
- ☐ There were fewer cars on the road.
- ☐ Other. Please specify:

Please list the roads that you used as part of your daily commute **IMMEDIATELY AFTER** the collapse of the I-35W Bridge, from the intersection nearest your RESIDENCE to the intersection nearest your WORKPLACE or SCHOOL (if same as before collapse, write SAME):

Please list the roads that you used as part of your daily commute **IMMEDIATELY AFTER** the collapse of the I-35W Bridge, from the intersection nearest your WORKPLACE or SCHOOL to the intersection nearest your RESIDENCE (if same as above, but in reverse order, or same as before collapse, write SAME):

Questions Regarding Your Travel Experiences and Choices Surrounding the I-35W Bridge Collapse and Reopening

On September 18th, 2008, Mn/DOT finished a new I-35W Bridge in place of the collapsed bridge and opened it for the driving public. This bridge reconnected the two segments of I-35W that had been separated because of the collapse. The following questions pertain to choices made ***BEFORE*** *the bridge reopening.*

Please list the roads that you used as part of your daily commute **BEFORE** the reopening of the I-35W Bridge, from the intersection nearest your RESIDENCE to the intersection nearest your WORKPLACE or SCHOOL (if same as after collapse, write SAME):

Please list the roads that you used as part of your daily commute **BEFORE** the reopening of the I-35W Bridge, from the intersection nearest your WORKPLACE or SCHOOL to the intersection nearest your RESIDENCE (if same as above, but in reverse order, write SAME):

Questions Regarding Your Travel Experiences and Choices Surrounding the I-35W Bridge Collapse and Reopening

*The following questions pertain to choices made **AFTER** the bridge reopening.*

Through which sources did you learn or receive coverage of the bridge reopening? (Check all that apply):

- ☐ National or International Media Outlets (CNN, MSNBC, FOX News Network, etc.)
- ☐ Local Media Outlets (FOX 9, KARE 11, WCCO 4, etc.)
- ☐ News Radio or other Radio Services (e.g. MPR, NPR, etc.)
- ☐ Newspapers (Star Tribune, Pioneer Press, etc.)
- ☐ Internet Websites (cnn.com, wcco.com, startribune.com, etc.)
- ☐ Word of Mouth (family, friends, coworkers, neighbors, etc.)
- ☐ Other. Please specify:

In the **DAYS FOLLOWING** the I-35W bridge reopening, how did the amount of media coverage you read or watched (through television, radio, newspaper, internet, or others) compare with a typical day?

No Change

Significant Decrease ◯1 ◯2 ◯3 ◯4 ◯5 ◯6 ◯7 Significant Increase

Because of information received about the bridge reopening, regardless of source, did you change your normal route in the days **IMMEDIATELY AFTER** the bridge reopened?

◯ Yes

◯ No

If you changed your normal route in the days **IMMEDIATELY AFTER** the bridge reopened, what was the reason? (Check all that apply):

- ☐ I expected less traffic congestion on a new route.
- ☐ My old route was closed for other reasons (e.g. ramp closure because of construction).
- ☐ The media coverage led me to believe that I should change routes.
- ☐ I followed recommendations from friends and/or government
- ☐ I decided against traveling that day (e.g. took a day off work, telecommuted, etc.).
- ☐ I had reasons unrelated to the bridge reopening (e.g. changed workplace, switched daycare, etc.).
- ☐ Other. Please specify:

If you changed your normal route in the days **IMMEDIATELY AFTER** the bridge reopened, were you familiar with your new route?

- Yes
- No
- Not Applicable

If you did **NOT** change your normal route in the days **IMMEDIATELY AFTER** the bridge reopened, what was your reason? (Check all that apply):

- I am familiar with my route and like it regardless.
- I expected many people to use the new bridge, hence increasing traffic congestion on that route.
- I am afraid of Minnesota bridges right now and chose not to try the new bridge.
- I had reasons unrelated to the bridge reopening that were not present when the bridge originally collapsed (e.g. new job location, new home location, etc.).
- Other. Please specify:

How did your commute following the reopening compare to your commute before the reopening?

- Worse than before
- No change
- Better than before

If your commute following the reopening was **WORSE** than before, how did your commute worsen? (Check all that apply):

- My travel time increased.
- I had to make more stops (e.g. at intersections, traffic lights, ramp meters, etc.).
- There were more cars on the road.
- I had to use an unfamiliar route.
- Other. Please specify:

If your commute following the reopening was **BETTER** than before, what was the reason? (Check all that apply):

- ☐ My travel time decreased.
- ☐ I had to make fewer stops (e.g. at intersections, traffic lights, ramp meters, etc.).
- ☐ There were fewer cars on the road.
- ☐ Other. Please specify:

Please list the roads that you used as part of your daily commute **IMMEDIATELY AFTER** the reopening of the I-35W Bridge, from the intersection nearest your RESIDENCE to the intersection nearest your WORKPLACE or SCHOOL (if same as before bridge reopening, write SAME):

Please list the roads that you used as part of your daily commute **IMMEDIATELY AFTER** the reopening of the I-35W Bridge, from the intersection nearest your WORKPLACE or SCHOOL to the intersection nearest your RESIDENCE (if same as above, but in reverse order, write SAME):

Please list the roads that you **CURRENTLY** use as part of your daily commute, from the intersection nearest your RESIDENCE to the intersection nearest your WORKPLACE or SCHOOL (if same as after reopening, write SAME):

Please list the roads that you **CURRENTLY** use as part of your daily commute, from the intersection nearest your WORKPLACE or SCHOOL to the intersection nearest your RESIDENCE (if same as above, but in reverse order, write SAME):

On a scale of 1 to 7 (1 being very bad and 7 being very good), please rate how you feel about your current route.

			Indifferent				
Very Bad	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Very Good

Questions Regarding Your Travel Experiences and Choices Surrounding the I-35W Bridge Collapse and Reopening

The following questions pertain to your general choices. Please answer as accurately as possible.

How much time did you spend watching national news (e.g. CNN, MSNBC, FOX News) **YESTERDAY?**

Hours Minutes

How much time did you spend watching local news (e.g. KARE 11, FOX 9, WCCO 4) **YESTERDAY?**

Hours Minutes

How much time did you spend watching television **YESTERDAY**?

Hours Minutes

How much time did you spend listening to radio for news reports (e.g. MPR, NPR) **YESTERDAY**?

Hours Minutes

How much time did you spend listening to broadcast radio **YESTERDAY**, regardless of purpose?

Hours Minutes

How much time did you spend using the internet for news sources (e.g. cnn.com, startribune.com, wcco.com) **YESTERDAY**?

Hours Minutes

How much time did you spend using the internet **YESTERDAY**, regardless of purpose?

Hours Minutes

Did you learn of newsworthy events through word of mouth **YESTERDAY**?

- Yes
- No

When hearing of an incident, such as a bridge collapse, which of the following sources makes you perceive the incident to be **MOST SERIOUS**?

- National or International Media Outlets (e.g. CNN, MSNBC, FOX News Network, etc.)
- Local Media Outlets (e.g. FOX 9, KARE 11, WCCO 4, etc.)
- News Radio or other Radio Services (e.g. MPR, NPR, etc.)
- Newspapers (e.g. Star Tribune, Pioneer Press, etc.)
- Internet Websites (e.g. cnn.com, wcco.com, startribune.com, etc.)
- Word of Mouth (e.g. family, friends, coworkers, neighbors, etc.)
- No single source stands out above the rest

As a result of the bridge collapse, do you feel uncomfortable with using bridges?

- Yes
- No

IF YES:

Do you choose your routes to avoid bridges if possible?

- Yes
- No

What is your gender?

- Male
- Female

What is your age group?

- Less than 18 Years
- 18 - 24 Years
- 25 - 34 Years
- 35 - 44 Years
- 45 - 54 Years
- 55 - 64 Years
- 65+ Years

What is your annual household pre-tax income group?

- $30,000 or less
- $30,000 - $49,999
- $50,000 - $74,999
- $75,000 - $99,999
- $100,000 - $124,999
- $125,000 - $149,999
- $150,000 or above

Please list the trips you took **YESTERDAY** (e.g. to work, grocery store, pharmacy, daycare, etc.), as well as the estimated length of travel time. If roundtrip, please note this next to the description. Identifying the route used is **NOT** necessary.