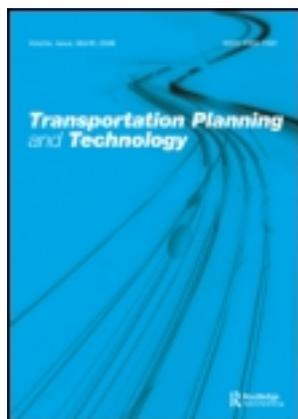


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### Evaluating the effects of the I-35W bridge collapse on road-users in the twin cities metropolitan region

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## Evaluating the effects of the I-35W bridge collapse on road-users in the twin cities metropolitan region

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This study evaluates the effects of the I-35W bridge collapse on road-users in the Minneapolis-St Paul, Minnesota Twin Cities metropolitan area. We adopted the Twin Cities Seven-County travel demand model developed in previous research, re-calibrated it against July 2007 loop detector traffic data, and used this model to carry out an evaluation of economic loss incurred by increased travel delay in alternative scenarios before and after the bridge collapse. We conclude that the failure of the I-35W bridge resulted in an economic loss of US\$71,000 to US\$220,000 a day, depending on how flexible road-users in the system adjusted their trip destinations in response to the bridge closing. We also estimate that the major traffic restoration projects Minnesota Department of Transportation has implemented in quick response to the bridge collapse can save road-users US\$9500–17,500 a day. This translates into a benefit–cost ratio of 2.0–9.0, suggesting these projects are highly beneficial in an economic sense. In this analysis, the use of a simplified, scaled-down travel demand model enabled us to carry out the analysis quickly and accurately, which could see its contributions in transportation planning under situations such as emergency relief and comprehensive design.

**Keywords:** transportation planning; economic impact; travel demand; benefit–cost

### 1. Introduction

On 1 August 2007, the I-35W bridge over the Mississippi River in Minneapolis, Minnesota tragically collapsed. Located immediately adjacent to downtown Minneapolis and the University of Minnesota, and only one mile northeast of the junction with interstate I-94, the eight-lane bridge had served as a region-wide corridor for commuters and drivers to get to and from business areas and destinations in the northern suburbs. In 2004, the bridge was crossed by 140,000 vehicles on an average day. In addition to the immediate costs incurred by casualties and property damage, the collapse of the bridge has significantly impacted the surrounding transportation system in the Twin Cities Metropolitan region.

The bridge failure has also dramatically changed the traffic conditions region-wide. The traffic that used to use this bridge has had to divert to alternative routes, leading to increased congestion in the nearby area, and many switching departure times, modes, or destinations to avoid traffic. The increased driving distance and

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travel time, on the other hand, caused economic losses to road-users. Although transportation-related costs incurred by unplanned network disruptions following natural disasters, terrorist attacks, infrastructure failures, etc. have been a subject of long-lasting interest for both scholars and practitioners, the literature is limited due to the difficulty of data collection after unplanned disruptions, especially when traffic monitoring devices are not widely deployed. Zhu and Levinson (2008) provide a comprehensive survey of both theoretical and empirical studies on the traffic and behavioral impacts of network disruptions. For example, among a few quantitative analyses, Wesemann et al. (1996) estimated that the transportation-related costs of the Northridge Earthquake in California exceeded US\$1.6 million per day.

Minnesota Department of Transportation's (Mn/DOT) initial study, based on the rough assumptions that only two detour routes were available to the 140,000 users of the bridge and that 90,000 of them would use one route while 50,000 would use the other, concluded that road-user costs due to the unavailability of the river crossing would total US\$400,000 per day (Minnesota Department of Transportation 2007). In response to a request from Mn/DOT Office Investment Management Office (OIM), we carried out a quick evaluation of the effect of the I-35W bridge removal five days after the tragedy. We estimated the traffic patterns before and after the bridge collapse using an established Twin Cities region travel demand and investment model, and evaluated the economic loss imposed on road-users in terms of increased travel time delay. This estimate had more than intellectual importance; it was used to value the payment to contractors for early completion of a replacement bridge.

This paper, extending our preliminary analysis, revisits the question regarding the effect of the I-35W bridge collapse on the regional transportation system. The remainder of this paper proceeds as follows: Section 2 introduces the Twin Cities Region travel demand model we constructed for previous research purposes, which was improved for this study through re-calibration against peak hour traffic counts in July 2007. Since no real-time traffic data for July 2007 was available when the preliminary analysis was conducted, the travel demand model in the analysis was calibrated to the 2005 peak hour traffic volumes for a quick assessment; the present analysis, on the other hand, calibrates the model to the peak hour traffic for the last week of July 2007 in order to better represent the traffic conditions immediately before the bridge collapsed. Except for the model calibration part, both analyses were carried out following the same procedure. Scenarios are then tested to predict the traffic pattern before and after the bridge collapse, and road-users' economic loss evaluated based on different assumptions. Section 5 highlights our findings and indicates their implications.

## 2. Model

The Travel Demand and Investment Model, SONG 2.0, was developed for the Mn/DOT-supported project *Beyond Business As Usual* to forecast the future Twin Cities Seven-County road network, with the assumption that travel demand will behave according to the same factors that have affected it in the past (Levinson *et al.* 2009), though still a function of population, employment, and accessibility. To be consistent throughout the periods of 1990–2030, the 1990 Transportation Planning Network was adopted, which consists of 20,380 links, 7723 nodes, 1165 Transportation Analysis Zones (TAZs) in the Seven County Metro Area, and 35 external stations,

which make a total of 1200 zones for analysis. Link capacities and other attributes were updated in different years.

The travel demand model in SONG 2.0 predicts traffic in the morning peak hour, calibrating against real traffic data in 2005, and then using peak hour to daily expansion factors where required to obtain Annual Average Daily Traffic (AADT) (which is required in some of the investment models). The duration of one model run was limited within an hour, though one needs to realize the short running time has been achieved at the cost of sacrificing some realism: this model simplifies the traditional four-step travel demand forecasting process by dropping mode choice, and instead directly estimates vehicle trips (in other words, we do not model freight trips directly, and instead calibrate the model to the real vehicular traffic volumes to account for missing trucks). We also do not differentiate trips by their purposes. The assumptions that enter into the SONG model are fully documented in Appendix B of the technical report for the *Beyond Business as Usual* project (Levinson *et al.* 2006). The three major components of the model are discussed in subsequent sections.

### 2.1 Trip generation

Trip generation estimates the number of personal motor vehicle trips that originate from or are destined for each zone. The production and attraction models were separately estimated by regressing the composite 2005 morning peak-hour vehicle trip rates by traffic analysis zones obtained from the Metropolitan Council on a series of zonal characteristic variables. The model that provided the highest goodness-of-fit in terms of R-Squared and had the most significant variables included the following explanatory variables: population; retail employment; non-retail employment; residential density; shortest distance from centroid zone to either downtown Minneapolis or St Paul; and shortest previous distance squared.

These variables are consistent with the zonal demographic and geographical variables identified in other planning studies. As zonal demographic information is not directly available for 2007, we used 2005 data and the 2010 forecasts, both obtained from the Metropolitan Council to produce trip generation estimates for 2007 by interpolation.

### 2.2 Trip distribution

Trip distribution procedures match trips produced with trips attracted. In this research the trip distribution is made for all trip purposes combined, since the trip generation model above does not distinguish trips by purpose. This study includes a doubly constrained gravity-based trip distribution model. The gravity model shows the interaction between zones, which decreases with travel cost but increases with the number of trips produced by or attracted to each zone:

$$T_{ij} = K_i K_j T_i T_j e^{-\theta C_{ij}} \quad (1)$$

where:

$K_i, K_j$  = balancing coefficients;  
 $T_i$  = trip production of zone  $i$ ;

$T_j$  = trip attraction of zone  $j$ ;

$C_{ij}$  = the travel time between  $i$  and  $j$  in hours.

The gravity model assumes that the effect of distance or ‘separation’ can be modeled by a decreasing function – in this case, the negative exponential function of the travel cost between the zones. The friction factor  $\kappa$  is a parameter in this function for calibration. A friction factor is an inverse function of travel time, which indicates whether people prefer longer or shorter trips. With the decline function specified, an iterative algorithm is executed to find the balancing coefficients ( $K$ ). The doubly constrained trip distribution model estimates balancing coefficients  $K_i$  and  $K_j$  such that the total number of trips originating from zone  $i$  matches with trip production of zone  $i$  (estimated from the trip production model) and the total number of trips destined for zone  $j$  matches with trip attraction of zone  $j$  (estimated from the trip attraction model).

### 2.3 Traffic assignment

Traffic assignment describes how trips between an origin and a destination are allocated to different routes. In this research the traveler chooses the route with the lowest perceived travel time, which is referred to as a Stochastic User Equilibrium (SUE)(Sheffi 1985), wherein no driver can unilaterally change routes to improve his/her perceived travel times. As elaborated by Sheffi (1985), Dial’s algorithm is used to perform network loading and the Method of Successive Averages (MSA) to find the stochastic user equilibrium. Coding work implementing Dial’s Algorithm was used by Davis and Sanderson (2002) for the traffic assignment phase, though the code has been translated by the authors from FORTRAN to Java and optimized. This codebase generates good results on smaller test networks such as Sioux Falls and Waseca. The algorithm adopts the Bureau of Public Roads (BPR) link performance function by which the congested link travel time increases with the volume-to-capacity ratio to the fourth power (Bureau of Public Roads 1964). The scaling coefficient used in the discrete choice model is 0.2 following Leurent (1995). The convergence for MSA is defined by a maximal allowable link flow change below a threshold of 100 vehicles. The selection of this threshold of 100 vehicles is again a tradeoff between accuracy and running time. A declining flow change across a network indicates the convergence of traffic assignment. When the maximal flow change is close to zero, the resulting flow pattern represents the user equilibrium traffic condition. Clearly the closer the specified threshold is to zero, the closer the resulting traffic pattern is to equilibrium.

### 2.4 Calibration

The travel demand model in SONG 2.0 was originally calibrated with 2005 morning peak hour volumes. In order to improve the level of accuracy of our analysis, the model was re-calibrated against real traffic data for July 2007 extracted from loop detector counts. Mn/DOT maintains around a 1000 traffic count detector stations on freeways and major highways throughout the Twin Cities Metro area. Measured volume and occupancy data are made public via XML files updated every 30 seconds. As much as the authors would like to calibrate the model with all the

stations, the complexity of matching every station with the corresponding link in the planning network involves an immense amount of work. To date, there is no correlation table for all the traffic count stations and the node and link structure of the Twin Cities planning model (Xie and Levinson 2008). Instead, we randomly picked 10% of the full set of detector stations, removed malfunctioning detectors, and matched 63 of the remaining stations with the planning network, which consist of a total of 166 detectors located around the Metro Area on routes I-35W, I-35E, I-94, I-394, I-494, I-694, TH 5, TH 36, TH 62, TH 77, TH 100, TH 169 and TH 212, as shown in Figure 1. The morning peak hour volumes were then produced using the average of real count data from 7:00 am to 9:00 am on Monday, Wednesday, and Friday in the last full week of July 2007.

The goal of this calibration is to minimize the difference between the morning peak hour volumes estimated by the model and actual morning peak hour volumes on the selected set of links. As trip generation models have been calibrated separately, the only parameter that was adjusted in this calibration is the distribution model friction factor. The final model has a friction factor of 0.14/min, resulting in an overall 0.71% error between the average volumes that go by the forecasts and the average real counts given by the detectors. The R-squared value, estimated by regressing forecast peak hour volumes on observed volume for selected stations, is 0.91. The root mean square error (RMSE) is about 33.6%. However, there may still be room to improve the RMSE by increasing the realism of our simplified model. Considering the geographical scale of the Twin Cities Metropolitan area, however, travel demand models developed for this region usually result in RMSEs at the high end of the 30–40% range. Taking this as a yardstick, our current model performs relatively well in terms of providing accurate travel forecasts for the region.

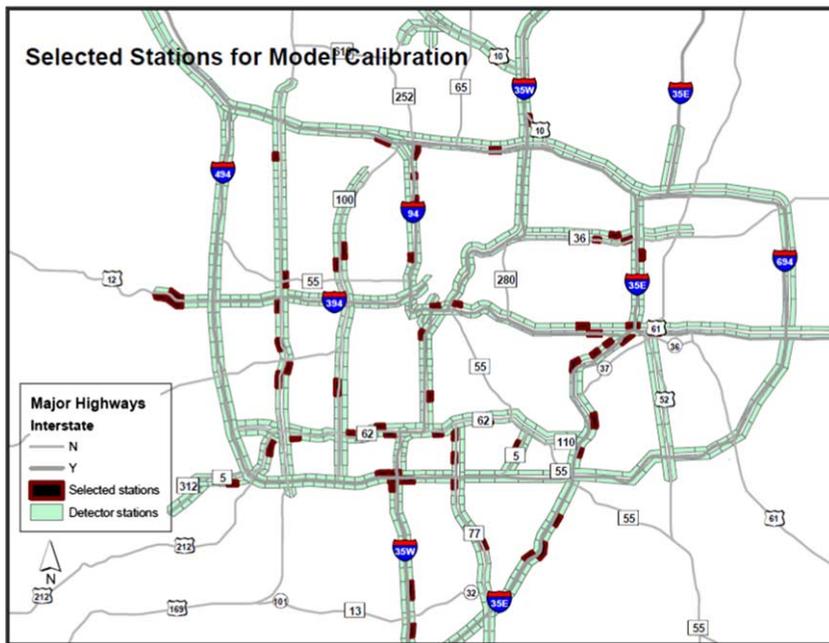


Figure 1. Selected 63 detector stations for calibration.

### 3. Evaluation

Using the calibrated travel demand model, we estimated traffic patterns across the Twin Cities road network with and without the I-35W bridge. Alternative after-bridge-collapse scenarios were tested under different assumptions. The first kept the trip table fixed as it was before the bridge collapsed. This means that people did not change the number of trips, or destinations, in response to the bridge failure. This should give an upper bound to the effects of the bridge failure. The second allowed destinations of all trips to vary (though keeping the number of trips fixed). This provides more of a lower bound of the effects. The assumption that all trip destinations can vary does not mean all trips actually change their destinations. As the gravity-type model predicts trip distribution on an aggregate level according to travel costs between origins and destinations, how many trips will change destinations depends on the extent to which travel cost increases to reach previous destinations.

We believe that the reality lies somewhere between the two extreme scenarios: clearly some people can switch destinations, change departure times to avoid peak hour traffic, or avoid trips altogether, if the cost of reaching their previous destinations are now too high; not everyone, on the other hand, has the flexibility to do so. Examples include commuting workers and college students. Scenarios 1 and 2 are tested on the crippled road network, which is created by directly removing the two directional I-35W bridge links from the base-scenario planning network, while ignoring Mn/DOT's efforts to restore traffic after bridge collapse through infrastructure upgrades. These traffic restoration projects and upgrades included converting a substandard interchange, temporary signals on ramps, widening ramps to two lanes and adding lanes. Scenarios 3 and 4 included these upgrades in an updated planning network and re-ran the model with a variable trip table and a fixed trip table, respectively.

Table 1 summarizes the tested scenarios based on alternative assumptions. As can be seen, the comparison between scenarios with fixed trip tables versus those with variable trip tables indicate how economic losses incurred by network disruptions could be affected by road-users' behavioral responses to the disruptions; on the other hand, the economic gains from the scenarios without network upgrades to those with upgrades are used to evaluate the cost-effectiveness of these restoration projects.

At an aggregate level, the model computes daily vehicle hours of travel (VHT) and vehicle kilometers of travel (VKT) as direct outputs. Our model estimates morning peak hour traffic, expands it into daily traffic, and computes daily VHT using peak hour travel time, which may exaggerate the actual vehicle travel time, as trips that occur in non-peak periods experience a shorter travel time as opposed to

Table 1. Description of scenarios.

Scenario	Time	Trip table after 1 August	Planning network
0 (Base)	Before bridge collapse	–	Complete network
1	After bridge collapse	Variable	Crippled network
2	After bridge collapse	Fixed	Crippled network
3	After bridge collapse	Variable	Crippled network with upgrades
4	After bridge collapse	Fixed	Crippled network with upgrades

those in peak periods. Given the fact that nearly half of all daily trips (45.7%) in 2000 occurred during the morning and evening peak periods (Metropolitan Council 2003), however, we believe our estimates constitute a close approximation without introducing too much error. A peak hour-to-daily factor of 0.08 is adopted from our previous research, estimated using the average peak hour and daily traffic counts from 2005 detector data. The model also computes average trip length and average trip time during the morning peak hour.

The economic loss incurred by the bridge collapse is evaluated by road-users' increased vehicle hours of travel due to the closed river crossing, monetized using values of time from Minnesota Department of Transportation (2005). Automobiles and trucks have different values of time of US\$12.63/hr and US\$20.41/hr, respectively. As our model does not differentiate between cars and trucks, we instead generated a composite value of time of US\$14.19 by assuming 80% auto and 20% truck – an admittedly rough assumption whose robustness needs to be examined in a future study that includes a separate freight model.

The model also computes a series of accessibility measures which indicate the relative ease of reaching valued destinations. The isochronic or cumulative opportunity measure is one of these basic accessibility measures. This approach counts the number of potential opportunities that can be reached within a predetermined travel time (or distance). In this case, we calculated the average number of job opportunities that can be reached in 10 mins, 20 mins, and 30 mins from a zone.

We also calculated the point accessibility from workers to jobs and from jobs to workers for each zone using the following mathematical relation:

$$A_i^E = \sum_j E_j f(C_{ij}) \tag{2}$$

$$A_i^W = \sum_j W_j f(C_{ij}) \tag{3}$$

where:

$E_i$  = employment (jobs) at zone  $i$ ;

$W_i$  = resident workers at zone  $i$ ;

$C_{ij}$  = the cost to travel between  $i$  and  $j$ .

The cost function  $f(C_{ij})$  is determined using a gravity model, which states that the cost of traveling from origin  $i$  to destination  $j$  is inversely related to the distance between them:

$$f(C_{ij}) = e^{-\theta C_{ij}} \tag{4}$$

Note that the friction factor  $\kappa$  takes the same value as the friction factor in the trip distribution model Eq. (1).

#### 4. Results

The failure of I-35W bridge has resulted in significant changes in traffic conditions in the surrounding area. Figure 2 and 3 display the estimated Volume-Capacity (V/C) ratios on individual links before (Scenario 0) and after (Scenario 2) the bridge collapse, respectively. Together they illustrate how the removal of the bridge connection has impacted the traffic pattern across the network. As we can see in Figure 2, before the bridge collapsed, the interchange between I-35W and I-94, as well as the junction of I-94 and I-394, represents the most congested spots around downtown Minneapolis. After the bridge collapsed, as shown in Figure 3, severe congestion occurred at I-94 around the I-394 junction, and at TH280 around the I-394 junction, two major detour routes designated by Mn/DOT after 1 August. All the remaining bridges across the Mississippi River became more congested, especially the 10th Ave bridge, the one immediately to the right of the I-35W bridge. In contrast, the I-35W section north of Mississippi River to the TH36 junction saw a significant drop in traffic after the bridge closing.

Table 2 reports the Measure of Effectiveness (MOE) and accessibility measures in alternative scenarios. Note that these are direct model outputs, so while the precision is high, the accuracy is not nearly as high as implied by the precision.

As can be seen in Scenario 1 under which all people are free to change their trip destinations, the bridge failure has resulted in a 0.35% increase of daily vehicle hours of travel from 1.427 million to 1.432 million due to increased congestion. The increase in total vehicle travel time translates into a monetary loss of about US\$71,000 a day, which represents the lower bound of economic loss as in this case people enjoy the highest flexibility among all the after-bridge-collapse scenarios in terms of adjusting trip destinations in response to the bridge failure. Total vehicle

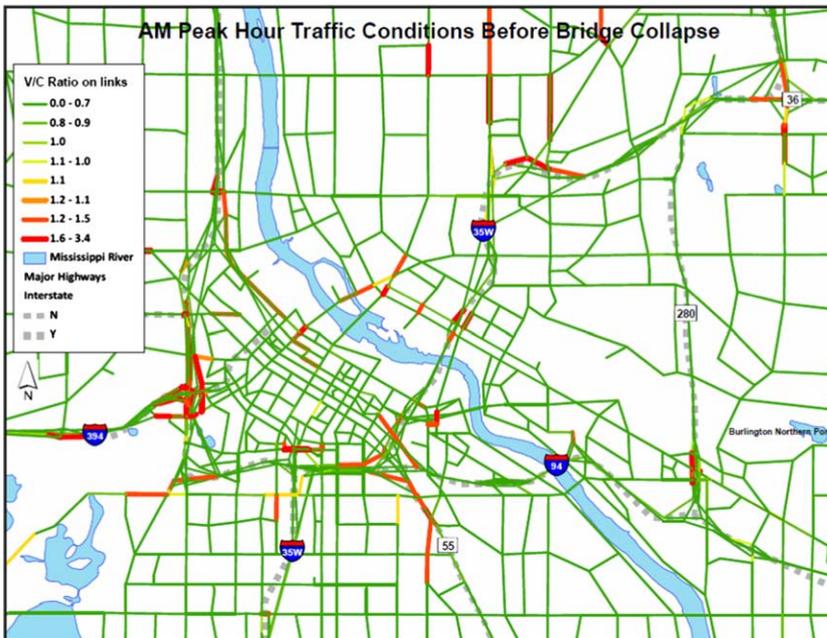


Figure 2. Traffic conditions before I-35W bridge collapse – morning peak hour.

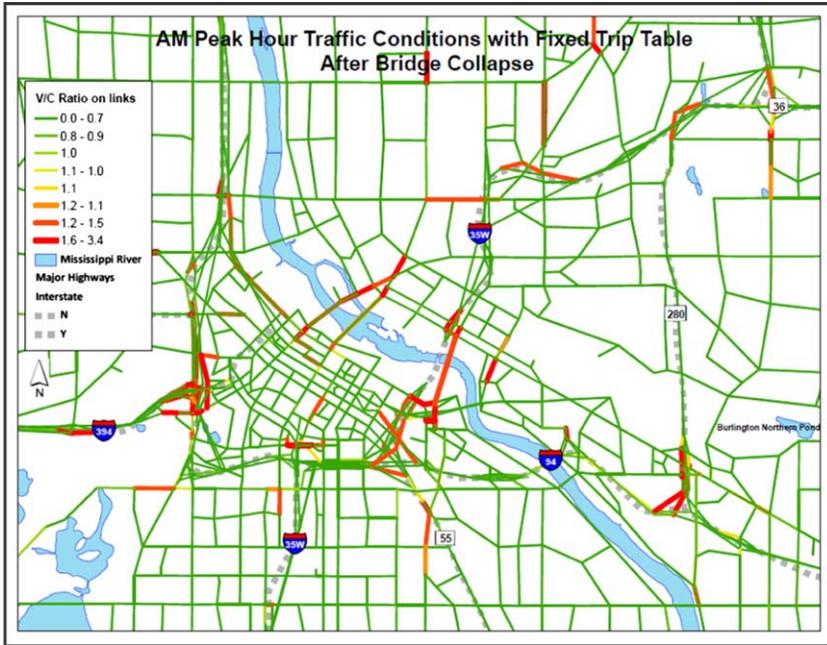


Figure 3. Traffic conditions with a fixed trip table after I-35W bridge collapse – morning peak hour.

kilometers of travel in Scenario 1, on the other hand, decreased by 0.31%. This is not surprising because some people switched to nearer destinations with a higher cost to reach their previous destinations. This can be corroborated by the results of a shorter average trip length but longer trip time as compared to the base scenario. Although people can switch to closer destinations, the job opportunities that can be reached during a specific duration have unavoidably decreased on the crippled network, so have the gravity-type measures of accessibility to jobs and workers in the metropolitan area. Scenario 2 represents the ‘worst-case’ scenario, as nobody can change their destinations despite increased travel cost after the bridge collapse. Consequently, both VHT and VKT have increased due to longer driving time and distance. Accordingly, accessibility to jobs and workers has significantly decreased after the bridge collapse. The increased vehicle time of travel with the fixed trip table amounts to about US\$220,000 a day, which suggests the upper bound of economic loss.

Thus it is estimated that the economic loss incurred by the I-35W bridge collapse on road-users in the Twin Cities Metro area is US\$71,000 to US\$220,000 a day, depending on how flexible people switch their destinations. As the exact number of people who change their destinations is not something we can easily know, we re-ran our model assuming that after the bridge collapse one-third and two-thirds of all trips are destined to their previous destinations, respectively. According to the Metropolitan Council (2003), home-based work trips account for 34.3% of all trips that occur during the morning peak hour. Thus the one-third assumption would be close to reality if all the home-based work trips had fixed their destinations but other

Table 2. MOEs and accessibility measures in alternative scenarios.

	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Daily VHT (10 <sup>6</sup> veh. hrs)	1.427	1.432 (0.35%)	1.442 (1.09%)	1.431 (0.31%)	1.441 (1.00%)
Daily VKT (10 <sup>6</sup> veh. kms)	86.53	86.27 (-0.31%)	86.58 (0.05%)	86.27 (-0.30%)	86.58 (0.06%)
Daily economic loss (US\$)	NA	71,466	220,198	62,408	203,409
Average trip length (kms)	18.82	18.76 (-0.31%)	18.83 (0.05%)	18.76 (-0.30%)	18.83 (0.06%)
Average trip time (mins)	18.61	18.68 (0.35%)	18.82 (1.09%)	18.67 (0.31%)	18.8 (1.00%)
Jobs reached in 10 mins	110,072	108,036 (-1.85%)	107,692 (-2.16%)	108,255 (-1.65%)	107,931 (-1.95%)
Jobs reached in 20 mins	557,514	545,791 (-2.10%)	543,669 (-2.48%)	546,751 (-1.93%)	545,230 (-2.20%)
Jobs reached in 30 mins	1,105,462	1,089,406 (-1.45%)	1,087,226 (-1.65%)	1,090,994 (-1.31%)	1,089,424 (-1.45%)
Accessibility to jobs	3.23E+11	3.17E+11 (-1.70%)	3.17E+11 (-2.00%)	3.18E+11 (-1.58%)	3.17E+11 (-1.83%)
Accessibility to workers	3.30E+11	3.25E+11 (-1.55%)	3.24E+11 (-1.79%)	3.25E+11 (-1.41%)	3.25E+11 (-1.60%)
August 2007, % from average	NA	0.52%	1.57%	0.61%	1.66%
August 2007, RMSE	NA	37.98%	38.35%	38.03%	38.44%
October 2007, % from average	NA	-5.81%	-4.82%	-5.73%	-4.74%
October 2007, RMSE	NA	32.18%	32.00%	32.17%	32.01%

Note: Numbers in parentheses indicate percentage change of a measure compared to its counterpart in the base scenario.

trips did not; the two-thirds assumption would be meaningful if we assume all the home-based work trips and half of other trips fix their destinations.

Not surprisingly results produced with one-third and two-thirds assumptions lie between those in Scenario 1 and in Scenario 2. With one-third of all trips being fixed, the economic loss amounts to about US\$120,000 a day, and if it is two-thirds, the loss increases to about US\$170,000 a day. Scenarios 3 and 4 that incorporate an updated planning network have resulted in a lower economic loss as compared to their counterparts, Scenarios 1 and 2. The calculated reduction in economic loss suggests that the major upgrades Mn/DOT has implemented on road infrastructure in response to the bridge failure can save road-users US\$9500 (with a variable trip table) to US\$17,500 (with a fixed trip table) a day, which translates into a direct economic benefit of approximately US\$4.8–21.3 million, as the new I-35W bridge did not open until 24 December 2008 (511 days after the bridge collapse). Given the total budget of the restoration projects we have included in this analysis amounts to no more than US\$2.4 million, the estimated benefit–cost ratio of these upgrades ranges from 2.0 to 9.0, indicating the restoration projects are highly beneficial in an economic sense.

To have an idea of how accurately our model under alternative assumptions predicted the real traffic pattern after the bridge collapse, we extracted the peak hour detector data for the selected stations in the last full week of August 2007 and in October 2007, respectively, and compared model forecasts to the real traffic counts. The percentage of average forecast traffic counts on selected links as compared to observations was computed, as well as the RMSE for all after-bridge-collapse scenarios. As shown in Table 2, our model achieves an average error below 2% and a RMSE of around 38% in all the scenarios when using the detector traffic counts in August. RMSE dropped significantly to about 32% in October, over two months after the shock of the bridge collapse, when traffic order was restored and a new equilibrium reached. Although no significant difference is observed, Scenarios 1 and 3 – assuming a variable trip table – seem to outperform their counterparts with a fixed trip table in August in terms of producing smaller average error and RMSEs, but this situation is reversed in October. This could be explained by the fact that in August people were still in shock of the tragedy and tended to adjust their destinations to avoid crossing the river; while in October, when order was restored, most people switched back to their previous destinations.

## 5. Conclusions

This study has evaluated the effects of the I-35W bridge collapse on road-users in the Twin Cities Metropolitan area. We adopted the Twin Cities Seven-County travel demand model developed in previous research, re-calibrated it against July 2007 loop detector traffic data, and used this model to carry out an evaluation of economic loss incurred by increased travel delay in alternative scenarios before and after the bridge collapse. We conclude that the failure of the I-35W bridge resulted in an economic loss of US\$71,000 to US\$220,000 a day, depending on how flexible road-users in the system adjusted their trip destinations in response to the bridge closing. The evaluation of road-users' daily economic loss provided some general guidance and insight for decision-makers in incident response and traffic restoration, in addressing issues like bonus-setting for contractors associated with the construction period of

the replacement bridge. According to Kaszuba and Foti (2007), Mn/DOT set a US\$200,000 a day bonus (up to 100 days) for an early finish of the I-35W new bridge, which nicely falls in the range of estimated users' economic loss between US\$71,000 and US\$220,000 a day. Considering that some people could switch their departure times, modes, or destinations in response to the bridge collapse, however, the bonus amount may have been a little high. Based on the economic loss calculation, we also estimated that the major traffic restoration projects Mn/DOT has implemented in quick response to the bridge collapse saved road-users US\$9500 to US\$17,500 a day. This translates into a benefit–cost ratio of 2.0–9.0, suggesting these projects are highly beneficial in an economic sense.

This analysis could be treated as a 'back of the envelope' calculation in order to capture the magnitudes of the economic impact of the bridge closure. The use of a simplified, scaled-down travel demand model enabled us to carry out the analysis quickly and accurately. The duration of one scenario test was limited to less than an hour's processing time, which is quite fast considering the magnitude of the Twin Cities transportation system; the travel demand model achieved an R-squared value of 0.91 and RMSE of 0.33 in calibration, and was able to predict the changes in traffic conditions after the bridge collapse. A longer period of time, improvements in the modeling techniques and assumptions may generate more accurate results. This type of analysis, however, could contribute to transportation planning in situations such as emergency relief and comprehensive design.

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