Travels Impacts of Bridge Closures 1: Lafayette Bridge Final Report

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Abstract

This study evaluates traffic reactions to two alternative construction plans of Lafayette Bridge crossing the Mississippi River in downtown Saint Paul, Minnesota. We calibrate a travel demand model previously developed and evaluate network performance in different construction phases of the two alternative scenarios. Most significant changes in traffic condition occur during the bridge closure phase of scenario 2. The measurable impacts of bridge closure on traffic conditions are limited within the region of I-494 and US 61 to the east and I-35E to the west. The increases in freeway traffic are moderate. Most travelers choose to use the arterial bridges as alternative routes. The Robert Street Bridge and the Wabasha Street Bridge will see significant traffic increases. Overall changes in consumer surplus indicate that scenario 2 has a somewhat higher user cost ($5,209/day). However, the magnitude of difference in consumer surplus is very small and well within "margin of error". The ultimate decision needs to consider construction cost savings due to faster construction, and safety issues in addition to changes in user cost.

1 Introduction

One of four bridges in the United States are operating in a "structurally deficient or functionally obsolete" state according to analysis of bridge inspection data posted by the US Department of Transportation (Lotke et al., 2008). Given limited available funding, it is important to evaluate different investment scenarios carefully and spend wisely to maximize social benefit. Therefore, this project investigates the potential traffic impacts on the regional transportation system under different scenarios for staging replacement of the US 52 Lafayette Bridge in Saint Paul, Minnesota. A regional travel demand model, which has been previously to support the project "Beyond Business as Usual", is adopted for this study after being re-calibrated against real traffic counts in 2010. The same model has been previously applied in investigating the traffic impacts of I-35W Bridge collapse (Xie and Levinson, 2009) and generated estimates that are consistent with posterior estimation obtained through GPS-based field study (Zhu et al., 2010). The reminder of this technical memo proceeds as follows: the next section introduces the background of the Lafayette Bridge replacement project and the two alternative construction plans. The travel demand model is then described in detail and re-calibrated against peak hour traffic counts in April 2010. Scenarios are then tested to predict the traffic pattern under alternative scenarios, and road-users' economic losses are evaluated based on different assumptions. The conclusion highlights findings from the study and their implications for transportation agencies.

2 Background

Lafayette Bridge carries US 52 across the Mississippi River in downtown Saint Paul, Minnesota. After more than 40 years of operation, it is scheduled to be replaced, beginning from the Winter 2010/2011. Two replacement plans have been proposed. Under scenario 1, the construction of a new northbound bridge will start Winter 2010/2011, while the existing bridge remains open with current lane geometry. The north bound bridge will be finished

in Fall 2012. Then all traffic will be directed to the new northbound bridge, which will be temporally configured as 2 lanes in each direction with very narrow shoulders and a median barrier. The southbound bridge will start in Spring 2013 and the entire project will be completed in Fall 2014. At completion, both northbound and southbound new bridges will have 2 lanes plus an auxiliary lane from I-94 to Plato Blvd plus shoulders.

Under scenario 2, the old Lafayette Bridge will be closed to traffic and demolished starting from Winter 2010/2011. The new bridges will then be constructed and both northbound and southbound new bridges will be opened in Fall 2012.

Under both scenarios, the traffic crossing the Mississippi River are expected to be significantly impacted. Alternative river-crossing bridges include the I-494 Wakota Bridge to the east and the I-35E bridge to the west (see Figure 1 for their locations). Wakota Bridge is currently under construction. Upon completion of the Wakota Bridge in July 2010, each direction of I-494 across the Wakota bridge will have three through lanes plus two auxiliary lanes. Also, each direction of I-494 between the Wakota Bridge and I-94 will have three lanes from July 2010. Besides these two freeway bridges, traffic could also use parallel arterial bridges, including the TH 149/Smith Avenue Bridge, the Wabasha Street Bridge, and the Robert Street Bridge. Additionally, rerouting of Lafayette Bridge traffic could further change travel behavior of other travelers in the region. Therefore, this project investigates regional traffic reactions to different scenarios, with a focus on neighboring Mississippi River crossings. Next section describes the model and its calibration.

3 Model

The travel demand model used in this project is based on the SONG 2.0 model which is originally designed to support project "Beyond Business as Usual" ((Levinson et al., 2010)). This model predicts the travel demand and forecasts the future metropolitan (Seven County) road network with assumptions that network investments are driven by travel demand growth and the factors that have shaped the travel demand in the past will affect future demand in a consistent pattern. Necessary refinement has been made in this study to account for the changes in network structure (e.g. new freeways and bridges) and demographics. The new 2009 Metropolitan Council planning network that has been conflated to real network geometry is adopted. This network includes 22,477 links, 8,619 nodes, 35 external stations, and 1,236 transportation analysis zones (TAZ) for demand analysis. Links are divided into 15 categories according to their functional classes and link capacities, including AM peak, PM peak and off-peak capacities, are estimated by Metropolitan Council. The travel demand model, an implementation of the model developed by Levinson, has been calibrated against the real traffic measured by the loop detectors, and then used to predict the morning peak hour traffic. The model also estimates the morning peak hour factor using the detector data and expands peak hour traffic to AADT. Given that the public transit ridership only accounts for 3% of daily travels in the Twin Cities area, our model drops the mode choice module and directly estimates vehicle trips as a simplification of the traditional four-step process. For the same reason, the freight traffic is not explicitly modeled in this study. Instead, we inflate the passenger car traffic to account for the missing freight traffic. More details about the three major components of our demand model is discussed in appendices.

3.1 Calibration

The travel demand model is calibrated against traffic data provided by loop detector stations. MnDOT maintains about a thousand traffic count stations on freeways throughout the Twin Cities Metro area. Volume and speed is measured every 30 seconds and the data are documented at MnDOT traffic data server. As much as the authors would like to calibrate the model with all the stations, the complexity of matching every station with the correspond link in the planning network involves immense amount of time. 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. Instead, we randomly picked 10% of the full set of detector stations, removed malfunctioning detectors, and matched 73 out of the remaining stations with the planning network. As shown in Figure 1, this set of detector stations represents a good sample of the entire Twin Cities freeway system, including I-35W, I-35E, I-94, I-494, I-694, I-394, TH 36, TH 52, TH 62, TH 77, TH 100, TH 169, TH 212 and TH 280. The morning peak hour traffic rate is estimated by averaging the traffic volume from 7:00 am to 9:00 am during the weekdays of the first full week, April 2010. The peak hour rate, which is used to expand peak hour cost to daily cost, is estimated by comparing the peak hour rate and daily volume of observed at these stations.

The target of calibration is to minimize the different between the morning peak hour volumes estimated by the model and the actual morning peak hour volume observed on the selected set of links. As trip generation models have been calibrated separately and the peak hour factor has been directly estimated from the traffic data, the only parameter to be adjusted in calibration is the trip distribution friction factor θ. The parameter is calibrated by using a brute force search technique. The friction factor that provides the best fit is 0.151/min, resulting in an overall 0.25% error between the average volumes that predicted by the model and the average real traffic count given by the detectors. The $R - Squared$, estimated by regressing forecast peak hour volumes on observed volume for selected stations is 0.94. The root mean square error (RMSE), defined by the formula below, is about 28%.

$$RMSE = \sqrt{\frac{(V_n^M - V_n^O)^2}{N-1}} / \bar{V}_n^M$$

Where:

V_n^M is the estimated traffic volume on link n; V_n^O is the observed traffic volume on link n; and N is the number of detector stations used for calibration.

Especially important, the model provides very accurate prediction on the neighboring links of Lafayette Bridge. Difference in peak hour volume between model prediction and real traffic counts is less than 0.5% on Lafayette bridge, 5% on the I-494 bridge, and 12% on I-35E bridge.

4 Evaluation

We estimate traffic patterns on the Twin Cities network under alternative construction scenarios of Lafayette Bridge by applying the calibrated travel demand model. Since there is no sign of significant change in demographics and land use pattern within the time frame of this

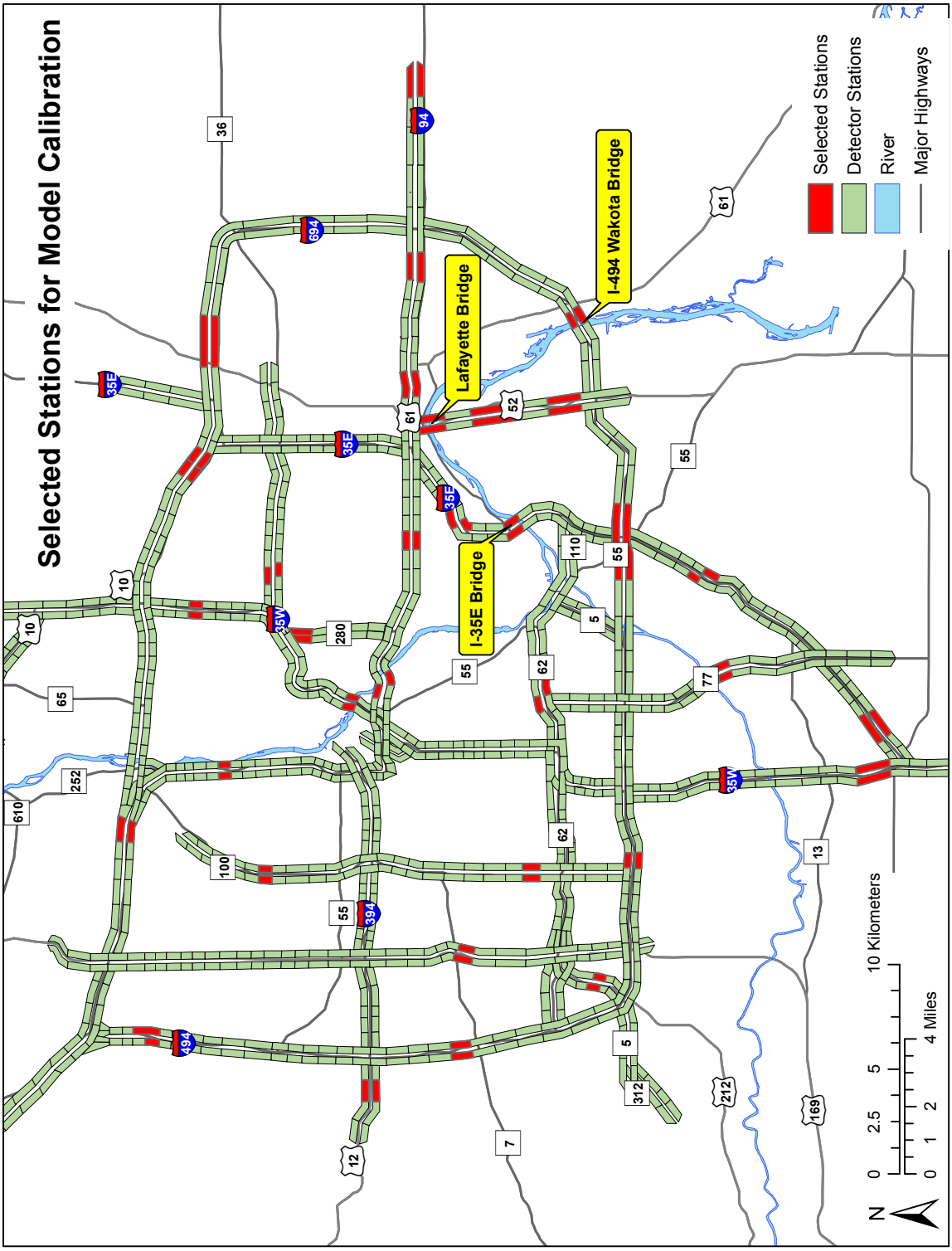

Figure 1: Selected 73 stations for model calibration

study (Winter 2010 - Fall 2014), we assume that the population, household, and employment remains unchanged for each TAZ. Consequently, the number of trips starting from and ending at each TAZ remains the same during the study period. However, this does not imply that the trip origin-destination tables (OD table) is also the same. Travelers may visit alternative places due to traffic congestion caused by bridge closure. For example, Zhu et al. (2009) finds that the number of trips crossing Mississippi River drops by 6.3% after the I-35W Bridge collapse in 2007. These travelers either find new destinations to satisfy their need or simply forego trips. Therefore, we assume travelers would adjust their travel pattern according to evolving traffic conditions until a new equilibrium could be reached. The model iterates a distribution-assignment loop until a clear convergence in link flow pattern is reached. In this study, our model converges after 10 iterations through the distribution-assignment loop. Table 1 summarizes assumptions of all cases.

Table 1: Descriptions of scenarios

Case	Scenario	Trip Tables	Lafayette Bridge
0	N.A.	Calibrated in April 2010	Status quo
1	1	Variable	Partial operation*
2	2	Variable	Full closure/Early opening**

∗ *Lafayette Bridge remains open with current lane geometry between Winter 2010 (December 21 2010) and Fall 2012 (September 22 2012). It operates with two narrow lanes in each direction, very narrow shoulders, and a median barrier between Fall 2012 (September 22, 2012) and Fall 2014 (September 23, 2014). According to the operating experience of I-94 Bridge after I-35W Bridge collapse, we assume the capacity and free flow speed unchanged despite the narrow lanes.*

∗∗ *Lafayette Bridge remains closed to traffic between Winter 2010 (December 21, 2010) and Fall 2012 (September 22, 2012). The new Lafayette Bridge, which has 2 lanes plus an auxiliary lane from I-94 to Plato Blvd. plus shoulders, starts to operate in Fall 2012 (September 22, 2012).*

Under bridge construction scenario 1, network condition remains unchanged through the entire study period. Therefore, traffic conditions under scenario 1 represent the baseline scenario in our study. There are two phases under bridge construction scenario 2: bridge closed from Winter 2010 to Fall 2012 (641 days) and new bridge opens to traffic from Fall 2012 to Fall 2014 (730 days). Traffic patterns are evaluated separately under different phases. Figure 2, Figure 3, and 4 present the estimated Volume/Capacity (V/C) ratios on individual links in scenario 1, phase 1 of scenario 2, and phase 2 of scenario 2 with variable travel demand tables, respectively. Figure 5 and Figure 6 display the difference in link flow between scenario 2 and scenario 1 under the bridge construction phase and completion phase, respectively. These figures together illustrate how the two alternative bridge construction plans would impact traffic differently.

As Figure 5 reveals, most traffic that used to travel on Lafayette Bridge will detour to the Robert Street Bridge and the Wabasha Street Bridge after the bridge is closed, while the rest will choose I-494, I-35E, and TH 149/Smith Avenue Bridge as alternative routes.

The East Lafayette Frontage Road, Plato Boulevard, and Robert Street become the most congested segments during the closure of Lafayette Bridge. These links have the highest Volume/Capacity ratio as shown by Figure 3. In contrast, traffic on the TH 52 south of the Lafayette Bridge will drop significantly at the same time. Travel demand on US 61, I-35E, and I-494 within the vicinity of Lafayette Bridge will increase moderately. After the new Lafayette Bridge opens in Fall 2012, traffic conditions under scenario 2 does not differ significantly when compared with that under scenario 1 (see Figure 6). This is not a surprise since the only difference in network configuration is an auxiliary lane on Lafayette Bridge between I-94 and the Plato Boulevard under scenario 2, which has limited impacts on overall traffic conditions.

We further evaluate the difference in overall network performance under the two alternative scenarios. Table 2 summarizes the measures of effectiveness (MOEs) and accessibility measures in difference cases. With variable trip tables, people travel less due to inconvenience generated by bridge closure and Vehicle Kilometers of Travel (VKT) drops about 0.14%. Total Vehicle Hours of Travel (VHT) drop by 0.10%. As expected, average travel speed during morning peak decreases slightly (0.06%). Consistent with that can be seen from the link flow and V/C ratio figures, travel speed improves slightly (0.01%) in scenario 2 when compared with scenario 1 after the new Lafayette Bridge opens. People travel a little farther (0.003%) once traffic improves.

In order to quantify the benefit and cost under alternative scenarios, we have to evaluate the changes in consumer surplus as a result of network condition changes. The consumer surplus in the context of travel demand is defined according to Figure 7. The Y axis represents the cost for consuming each unit of travel (defined as *pace* in the literature), which is the reciprocal of travel speed. The point $(X1, Y1)$ represents the baseline scenario (scenario 1 here). If average travel speed increases due to network improvement in scenario 2, from $Y1$ to $Y2$ and travelers further benefit from improved traffic conditions by traveling farther (VKT increases from $X1$ to $X2$). The shadowed trapezoidal area represents the increases in consumer surplus. Similarly, consumer surplus drops if speed decreases and people travel less. Compared to scenario 1, average speed decrease due to bridge closure in phase 1 of scenario 2 and losses in consumer surplus are expected. However, people travel faster and longer in distance after the new Lafayette Bridge opens and a gain in consumer surplus is expected. After summing up all changes in user surplus during the entire study period by comparing network conditions in scenario 2 with that in scenario 1, we obtain a net loss of 476,102 vehicle-hours. The negative sign implies that scenario 2 is costlier for travelers. However, this loss is very small in magnitude, which is equivalent of a daily loss of 347 vehicle-hours. Assuming that the value of time is \$15/hour, the monetary cost for travelers under scenario 2 is \$7,141,527 (\$5,209 daily) larger when compared with scenario 1.

5 Conclusion

This study evaluates traffic reactions to two alternative construction plans of Lafayette Bridge crossing the Mississippi River in downtown Saint Paul, Minnesota. We re-calibrated the travel demand model of Twin Cities area that has been developed for previous research against real traffic conditions in April, 2010. We then applied the calibrated model to evaluate network

performance in different construction phases of the two alternative scenarios. Overall changes in consumer surplus indicate that scenario 2 has a somewhat higher user cost. However, the magnitude of difference in consumer surplus is very small and well within "margin of error". This needs to be weighted by construction cost savings due to faster construction, and safety issues. It would be possible with slightly different assumptions for Scenario 1 to have a higher user cost.

Both figures of flow changes and V/C ratio indicate that the impacts of bridge closure on traffic conditions are limited within the region of the I-494 & US61 to the east and I-35E to the west. The increases in freeway traffic are moderate. Most travelers choose to use the arterial bridges as alternative routes. The Robert Street Bridge and the Wabasha Street Bridge will see significant traffic increases. Other arterial links which are connect with these bridges will also carry more traffic. However, the size of impact zone is limited. Additional traffic mitigation measures on these links such as temporary conversion of shoulder to narrow lanes and better signal control plan would help to reduce user cost.

Table 2: Measures of effectiveness and accessibility in alternative scenarios. Number in parenthesis indicate the percentage change of a measure under construction scenario 2 as compared to its counterpart under construction scenario 1

	case 1		**case 2**	
Construction Scenario	1		2	
Trip Tables	Variable		Variable	
Phase	1	2	1	2
Daily VHT*10^6	1.7411	1.7411	1.7393 (-0.10%)	1.7410(-0.006%)
Daily VKT*10^8	1.0458	1.0458	1.0443 (-0.14%)	1.0459 (0.003%)
Average speed (km/h)	60.07	60.07	60.04 (-0.06%)	60.07 (0.01%)
Average trip length (km)	19.62	19.62	19.59 (-0.15%)	19.62 (0.00%)
Average trip time (min)	19.60	19.60	19.58 (-0.10%)	19.60 (0.00%)
Jobs reached in 10 min	124,449	124,449	123,609 (-0.67%)	124,444 (0.00%)
Jobs reached in 20 min	656,919	656,919	652,795 (-0.63%)	655,919 (-0.15%)
Jobs reached in 30 min	1,263,791	1,263,791	1,260,050 (-0.30%)	1,263,801 (0.00%)
Number of days	641	730	641	730
Consumer surplus (hr)			-476,102(-347/day)*	
Total economic loss ($15/hr)			$-7,141,527($-5,209/day)*	

**Negative indicates Scenario 2 is costlier*

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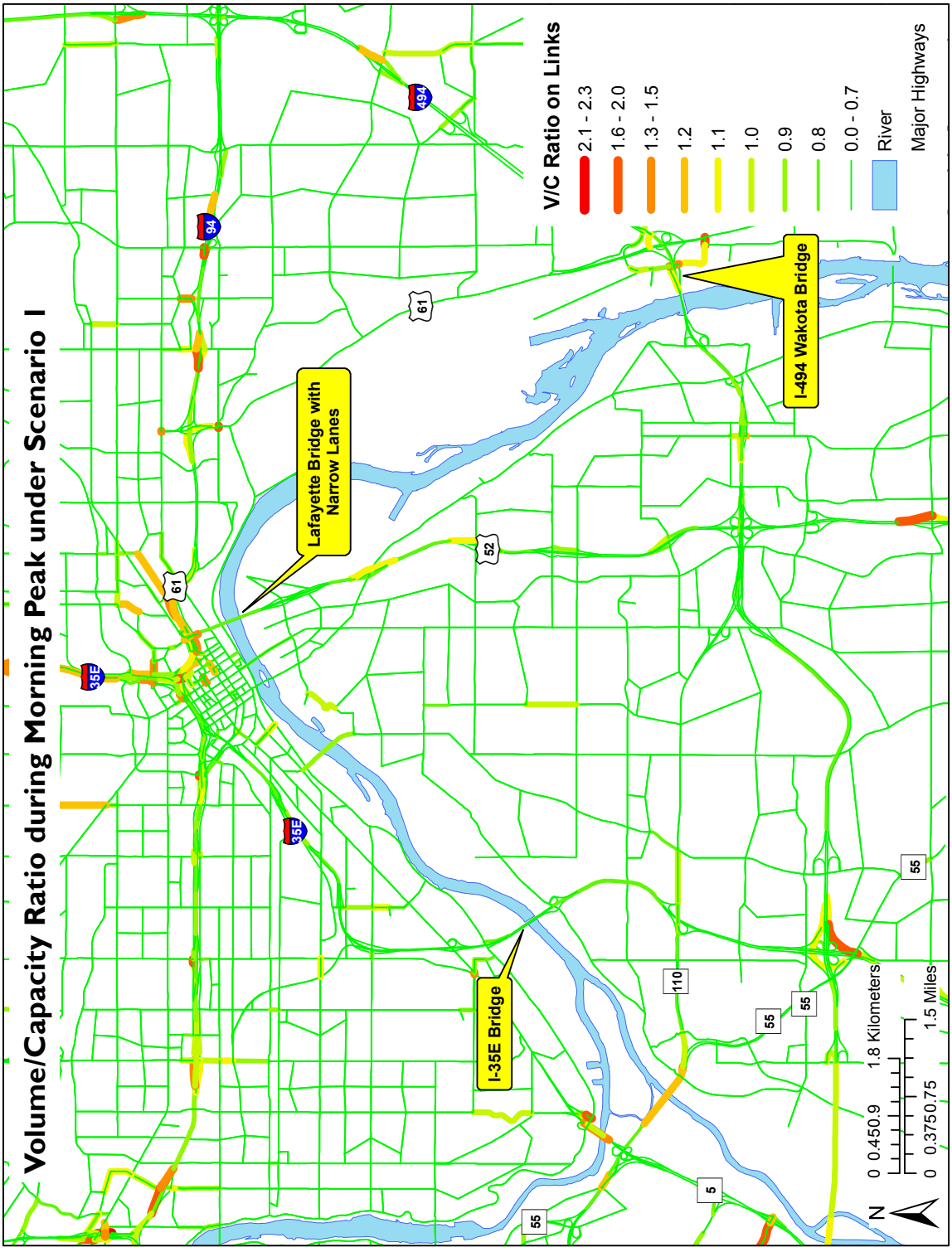

Figure 2: Traffic conditions under bridge construction scenario 1 with variable trip table

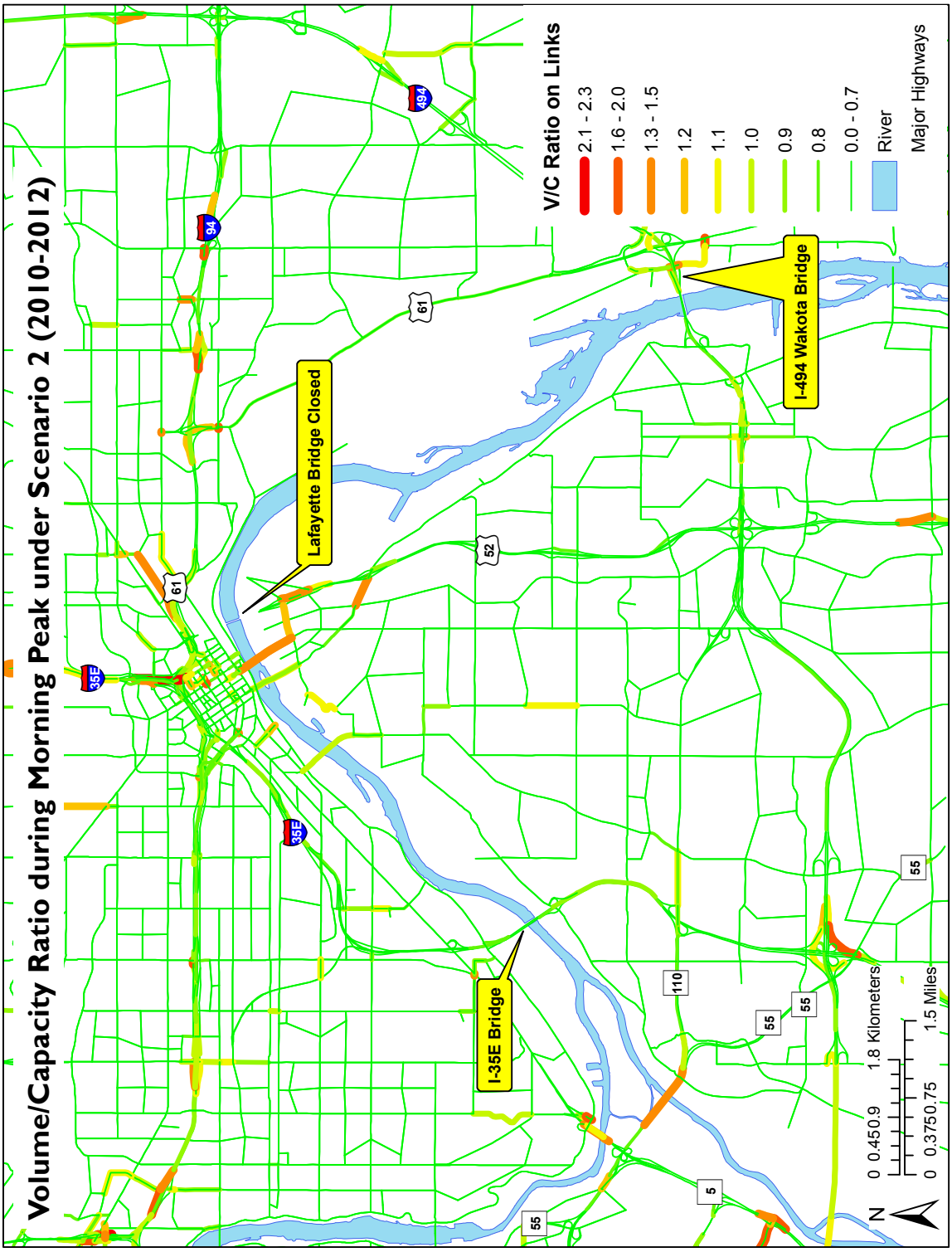

Figure 3: Traffic conditions under bridge construction scenario 2 during the bridge closure phase with variable trip table

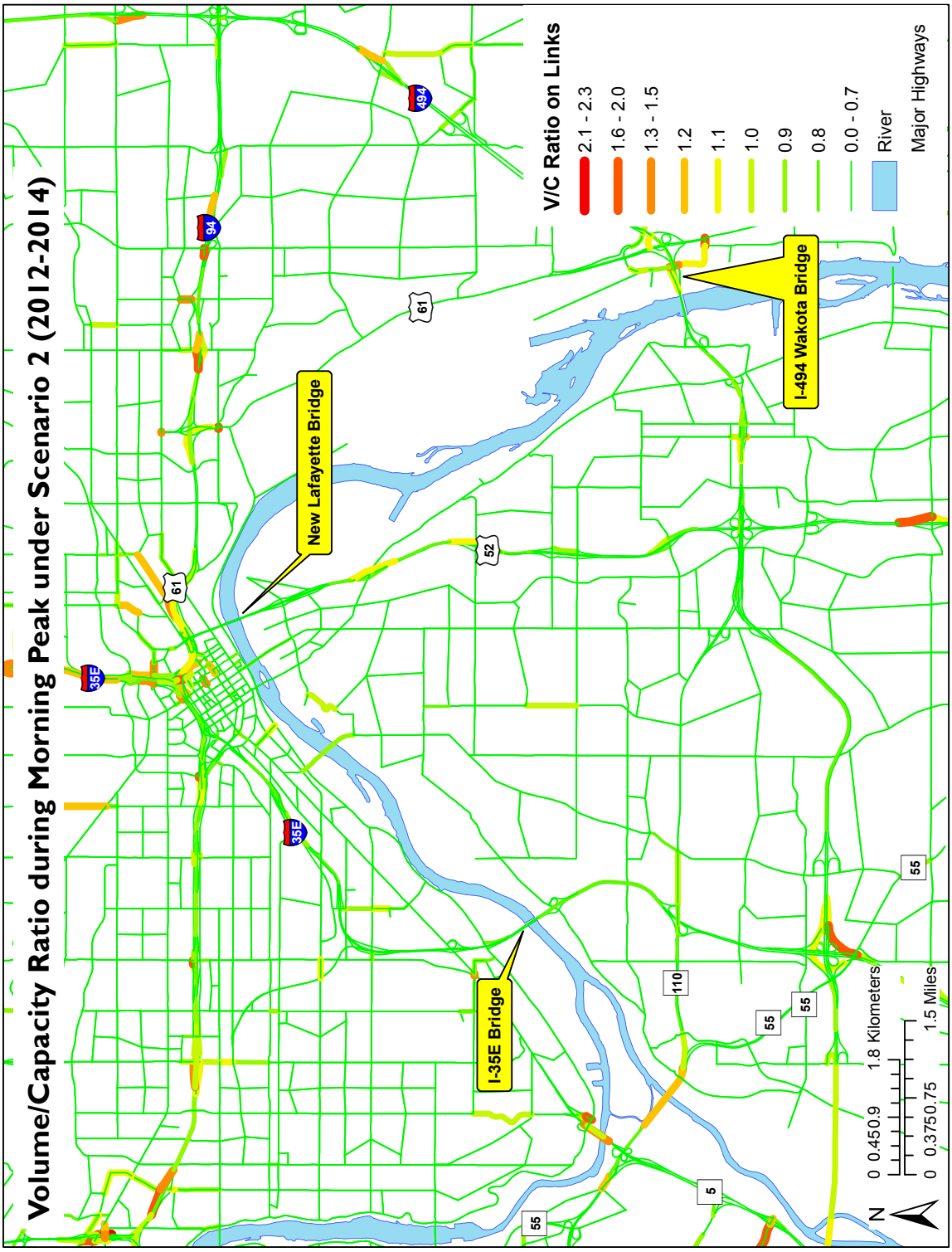

Figure 4: Traffic conditions under bridge construction scenario 2 during the bridge completion phase with variable trip table

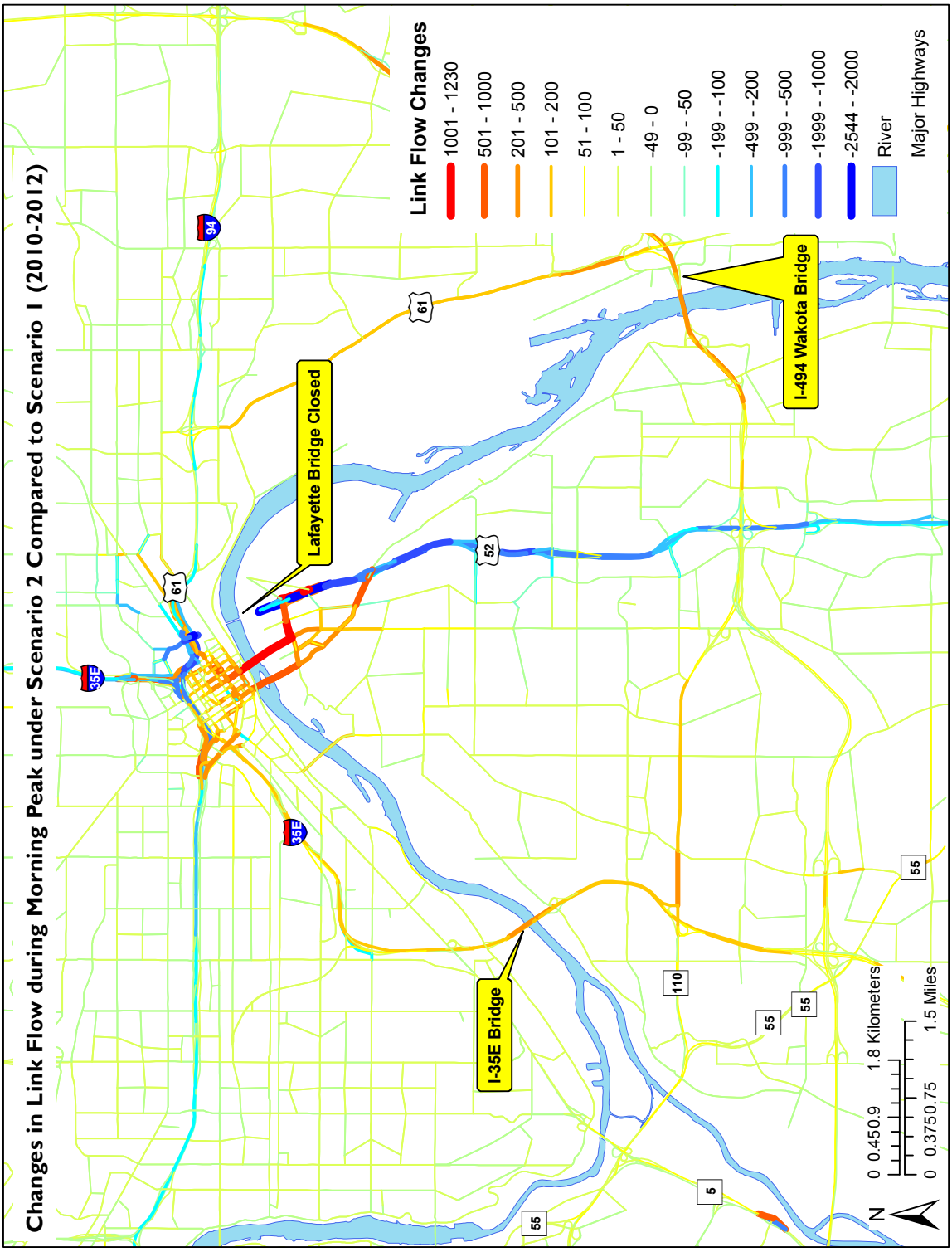

Figure 5: Difference in link flow between scenario 2 and scenario 1 during the bridge closure phase with variable trip table

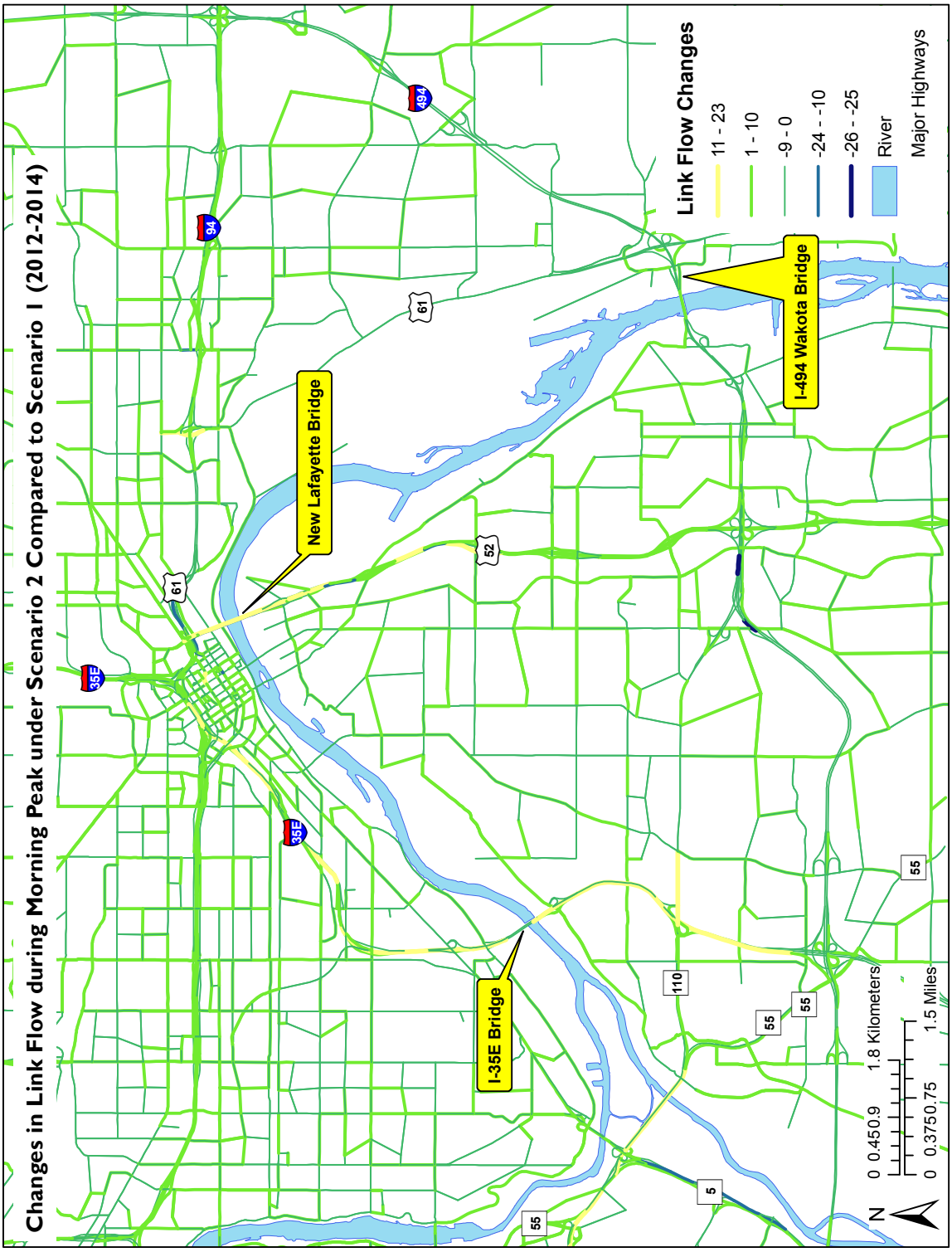

Figure 6: Difference in link flow between scenario 2 and scenario 1 during the bridge completion phase with variable trip table

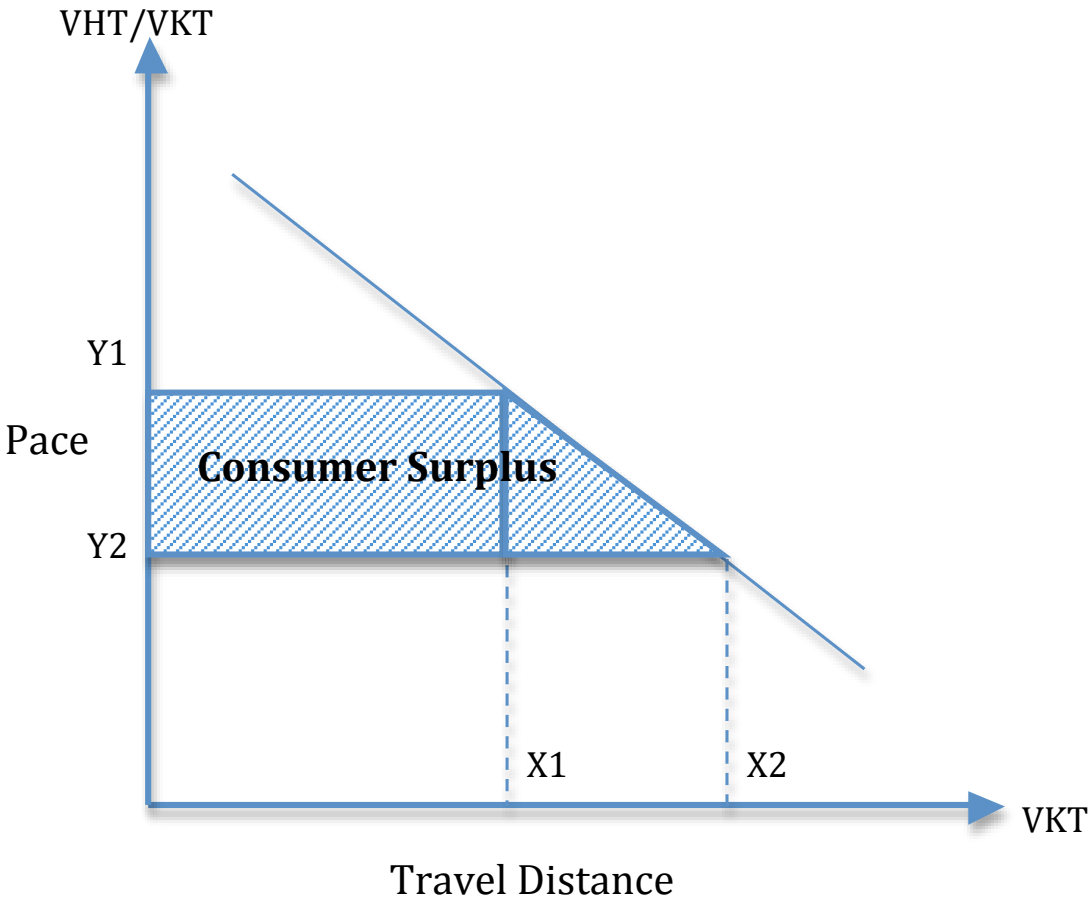

Figure 7: Consumer Surplus in Travel Demand

Appendices

A Travel Demand Model

A.1 Trip Generation

Trip generation module estimates the number of personal vehicle trips that originate from (production) or are destined to (attraction) each traffic analysis zone. The traffic production and attraction models are separately estimated by regressing the 2005 composite vehicle trip rates by TAZ, which is provided by Metropolitan Council, on a set of zonal characteristics variables. The model that provided the best goodness-of-fit is adopted. The following explanatory variables turn out to be significantly correlated with the dependent variable:

- Population
- Retail Employment
- Non-retail employment
- Residential density
- Shortest distance from centroid zone to either downtown Minneapolis or St. Paul
- Shortest previous distance squared

Data for 2010 is used throughout the period.

A.2 Trip Distribution

Trip distribution allocates trips generated in one zone to destination zones in the study area. In our study all trips are treated equally and one aggregate Origin-Destination matrix is generated through this process since we do not distinguish trips by purpose. Many trip distribution models have been proposed in the literature, including the gravity model, growth factor models, and intervening opportunity models. The gravity model is chosen here because of its simplicity, accuracy, and wide application in many US urban areas. This study adopts a doubly constrained gravity-based trip distribution model. The number of trips $T_{i,j}$ between zone i and zone j is determined by:

$$T_{i,j} = K_i K_j T_i T_j e^{-\theta C_{i,j}}$$

Where:
K_i and K_j are balancing coefficients;
T_i is the traffic production of zone i;
T_j is the traffic attraction of zone j;
and $C_{i,j}$ is the travel cost between zone i and j.

The gravity model assumes that the interaction (here travel demand) between two locations is positively associated with the amount of activity at each location but declines with

increasing impedance between them, which is modeled by a the negative exponential function of the travel cost here. The friction factor θ is a parameter to be calibrated in the model. It is an inverse function of travel time, which captures where people prefer longer or shorter trips. The balancing coefficients K_i and K_j ensure that the aggregate trips match both the number of traffic generation at the origins and the number of traffic attraction at the destinations. These coefficients are solved iteratively in the model by following:

$$K_i = \frac{1}{\sum_j K_j T_j f(C_{i,j})} \text{ and } K_j = \frac{1}{\sum_i K_i T_i f(C_{i,j})}$$

A.3 Assignment

Traffic assignment determines the actual route that will be used by travelers between each Origin-Destination pair and the number of vehicle trips can be expected on each network link. The predicted network traffic pattern depends on the assumption about route choice preferences among travelers. For example, User Equilibrium (UE) models assume each traveler chooses the route minimizing their own travel time. In this study, we adopt the Stochastic User Equilibrium (SUE) model which is originally introduced by Sheffi, and assumes that travelers choose the route with minimum perceived travel time. Dial's algorithm is used to perform network loading and the Method of Successive Average (MSA) is used to find the SUE link flow. The Bureau of Public Road (BPR) link performance function is adopted to derive the congested link travel time as a function of link flow rate and capacity. Following Leurent, a scaling coefficient of 0.2 is used in the discrete choice module. The convergence for MSA is defined by a maximal allowable link flow change below a threshold of 100 vehicles.