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IDENTIFY POTENTIAL CAUSES OF TRUCK BOTTLENECKS ON FREEWAYS AND DEVELOP MITIGATION STRATEGIES

Final Report

by

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EXCUTIVE SUMMARY

The Moving Ahead for Progress in the 21st Century Act (MAP-21) includes freight planning and project delivery provisions. Specific goals were identified in the National Freight Policy (NFP) to increase economic competitiveness, efficiency, and productivity; reduce congestion; and enhance the safety, security, and resilience of the freight network.

A reliable and accessible freight network enables the business to be competitive in the US. However, many urban roadways are facing challenges with traffic volumes being over capacity during peak periods. As a result, time and money are lost due to traffic congestion. Operational and design constraints such as interchange, steep grade, signalized intersection, work zone, merging, lane drop, and others, could contribute additional delays for commercial vehicles.

This study leveraged our previous effort to measure and identify truck bottlenecks in the Twin Cities Metropolitan Area (TCMA) by using the National Freight Performance Management Research Data Set (NPMRDS). The research team worked with stakeholders to prioritize a list of key truck corridors in the TCMA. Monthly NPMRDS data were processed to measure travel time reliability and estimate truck delay at the corridor level and then to identify system impediments during peak hours. Performance measures, including truck mobility ratio, travel time reliability, and delay, were defined and computed using 24 months of NPMRDS data.

On average, roadways with signalized or un-signalized intersections have a higher percentage of truck-to-car travel time ratio (TTR). On average, trucks travel an average of 10% slower than cars on freeways.

A reliability measure was analyzed to evaluate the truck travel time reliability. The results indicate that the truck travel time in the PM peak period is less reliable than the travel time in the AM peak period. Similar to the TTR measure, roadways with signalized or un-signalized intersections are generally less reliable than freeways.

The research team identified six truck bottlenecks in the TCMA during the PM peak period to further investigate the potential causes of the congestion. Among the six bottlenecks, I-94 WB at I-35W in Minneapolis has the highest truck delay per mile in the PM peak on an average weekday. Average truck delay in the PM peak in this segment is 570 hours per mile or 775 hours in total. We found insufficient capacity, increasing demand, roadway geometry, and density of weaving points in a roadway segment are the key causes of traffic congestion among the identified bottlenecks.

We recommend using a solid white line on the main roadway to discourage drivers from changing lane near the bottlenecks as a less expensive solution. Traffic signs and real-time traveler information could also be placed at locations prior to approaching the bottlenecks. Ongoing performance monitoring using NPMRDS or other sources of traffic data is needed to support transportation planning and operation.

1.0 INTRODUCTION

1.1 BACKGROUND

Freight transportation provides a significant contribution to our nation's economy. In the US the trucking industry represents the largest portion of domestic freight movement. Safe, efficient, and reliable trucking services are essential, not only to provide door-to-door freight transportation, but also to ensure the effective operation of other freight modes and facilities. Heavy commercial vehicles usually occupy more than twice the space of passenger vehicles on the roadway. Truck delays from traffic congestion or adverse weather conditions can have a significant impact on truck travel time reliability.

A reliable and accessible freight network enables business in the Twin Cities Metropolitan Area (TCMA) to be competitive in the Upper Midwest region. Many urban roadways are facing challenges with traffic volumes being over capacity during peak periods. As a result, time and money are lost due to traffic congestion. Operational and design constraints such as interchange, steep grade, signalized intersection, work zone, merging, lane drop and others, could contribute additional delays for commercial vehicles.

The Minnesota Department of Transportation (MnDOT) and the Metropolitan Council (MetCouncil) conducted a study in 2012 to evaluate the regional freight transportation system. A joint report, titled "Twin Cities Metropolitan Region Freight Study" [1] suggested a need to understand where and when trucks are most affected by highway congestion. Development of a framework for truck data collection and analysis is necessary to better understand the relationships between peak hour truck traffic and peak congestion. In addition, the report recognized the concerns of increasing freight shipping costs caused by congestion delays. Cost-effective and operationally focused solutions are needed to improve travel time reliability. Performance measures derived from this study can also be used to calibrate truck model parameters in MetCouncil's transportation planning and forecasting model.

A framework for truck data collection and analysis was recommended to better understand the relationships between truck traffic and congestion in peak periods. Building on our previous study to measure freight mobility and reliability along key freight corridors in the TCMA, this study leveraged our previous development to calculate the truck mobility measures using the National Performance Measurement Research Dataset (NPMRDS) from the USDOT.

In 2013, the Federal Highway Administration (FHWA) announced the NPMRDS to support its Freight Performance Measurement (FPM) and urban congestion report programs. The NPMRDS includes probe vehicle-based travel time data (for both passenger and freight vehicles) at 5-minute intervals for all National Highway System (NHS) facilities. NPMRDS travel time is reported based on Traffic Message Channel (TMC) segments with link length varying from less than a mile to several miles. NPMRDS is intended for state agencies to measure system performance in meeting new federal performance management requirements. However, it may be difficult to extract information from the average travel time at 5-minute intervals for analyzing traffic dynamic at the per vehicle level and assessing the impact of signal delay within a relatively long TMC segment.

The author previously developed methodologies to measure truck mobility, delay, and reliability on key freight corridors in Minnesota using truck GPS data. In recent years, the author took advantage of the availability of NPMRDS by working with MnDOT to systematically measure truck travel time performances on National Highway System (NHS) and other major corridors.

1.2 OBJECTIVES

The research team previously used 24 months of NPMRDS data obtained from the MnDOT to measure truck mobility, reliability, and congestion at corridor level in the Twin Cities Metropolitan Area (TCMA). The goal of this study is to identify any operational bottlenecks or physical constraints based on the performance metrics. Trucking activities nearby congested areas were further examined to analyze traffic pattern, investigate possible causes of the recurring congestions, and recommend mitigation strategies.

1.3 LITERATURE REVIEW

In 2017, MnDOT freight office released a statewide freight system plan [2] with goals to identify significant freight system trends, needs and issues. The multi-model plan provided a framework that includes recommended freight policies, strategies and performance measures to guide decision making on future investments. The new plan will be developed as a policy, project development and investment strategy, in compliance with Moving Ahead for Progress in the 21st Century (MAP-21), highlighting best practices, Minnesota initiatives, cooperative partnership and associations [3].

One of the key elements of the MAP-21 Act is to focus on performance and outcome-based programs. The FAST Act also includes several goals focused on ensuring the safe, efficient, and reliable movement of freight. AASHTO also recommended performance measures in six areas (safety, pavement condition, bridges, freight, system performance, and congestion mitigation and air quality) to help state agencies meet new federal performance management requirements. Performance measures in categories such as safety, maintenance, mobility, reliability, congestion, accessibility, and environment, are recommended for the freight.

Travel time reliability is one of the key measures of freight performance along interstates or interregional corridors in the nation [4 & 5]. Pu examines several reliability measures and recommended a median-based buffer index or a failure rate estimate as more appropriate to handle heavily skewed travel time distributions [6]. Gong & Fan [7 & 8] used a systematic approach that incorporates both congestion intensity and travel time reliability to evaluate freeway performance, identify and rank freeway bottlenecks.

The FHWA has established a partnership with the American Transportation Research Institute (ATRI) and the trucking industry since 2002 to measure average truck travel speed on major freight-significant corridors in North America [9]. A spatial data processing methodology has been evaluated, refined, and assisted by Liao [10] to improve the effectiveness of generating Freight Performance Measures (FPM). Analyses of truck speed, volume and travel time by location help identify network impediments and variations of seasonal flow changes [11]. Derived vehicle speed and travel time from GPS and/or terrestrial wireless systems used by the trucking industry provide potential opportunities to support freight planning and operations on the surface transportation system. In 2015, the FHWA has developed a guide [12] to provide best practices and approaches on several key areas of freight performance measurement; and to develop practical guidance in analyzing truck freight bottlenecks to State DOTs and metropolitan planning organizations (MPO).

In Washington state, McCormack and Hallenbeck used 25 portable GPS data collection units with a 1-second polling rate to gather truck positioning data for measuring freight movements along freight significant corridors [13]. The study concluded that GPS data can be collected cost-effectively and can provide an indication of roadway performance. Based on processed truck speed data, a route model including analyses of truck travel time, delay and reliability can be developed to better understand current freight network performance, freight origin to destination flows, and to study possible solutions to future freight demand growth [14].

FHWA is leading the effort to assess and validate the appropriateness of using GPS data from commercial vehicles to derive mobility and reliability performance measures and to support congestion monitoring on the highway system. Four key factors, including average daily traffic (ADT) per lane, percent of the heavy vehicle, grade, and congestion level, were investigated. The preliminary findings indicated that (1) estimates of speed from Freight Performance Measurement (FPM) data are sufficiently accurate for performance measurement on most roadways in the United States, (2) FPM speed estimates show a consistent negative bias due to differences in operating characteristics of trucks and autos, and (3) grade and congestion have the greatest effect on FPM data accuracy among the four key factors evaluated [15].

In July 2013, the FHWA announced the NPMRDS to support its FPM and urban congestion report programs. The NPMRDS includes probe vehicle-based travel time data (for both passenger and freight vehicles) for every 5-minute interval for all National Highway System (NHS) facilities. The NPMRDS aims to support transportation agencies' needs by obtaining a comprehensive and reliable set of data that can be broadly deployed for use in measuring, managing, and improving the transportation system in the U.S.

Liao conducted a study to generate and analyze freight performance measures along 38 key freight corridors in the TCMA and four major freight corridors that connect the Twin Cities to three regional freight centers (St. Cloud, Mankato, and Rochester) outside the TCMA [16]. Several performance measures, such as truck mobility, delay, and reliability index, were identified. Statistical analyses were performed to derive performance measures by route, roadway segment (1-mile), and time of day. In addition to generating performance measures, the research team also identified key freight corridors by comparing the percentage of miles with Heavy Commercial Annual Average Daily Traffic (HCAADT). Truck bottlenecks were also identified and ranked based on hours of truck delay and the number of hours with speeds less than the target speeds (set by MnDOT) during the peak periods.

For congestion mitigation, FHWA has initiated a localized bottleneck reduction program to focus on the causes, impacts, and potential solutions for recurring congestions. Several studies have been conducted to help agencies reduce localized bottleneck congestion [17-20].

The cost of traffic mobility deficiencies can be estimated as a means of expressing the financial impact of congestion. The congestion cost measures can have utility to both transportation decision-makers and system users when they accurately reflect the tangible costs of transportation use on congested facilities. Adams et al. evaluated the value of delay to commercial vehicle operators due to highway congestion by including factors such as direct operational cost, travel length, travel time variation, inventory holding, and warehouse management [21].

The annual Urban Mobility Scorecard [22] produced by the Texas Transportation Institute measures the costs of congestion at both the national and local levels. The 2015 report estimated that the overall cost of congestion in the US was $160 billion (using 2014 data) based on wasted fuel and lost productivity. In the Minneapolis-St. Paul, Minnesota, area, the cost of annual truck congestion was $327 million and the total congestion cost was $2.196 billion in 2014. The estimated cost of truck congestion in 2014 was $94 per hour.

In addition, the ATRI has conducted an analysis to assess the operational costs of truck delays since 2008. Its recent update [23], An Analysis of the Operational Cost of Trucking: 2017 Update, reported that the total marginal costs for the industry across all sectors, fleet sizes and regions were $1.592 per mile and $63.66 per hour based on 2016 data.

In 2016, NCHRP took the first step to incorporated truck travel time reliability into the truck freight benefit-cost estimation in order to better assess mobility projects and provide quantitative data for transportation project prioritization [24].

2.0 PERFORMANCE MEASURES

The 2015 and 2016 (24 months) FHWA National Performance Management Research Data Set (NPMRDS) was received from MnDOT. The travel time data (in 5-min intervals) and truck volume data have been imported to our database in order to compute performance measures on the selected truck highway corridors. A GIS shapefile containing static roadway information was used to relate the travel time information to each roadway segment. A Traffic Message Channel (TMC) file contains TMC segment geometry information. A database file set includes average travel times of passenger, freight and combined for identified roadways geo-referenced to TMC segment IDs.

The research team processed 24 months of NPMRDS data and generated monthly mobility and reliability measures for each TMC segment in the study area.

Truck travel time ratio, reliability, and delay measures were computed for each time period as listed in Table 1.

Table 1: Time Periods.

Time Period	Duration
Weekday AM Peak	6AM – 10AM
Weekday Mid-Day Peak	10AM – 4PM
Weekday PM Peak	4PM – 8PM
Weekend	6AM - 8PM

The truck to car travel time ratio, truck travel time reliability and truck delay metrics were defined and discussed as follows.

2.1 TRAVEL TIME RATIO (TTR)

The travel time ratio (TTR) is defined as the truck travel time divided by the passenger vehicle travel time as expressed in Eq. 1. The travel time ratios for each TMC segment in each epoch (5-minute interval) were computed in the AM (6-9AM), mid-day, and PM (4-8PM) periods, respectively, using the NPMRDS data. The TTR measure allows us to quickly identify time periods and locations where there is significant speed differential between the trucks and passenger vehicles.

$$TTR = \frac{Median\ Truck\ Travel\ Time\ in\ 5\ min.}{Median\ Car\ Travel\ Time\ in\ 5\ min.} \quad (1)$$

2.2 RELIABILITY MEASURE

To quantify travel time reliability, a 95th percentile travel time is usually used to represent a near-worst case travel scenario[1]. There are other measures that use 80th, 85th, 90th, or even 99th percentile travel time to quantify travel time reliability. We use 95th percentile based on the national performance measures [25]. The reliability measure, TTTR95, is defined as the 95th percentile truck travel time divided by the median truck travel time (50th percentile) in each TMC segment, as calculated using Eq. (2) for each time period. This reliability measure was chosen by MnDOT based on the "*National Performance Measures for Congestion, Reliability, and Freight, and CMAQ Traffic Congestion*" report [25] published by the FHWA.

$$TTTR_{95} = \frac{95th\ Percentile\ Truck\ Travel\ Time}{50th\ Percentile\ Truck\ Travel\ Time} \tag{2}$$

2.3 TRUCK DELAY

The truck delay was computed by comparing the actual and targeted travel time in each TMC segment, as defined in Eq. (3). Truck delays were calculated for AM and PM peak periods on weekdays. The computed monthly delay result contains performance measures for AM and PM peak periods. The target speed or threshold speed in Eq. (3) is determined using the recommendation from the "*Developing Twin Cities Arterial Mobility Performance Measures Using GPS Speed Data*" report [26] (p.15-19). Roadway speed limit dataset was obtained from MnDOT to determine base free-flow speed (BFFS) for delay computation. The BFFS is determined based on the speed limit and guidance from the highway capacity manual [27] using the following equations.

$$Delay_{rte} = \sum_{tmc} \sum_{hr} \sum_{epoch}^{12} (Truck\_Travel\_Time - \frac{Segment\ Length}{BFFS}) \times Volume_{\ hr,\, tmc}$$

$$\forall \quad Truck_{Travel\_Time} > \frac{Segment\ Length}{BFFS} \tag{3.a}$$

BFFS = 40 mph, *for posted speed limits < 40 mph*
= Speed Limit + 7, *for posted speed limits 40 - 45 mph*
= Speed Limit + 5, *for posted speed limits ≥ 50 mph*

(3.b)

The NPMRDS dataset does not include the sample size of the probe vehicles in each TMC. Truck volume data (HCAADT) and hourly truck volume distribution from our previous study [11] and

[1] Travel Time Reliability: Make it There on Time, All the Time, https://ops.fhwa.dot.gov/publications/tt_reliability/TTR_Report.htm

additional data collection from five selected locations in the TCMA were used to estimate truck delays at each roadway segment during the AM and PM peak hours. Ideally, we would prefer to using Weigh-In-Motion (WIM) data to compute hourly truck distribution. However, there are only four WIM stations installed in the TCMA. Most of the WIM stations were installed outside the metropolitan areas.

We selected five locations, as listed in Table 2, in the TCMA to collect vehicle classification counts over a period of several weeks. The collected classification data were used to validate hourly truck volume distribution for truck delay calculation. More details on hourly truck volume distribution at each location are included in Appendix A.

Table 2: Truck Volume Data Collection Sites.

Site	Location	# of Lanes	Data Collection Period	2016 HCAADT	2016 AADT
1	US-169 at CR59	4	12/14/2017 – 02/06/2018	2,550	23,000
2	US-169 at TH-282	4	12/06/2017 – 01/18/2018	2,450	21,000
3	TH-13 at Lynn Ave.	4	11/03/2017 – 12/06/2017	4,400	48,500
4	I-35E at McAndrews Road	4	11/01/2017 – 12/14/2017	2,500	55,000
5	I-94 at N. Victoria St.	8	02/14/2018 – 04/24/2018	6,000	154,000

2.4 TRUCK BOTTLENECK RANKING

Our truck bottleneck ranking methodology is based on the estimated truck delays per mile. The delay-based approach is different from the bottleneck ranking methodology used by the American Transportation Research Institute (ATRI). The recent top-100 truck bottlenecks report[2], published by ATRI in January 2018, included five truck bottlenecks in the TCMA (see Table 3). The ATRI's truck bottlenecks are ranked by congestion values based on calculation of truck speed below free flow speed and volume [28].

Table 3: ATRI's Top Truck Bottlenecks in Minnesota.

Congestion Ranking (2017)	Location Description	Average Speed (MPH)	Peak Average Speed (MPH)
42	I-94 at US 52	42.9	35.2
55	I-35W at I-494	47.2	38.2
56	I-35W at I-94	38.4	28.8
61	I-35E at I-94	43.5	35.7

[2] The Nation's Top 100 Truck Bottlenecks. http://atri-online.org/2018/01/25/2018-top-truck-bottleneck-list/

Our truck bottleneck ranking is determined by computing the average daily truck delay in each TMC segment and dividing the delay over the segment length as expressed in Eq. (4).

$$Daily\ Delay_{tmc} = \sum_{hour}^{24} \sum_{epoch}^{12} \left(\frac{Truck\_TT_{tmc}}{TMC\ Length} - \frac{1}{BFFS} \right) \times Volume_{\ hour,\ tmc}$$

$$\forall \quad \frac{Truck\_TT_{tmc}}{TMC\ Length} > \frac{1}{BFFS} \tag{4}$$

3.0 DATA ANALYSIS

The author worked with stakeholders to prioritize a list of key truck corridors in the TCMA. Figure 1 displays a tiered based freight corridor network in the Twin Cities 7-county metro area. Weighted score of each corridor was computed by applying weights to average daily truck volumes (60%), truck percent of total traffic (20%), proximity to freight clusters (10%), and proximity to freight facilities (10%). Freight Clusters identified through analysis of intensity of freight-generating establishments in four sectors including consumer goods, natural resources, manufacturing, and transportation/logistics [29].

Figure 1: Tiered Based Truck Corridors with NPMRDS Data Coverage.

MnDOT provided 24 months (Jan. 2015 – Dec. 2016) of FHWA's National Performance Management Research Data Set (NPMRDS). The travel time data (in 5-min intervals) and a separate truck volume data from MnDOT were imported to a database in order to compute performance measures on the freight corridors. A GIS shapefile containing static roadway information was used to relate the travel time information to each roadway segment, i.e., a Traffic Message Channel (TMC) segment.

Monthly NPMRDS data were processed to measure travel time reliability and estimate truck delay at the corridor level and then to identify system impediments during peak hours. Performance measures, including truck mobility measure, travel time reliability, and delay, were computed and analyzed using the NPMRDS data.

3.1 MOBILITY

The travel time ratio (TTR) is defined as the truck travel time divided by the passenger vehicle travel time (Eq. 1). The travel time ratios for each TMC segment in each 5-minute interval were computed in the AM, mid-day, and PM peak periods using the 24-month NPMRDS data. For example, a TTR value of 1.0 means that, on average, the trucks and the passenger vehicles have the same travel time. Similarly, a TTR value of 1.2 means that, on average, truck travel time is 20% longer than car travel time.

Figure 2 displays the average median TTR and the corresponding standard deviation (SD) of TTR in the AM peak period in each month for the entire network. The network-wide monthly TTR in the AM peak period is relatively steady, around 1.3, over the 24-month period with an SD varying from 1 to 2.4. The average network-wide median TTR during mid-day is about 1.2 with an SD varying from 0.7 to 2.2 as shown in Figure 3. Similarly, the network-wide monthly median TTR in the PM peak period is around 1.3 over the 24-month period with an SD varying from 1 to 2.9 as displayed in Figure 4. The variations of standard deviation of TTR in the PM peak is significantly larger than the variations in the AM and mid-day periods. This is probably caused by increasing trucking activities and dynamic nature of traffic congestion in the PM peak period.

According to studies conducted by Puget Sound Regional Council [30], trucks travel by an average of 10% slower than cars on freeways. Based on the NPMRDS data in the Twin Cities metro area, the 24-month average of median travel time ratio in each epoch (a 5-minute interval) in a month by roadway type and time period is listed in Table 4. In general, trucks on the US and interstate highways have about 10% longer travel time than cars. On state highway, the TTR reaches to 1.2 and 1.4 in the AM and PM peak periods, respectively. Trucks travel significantly slower than cars on county roads. The TTR on county road is around 1.5 during mid-day and the TTR spikes to 1.7 and 1.9 in the AM and PM peak periods, respectively. The increase of TTR on county road may largely contributed by number of intersections in a TMC segment and delays at signalized intersections.

It is suggested that a reasonable range of median TTR would be less than 1.2 for trucks traveling on highways. Highway TMC segments with TTR greater than 1.2 require further investigation to understand the possible causes. A reasonable range of TTR for arterials requires additional investigation since it could be affected by number of traffic lights in a TMC segment.

Table 4: Average Median Travel Time Ratio by Roadway Type.

Roadway Type	AM Peak	Mid-Day	PM Peak
U.S. Highway	1.07	1.06	1.09
Interstate Highway	1.09	1.08	1.13
MN State Highway	1.19	1.13	1.37
County Road	1.68	1.49	1.85
Others	1.28	1.20	1.29

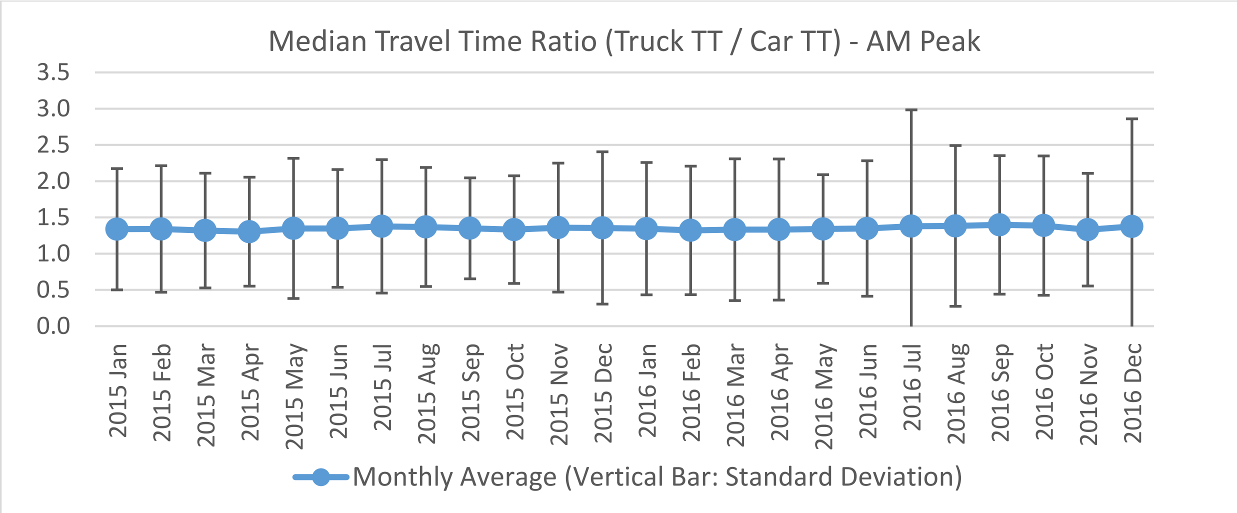


Figure 2: Network-wide Monthly Median Travel Time Ratio in the AM Peak Period.

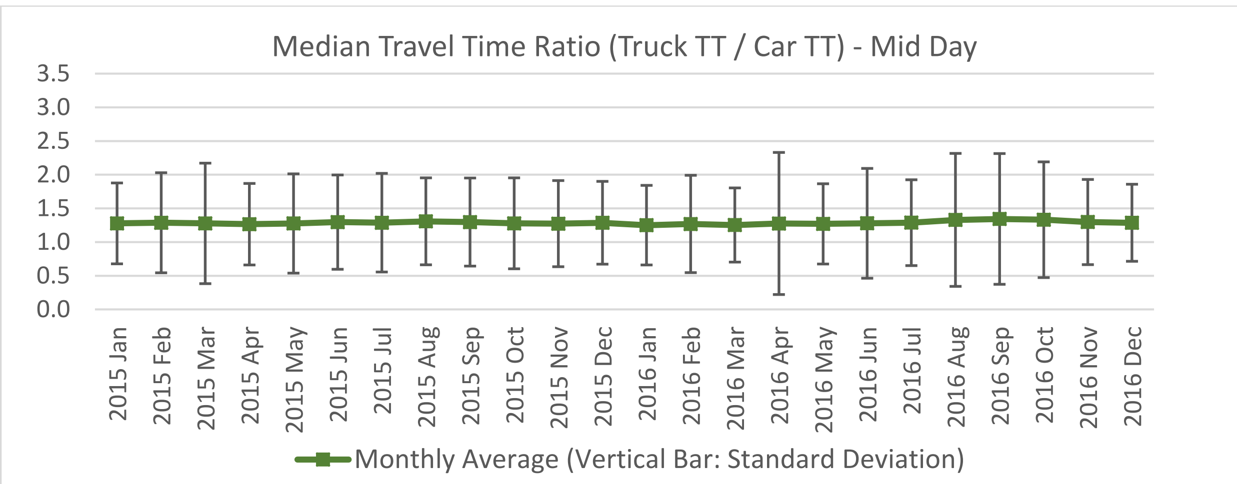


Figure 3: Network-wide Monthly Median Travel Time Ratio in the Mid-Day Period.

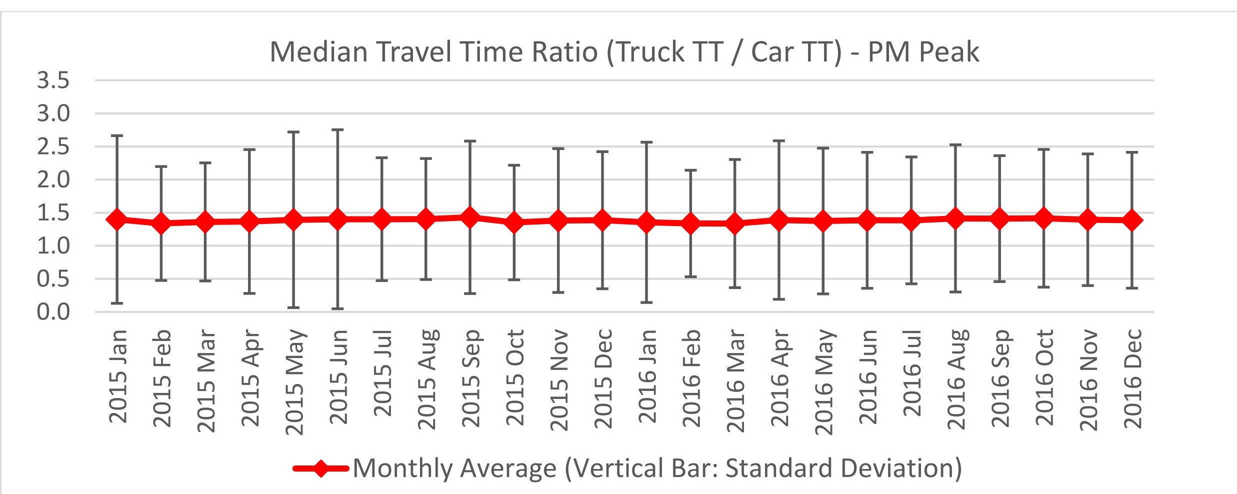


Figure 4: Network-wide Monthly Median Travel Time Ratio in the PM Peak Period.

The travel time ratio measure is further analyzed by route. Figure 5 displays the percent of miles with average TTR greater than or equal to 1.5 for AM, mid-day, and PM periods. In general, roadways with signalized or un-signalized intersections have higher percentage of truck to car travel time ratio. For example, the average truck travel time on 34% of county road 30 in Hennepin County is over 50% longer than the average passenger vehicle travel time in the PM peak. In the PM peak hours, the average truck travel time on 6.8% of I-94 roadway in the Twin Cities metro area is over 50% longer than the average passenger vehicle travel time. Similarly, the average truck travel time on 6.6% of I-394 roadway is over 50% longer than the average passenger vehicle travel time.

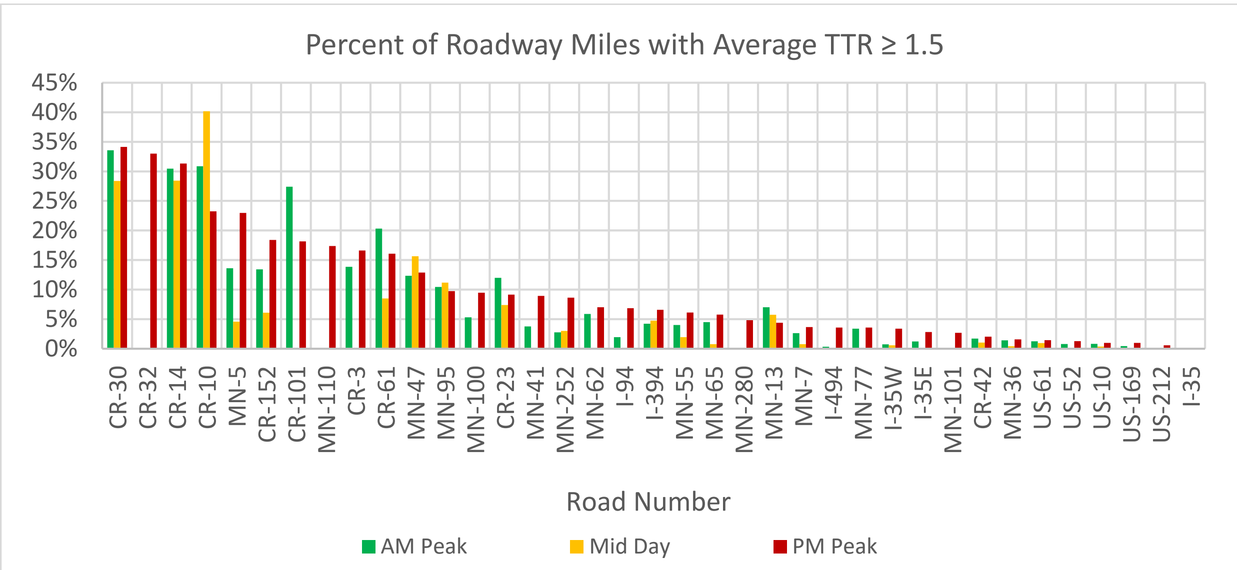


Figure 5: Percent of Roadway Miles with TTR $\geqslant$ 1.5 by Time Period.

3.2 TRAVEL TIME RELIABILITY

The TTTR95 measure is calculated using Eq. (2) for each time period. However, only measures in the AM peak, mid-day, and PM peak hours are discussed here. Figure 6 displays the average TTTR95 and its corresponding standard deviation (SD) in the AM peak period in each month for the entire network. The network-wide monthly TTTR95 in the AM peak period is around 3.2 over the 24-month period with an SD ranging from 3.8 to 5.6. The average network-wide average TTTR95 in mid-day is about 2.9 with an SD ranging from 3.5 to 4.9 as shown in Figure 7. Similarly, the network-wide monthly median TTTR95 in the PM peak period, as shown in Figure 8, is around 3.6 over the 24-month period with an SD varying from 3.9 to 6.7.

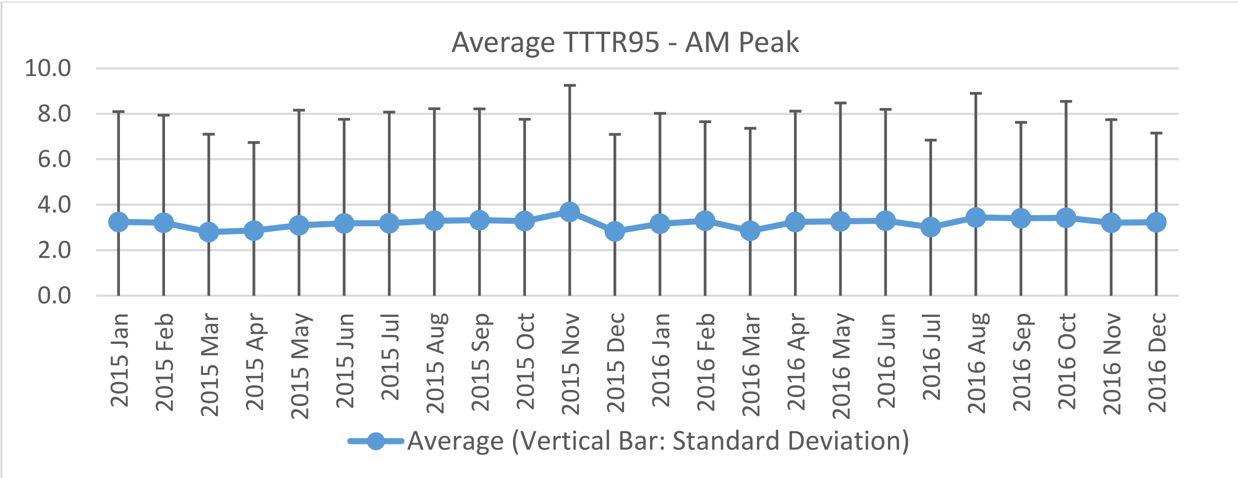


Figure 6: Network-wide Monthly Average TTTR95 in the AM Peak.

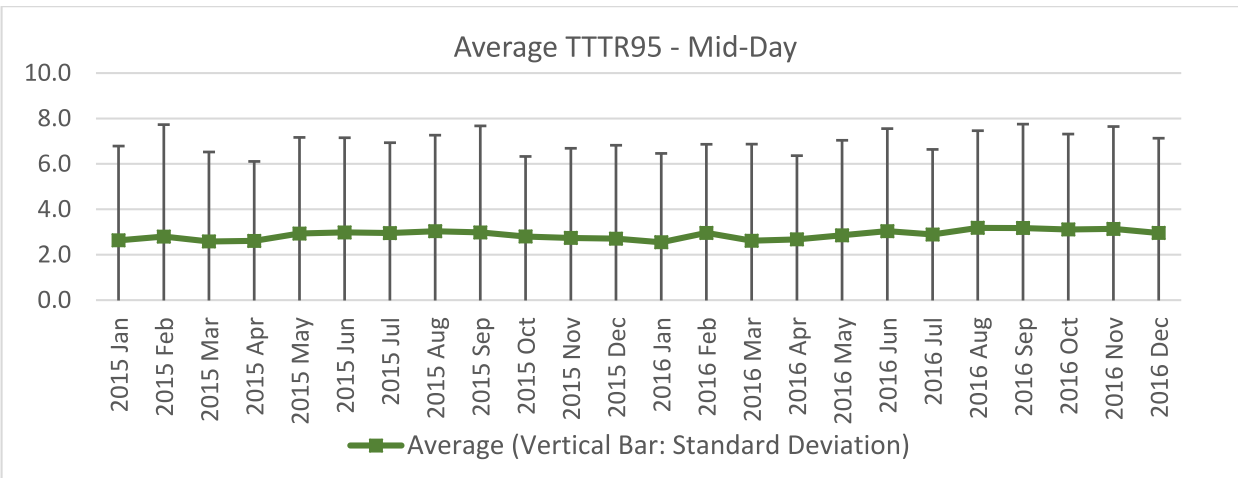


Figure 7: Network-wide Monthly Average TTTR95 in Mid-Day.

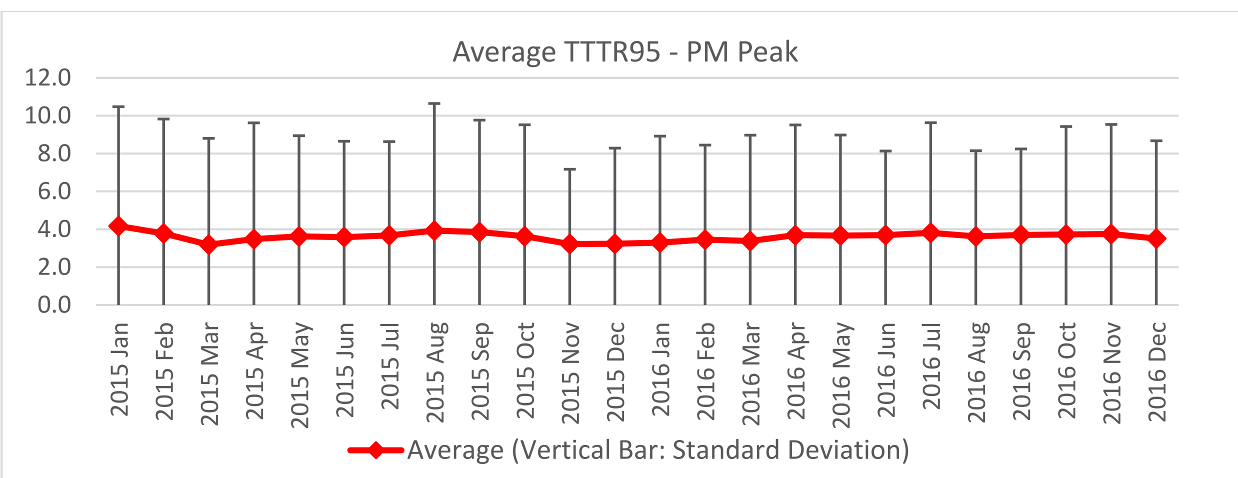


Figure 8: Network-wide Monthly Average TTTR95 in the PM Peak.

The TTTR95 measure is further analyzed by route. Figure 9 displays the percent of miles with average TTTR95 greater than 2.0 for AM, mid-day, and PM periods. In general, roadways with signalized or un-signalized intersections are less reliable than freeways. For example, the 95th percentile truck travel time on 80% of CR-42 is over twice as long as the average truck travel time in the PM peak. In the PM peak hours, the 95th percentile truck travel time on 75.5% of MN-65 roadway in the Twin Cities metro area is over twice as long as the average truck travel time. Similarly, the 95th percentile truck travel time on 52.7% of I-394 roadway is over twice as long as the average truck vehicle travel time.

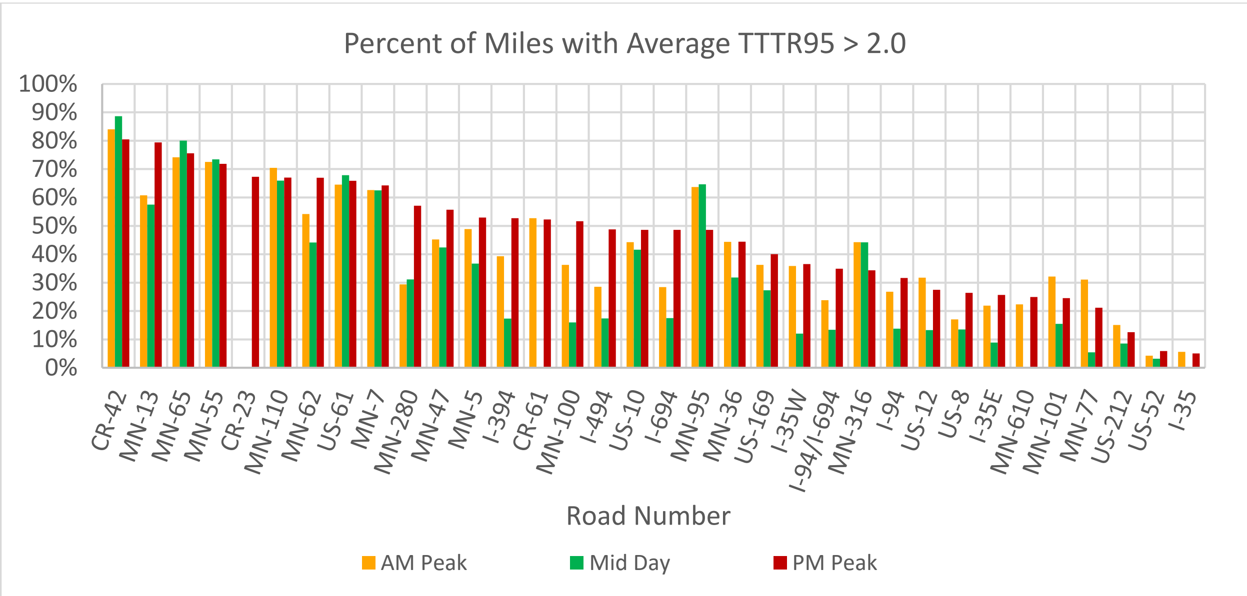


Figure 9: Percent of Roadway Miles with TTTR95 $\geqslant$ 2.0 by Time Period.

3.3 DELAY

Truck delay was computed for each TMC segment in both AM and PM peak periods. Base free flow speed (BFFS) for commercial heavy vehicles, as defined in Eq. (3), was used to determine free flow truck travel time in each roadway segment. Observed truck travel time (from NPMRDS data) was compared to the free flow truck travel time to determine delay in each segment. Hourly truck volume distributions from our previous study [11] were used to estimate total truck delay at each TMC in peak periods.

3.3.1 Truck Delay at Corridor Level

Average daily truck delay in the AM peak at the corridor level during the 24-month period was analyzed. Figure 10 displays the average daily truck delay for each corridor with total delay greater than 1,000 hours. I-35W, I-94, US-169, I-494, and MN-55 have an average total truck delay over 3,000 hours in the AM peak period. Similarly, Average daily truck delay in the PM peak at the corridor level during the 24-month period was also computed. Figure 11 displays the average daily truck delay for each corridor with total delay greater than 1,000 hours. I-94, I-35W, I-494, US-169, I-694, and MN-55 have an average total truck delay over 3,000 hours in the PM peak period.

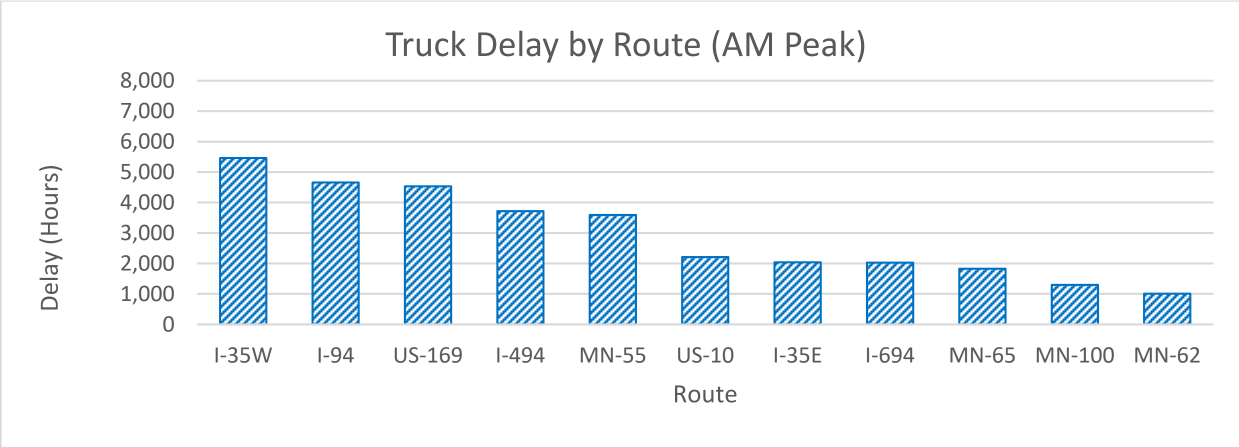


Figure 10: Average Daily Truck Delay (Over 1,000 hours) by Corridor in the AM Peak.

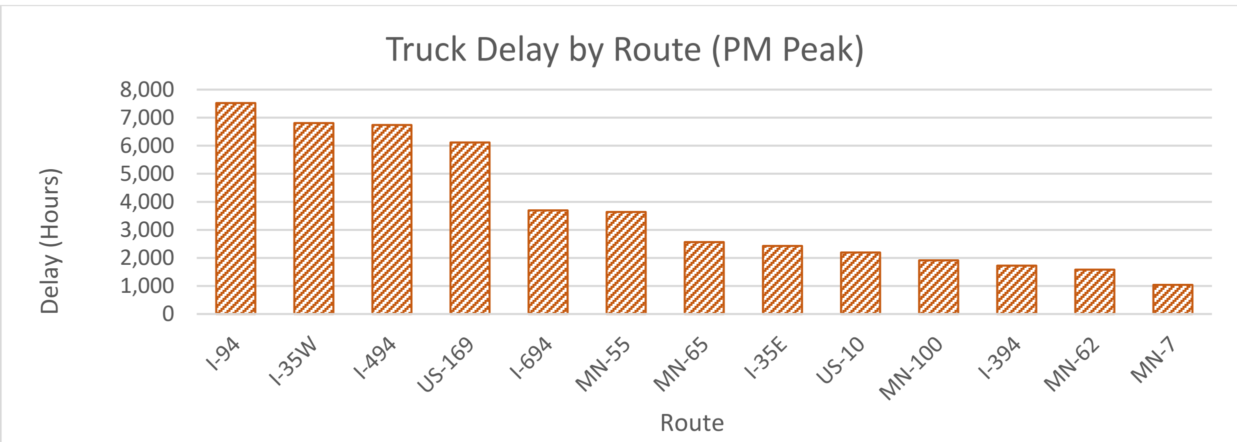


Figure 11: Average Daily Truck Delay (Over 1,000 hours) by Corridor in the PM Peak.

3.3.2 Truck Delay at TMC Segment Level

Average daily truck delays were examined at six locations in the PM peak hours. Truck delays at these locations indicated some seasonal variations. Overall, the recurring truck delays at these locations are consistent throughout the 24-month study period.

- I-494 EB E & W MN-100 – TMC 118N04131 & TMC 118N04133
- I-94 WB W of US-169 – TMC 118P04153
- I-394 EB W of I-94 – TMC 118P04354
- I-35W NB S of Downtown Minneapolis – TMC 118P04237
- I-94 WB at I-35W – TMC 118P04198 & TMC 118P04199
- I-94 EB at Marion Street – TMC 118N04188

A list of TMC segments (non-interchange locations) with recurring truck delays in the PM peak hours are listed in Table 5 as follows. TMC 118P04198 & TMC 118P04199 segments (I-94 WB at I-35W in Minneapolis) has the highest truck delay per mile in the PM peak on an average weekday. Average truck delay in the PM peak in this segment is 570 hours per mile, or 775 hours in total. TMC 118P04237 (I-35W NB south of Downtown Minneapolis) has the second highest truck delay in the PM peak on an average weekday. Average truck delay in the PM peak in this segment is 523 hours per mile. TMC 118N04188 (I-94 EB west of Downtown St. Paul) has the third highest truck delay in the PM peak on a regular weekday. Average truck delay in the PM peak in this segment is 495 hours per mile, or 366 hours in total.

Table 5: Top Congested TMC Segment in the PM Peak.

Ranking	TMC	Description	Length (Miles)	Average Delay Per Mile (Hours)	Total Segment Delay (Hours)
1	118P04198 118P04199	I-94 WB at I-35W	1.36	570	775
2	118P04237	I-35W NB S of Downtown Minneapolis	1.00	523	523
3	118N04188	I-94 EB at W of Downtown St. Paul	0.74	495	366
4	118N04131 118N04133	I-494 EB at MN-100	2.33	480	1,118
5	118P04153	I-694/94 WB West of US-169	1.17	321	376
6	118P04354	I-394 EB West of I-94	1.23	310	381

4.0 POTENTIAL CAUSES OF TRUCK BOTTLENECKS

This chapter focuses on examining and evaluating the potential causes of truck congestion at six identified bottlenecks in the PM peak hours. The examination and evaluation were conducted by driving through the congested locations and reviewing video from MnDOT traffic cameras[3] during PM peak. Table 6 lists the annual average daily truck and all traffic volume in 2016 at six locations where recurring truck congestion occurred during PM peak period. On average, heavy commercial vehicles consist of 5% of overall traffic at the selected sites. Among the six locations, the I-694/94 WB west of US-169 has the highest HCAADT volume and truck volume percentage. I-394 EB west of I-94 has the lowest HCAADT volume and truck volume percentage in the PM peak period. Each of these truck bottlenecks is discussed in the following sections.

Table 6: Truck Volume at Selected TMC Segments.

#	TMC	Location Description	Length (Miles)	HCAADT 2016	AADT 2016	Heavy Truck %
1	118P04198 118P04199	I-94 WB at I-35W	1.36	6,800	155,000	4.4%
2	118P04237	I-35W NB South of Downtown Minneapolis	1.0	7,500	193,000	3.9%
3	118N04188	I-94 EB at West of Downtown St. Paul	0.74	7,500	142,500	5.3%
4	118N04131 118N04133	I-494 EB at MN-100	2.33	8,750	164,500	5.3%
5	118P04153	I-694/94 WB West of US-169	1.17	10,000	118,000	8.5%
6	118P04354	I-394 EB West of I-94	1.23	3,400	134,000	2.5%

4.1 SITE #1 - I-94 WB AT I-35W

The location of I-94 and I-35W interchange in Minneapolis is illustrated in Figure 12. The 2016 HCAADT and AADT for I-94 WB traffic at this location (TMC 118P04198 & TMC 118P04199) were 6,800 and 155,000, respectively. Commercial trucks make up 4.4% of all vehicles traveling through this location. Recurring traffic congestion occurred in peak hours on a daily basis. Speed limit in the Lowry tunnel (A) in the west was reduced to 40 MPH due to horizontal and vertical curves. In addition, multiple paths of traffic weaving in (from I-35W NB and Downtown Minneapolis) and out (to local streets in Downtown Minneapolis) generate several potential points of disruption in this area (between point A and B as illustrated in Figure 12). Traffic congestion queue on I-94 WB often goes couple miles from the tunnel to the Mississippi River.

In addition, heavy traffic going from I-94 WB to I-35W SB through a single lane off-ramp (B) often generates delays when I-35W SB is already congested. Insufficient capacity, roadway geometry, and density of on/off-ramps are the key causes of the congestion in this location. The

[3] MnDOT. MN511 Traffic Cameras, https://hb.511mn.org/#roadReports?timeFrame=TODAY&layers=cameras

truck mobility (TTR), reliability (TTTR95) and delays are plotted in Figure 13. The average TTR at this location is 1.36 with a standard deviation of 0.19. The average TTTR95 is 3.19 with a standard deviation of 0.3. The column chart in Figure 13 displays the daily average truck delay in the PM peak by month at this location. In 2015 & 2016, the average truck delay in the PM peak at this location ranges from 374 to 625 hours on a daily basis.

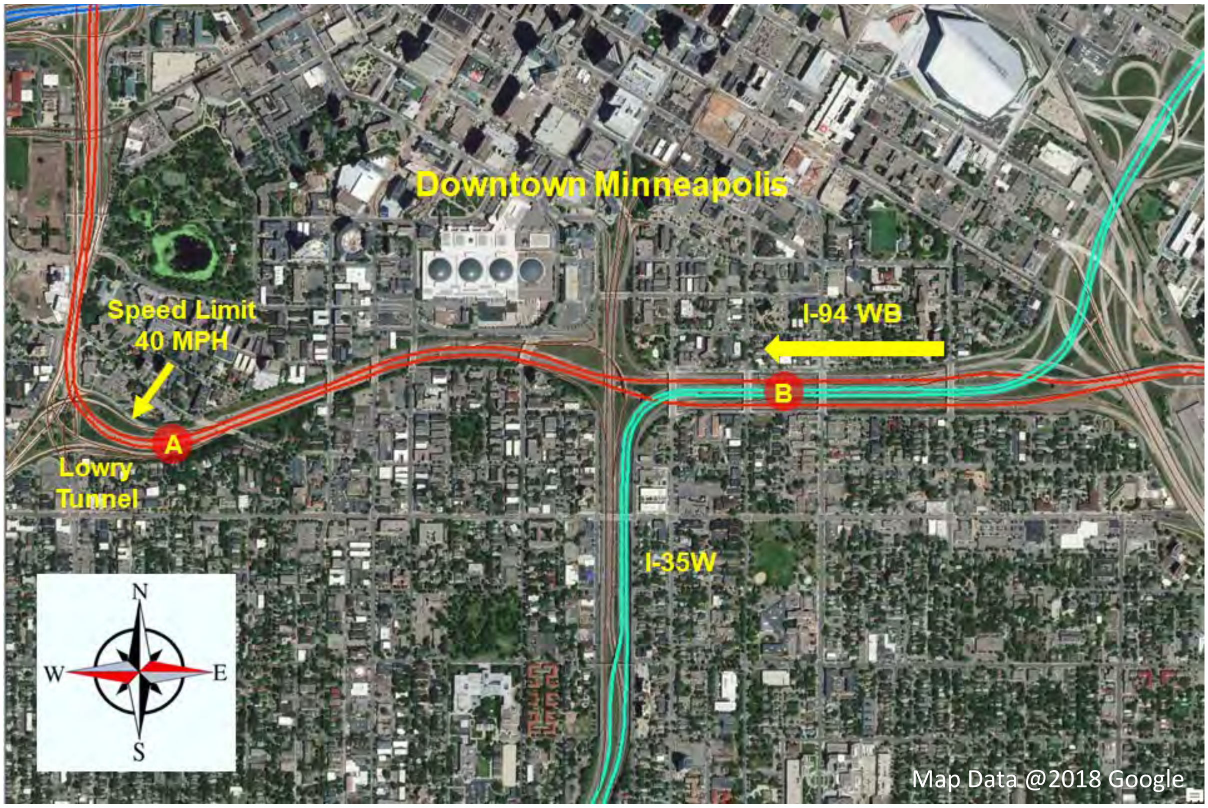


Figure 12: Aerial Map of I-94 and I-35W Interchange in Minneapolis, MN.

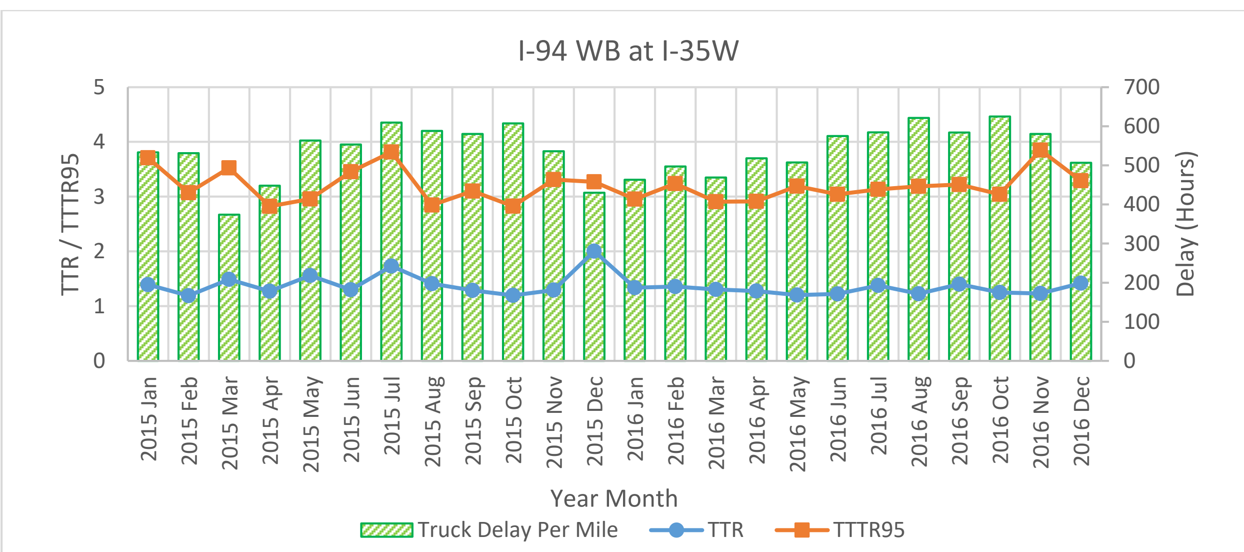


Figure 13: Average TTR, TTTR95, and Delay per Mile at I-94 WB & I-35W.

Figure 14 is a photo from MnDOT RTMC camera at I-94 and Cedar Ave in Minneapolis in the PM peak period. The I-94 WB and I-35W SB interchange is less than 1 mile downstream.

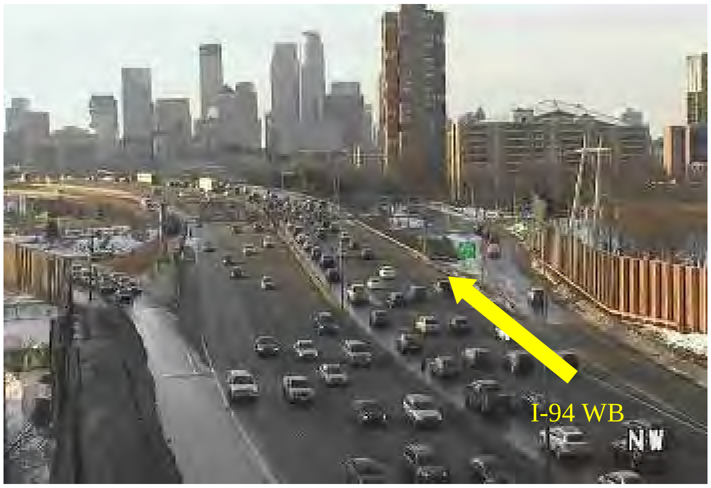


Figure 14: Screenshot of MnDOT RTMC Camera at I-94 and Cedar Ave.

4.2 SITE #2 - I-35W NB SOUTH OF DOWNTOWN MINNEAPOLIS

The location of I-35W NB and I-94 interchange in south of Downtown Minneapolis is illustrated in Figure 15. The 2016 HCAADT and AADT for I-35W NB traffic at this location (TMC 118P04237) were 7,500 and 193,000, respectively. Commercial trucks make up 3.9% of all vehicles traveling through this location. Recurring traffic congestion occurred in peak hours on a daily basis. Point A (as illustrated in Figure 15) is a weaving location for traffic coming from I-94 EB to I-35W NB and leaving I-35W NB to I-94 EB. Another weaving point (I-35W NB & MN-55/Hiawatha Ave.) with horizontal and vertical curves ahead of point A creates additional frictions to the traffic flow in this area. Speed limit on I-35W NB at the 90-degree turn (B) was reduced from 55 to 35 MPH due to the sharp horizontal curve. In addition, multiple paths of traffic weaving in (from 33rd and 38th Street) and out (to I-94 WB and Downtown Minneapolis) generate several potential points of disruption in this area (between C and D as illustrated in Figure 15). Traffic congestion queue on I-35W NB often grows beyond point D.

Insufficient capacity, roadway geometry, and multiple weaving points at this location are the key causes of recurring congestion. The truck mobility (TTR), reliability (TTTR95) and delays are plotted in Figure 16. The average TTR at this location is 1.42 with a standard deviation of 0.17. The average TTTR95 is 3.91 with a standard deviation of 1.34. The truck travel time reliability measures in Jan. & Feb. 2015 were significantly higher (8.0 & 7.8) than the TTTR95 in the other months (see Figure 16). The unreliable truck travel time may be caused by winter weather or roadway incidents in Jan. & Feb. 2015. The column chart in Figure 16 indicates a seasonal pattern in the daily average truck delay in the PM peak by month at this roadway segment. In 2015 & 2016, the average truck delay in the PM peak at this location ranges from 208 to 735 hours on a daily basis. In general, trucks traveling though the location in non-winter months (Apr. to Nov.) have longer travel time delay than traveling in winter months.

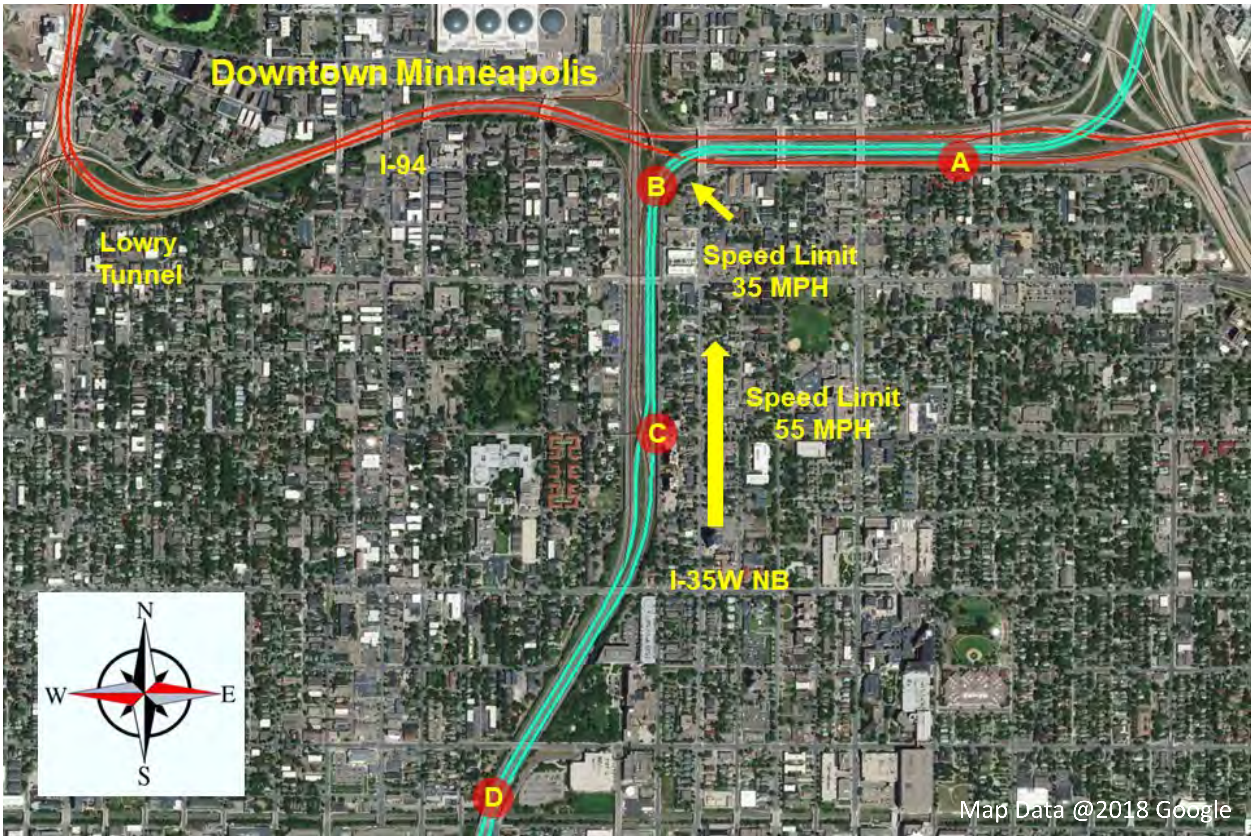


Figure 15: Aerial Map of I-35W and I-94 Interchange in Minneapolis, MN.

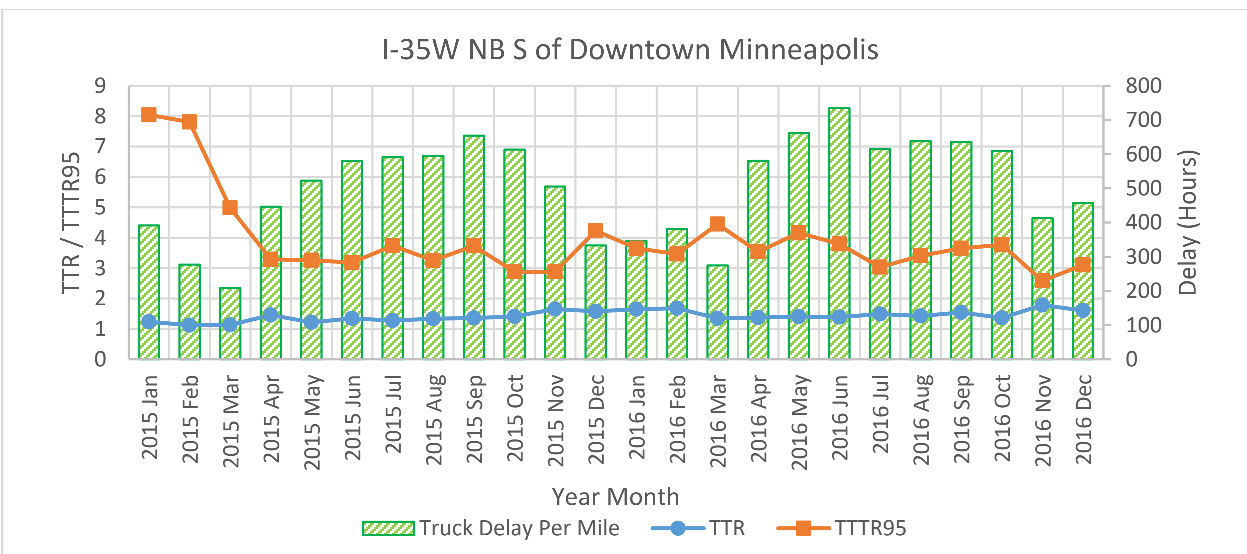


Figure 16: Average TTR, TTTR95, and Delay per Mile at I-35W NB & I-94.

4.3 SITE #3 - I-94 EB WEST OF DOWNTOWN ST. PAUL

The location of I-94 EB and I-35E interchange in west of Downtown St. Paul is illustrated in Figure 17. The 2016 HCAADT and AADT for I-94 EB traffic at this location (TMC 118N04188) were 7,500 and 142,500, respectively. Commercial trucks make up 5.3% of all vehicles traveling through this location. Recurring traffic congestion occurred in peak hours on a daily basis. Point A (as illustrated in Figure 17) is a weaving location for traffic coming from I-94 EB to US-52. Horizontal and vertical curves between point A & B also slow down the traffic flow in this area in rush hours. Speed limit between point A and C is reduced to 50 MPH due to multiple horizontal and vertical curves. In addition, multiple paths of traffic weaving in (from I-35E and Downtown St. Paul) and out (to I-35E NB, 7th Street and US-52) generate several potential points of disruption in this area (between A and C as illustrated in Figure 17). Traffic congestion queue on I-94 EB often grows beyond point C.

Figure 17: Aerial Map of I-94 and I-35E Interchange in St. Paul, MN.

Insufficient capacity, roadway geometry, and multiple weaving points at this location are the key causes of recurring congestion. The truck mobility (TTR), reliability (TTTR95) and delays are plotted in Figure 18. The average TTR at this location is 2.02 with a standard deviation of 0.34. On average, truck travel time on a weekday PM peak period is twice as long as the travel time of a passenger vehicle. The average TTTR95 is 4.15 with a standard deviation of 1.56. The truck travel time reliability measure in Mar. 2015 was significantly higher (9.9) than the TTTR95 in the other months (see Figure 18). The TTR in Mar. 2015 was relatively lower (1.17) than the TTR in the other months. The unreliable truck travel time may be caused by winter weather or roadway incidents in Mar. 2015. The column chart in Figure 18 displays the daily average truck delay in the PM peak by month at this location. In 2015 & 2016, the average truck delay in the PM peak at this location ranges from 344 to 843 hours on a weekday. Figure 19 is a photo from MnDOT RTMC camera at I-94 and I-35E in St. Paul in the PM peak period. The I-94 EB and I-35E NB interchange is less than 1/2 mile downstream.

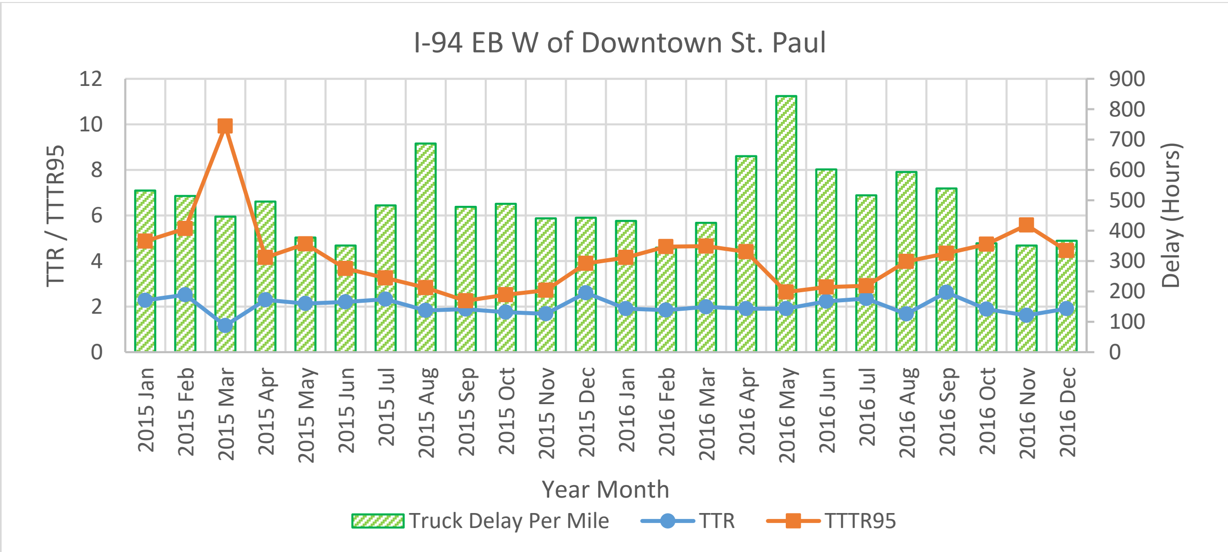


Figure 18: Average TTR, TTTR95, and Delay per Mile at I-94 EB & I-35E.

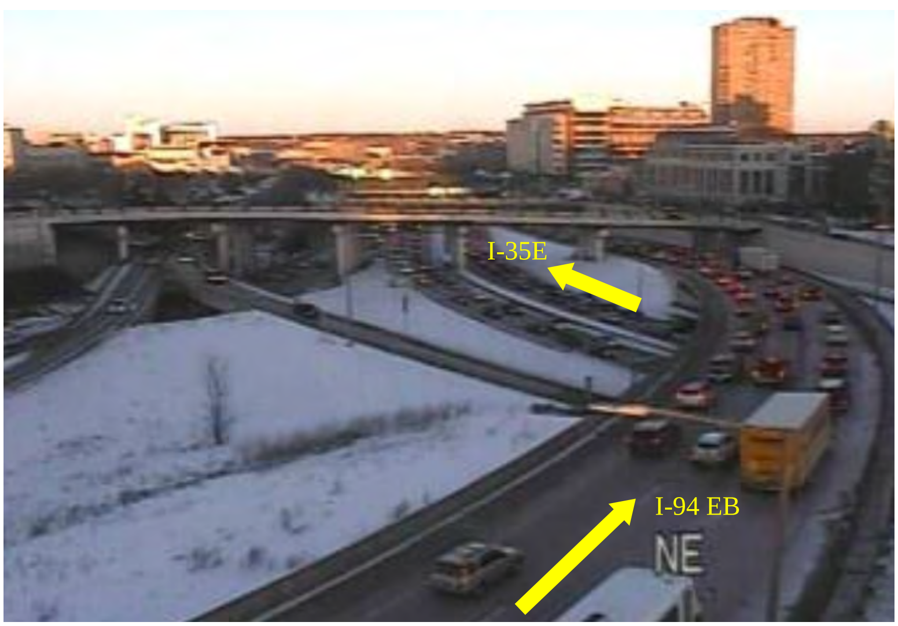


Figure 19: Screenshot of MnDOT RTMC Camera at I-94 and I-35E.

4.4 SITE #4 - I-494 EB AT MN-100

The location of I-494 EB at MN-100 interchange in Bloomington is illustrated in Figure 20. The 2016 HCAADT and AADT for I-494 EB traffic at this location (TMC 118N04131 & TMC 118N04133) were 8,750 and 164,500, respectively. Commercial trucks make up 5.3% of all vehicles traveling through this location. Recurring traffic congestion occurred in peak hours on weekdays. Roadway geometry on I-494 from US-169 to I-35W is pretty straight with posted speed limit of 60 MPH. However, there are many office and retail business on both sides of the highway. There are six on/off-ramps and interchanges between I-35W and US-169. Many motorists try to get on/off/through this highway segment during the peak hours. Congestion queue on I-494 EB in the PM peak period often goes beyond point C on a regular weekday

In addition, heavy traffic going from I-494 EB to I-35W SB through a single lane off-ramp (A) often generates delays when I-35W SB is usually busy. Insufficient capacity and density of weaving points in this location are the key causes of traffic delays. The truck mobility (TTR), reliability (TTTR95) and delays are plotted in Figure 21. The average TTR at this location is 1.36 with a standard deviation of 0.16. The average TTTR95 is 3.23 with a standard deviation of 0.82. The truck travel time reliability measures in Jan. 2015 was relatively higher (5.9) than the TTTR95 in the other months (see Figure 21). The unreliable truck travel time at this location may be related to winter weather. The column chart in Figure 21 displays the daily average truck delay in the PM peak by month at this location. In 2015 & 2016, the average truck delay in the PM peak at this location ranges from 314 to 701 hours on a daily basis.

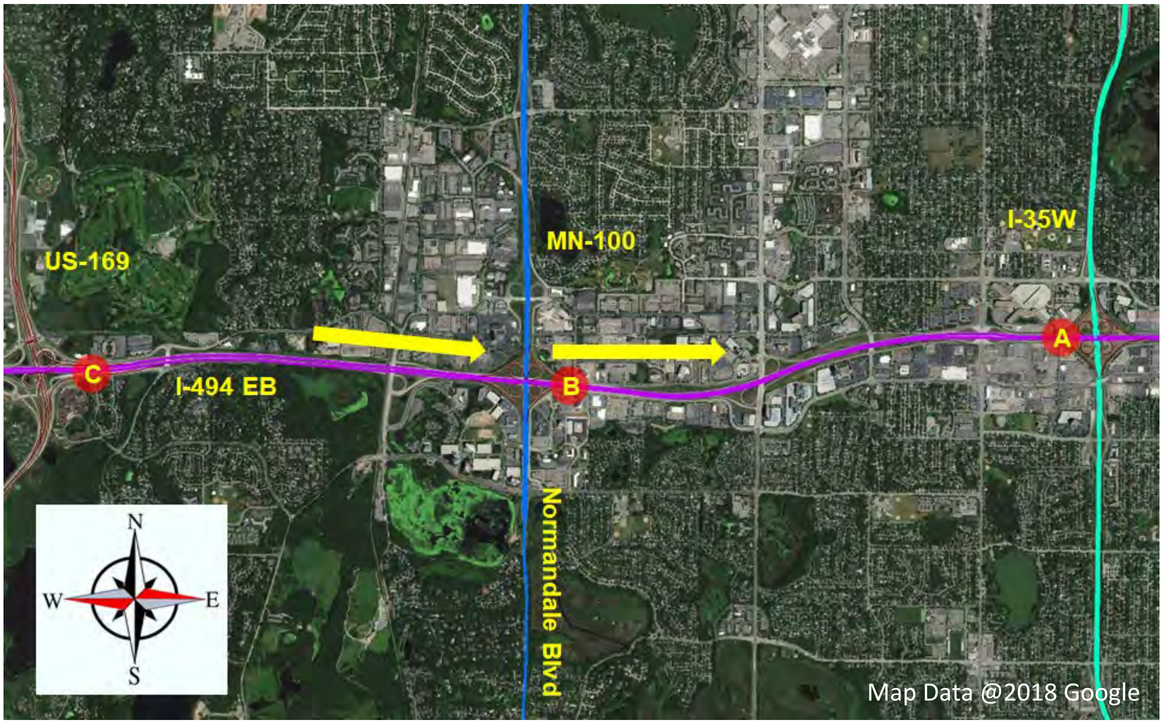


Figure 20: Aerial Map of I-494 and MN-100 in Bloomington, MN.

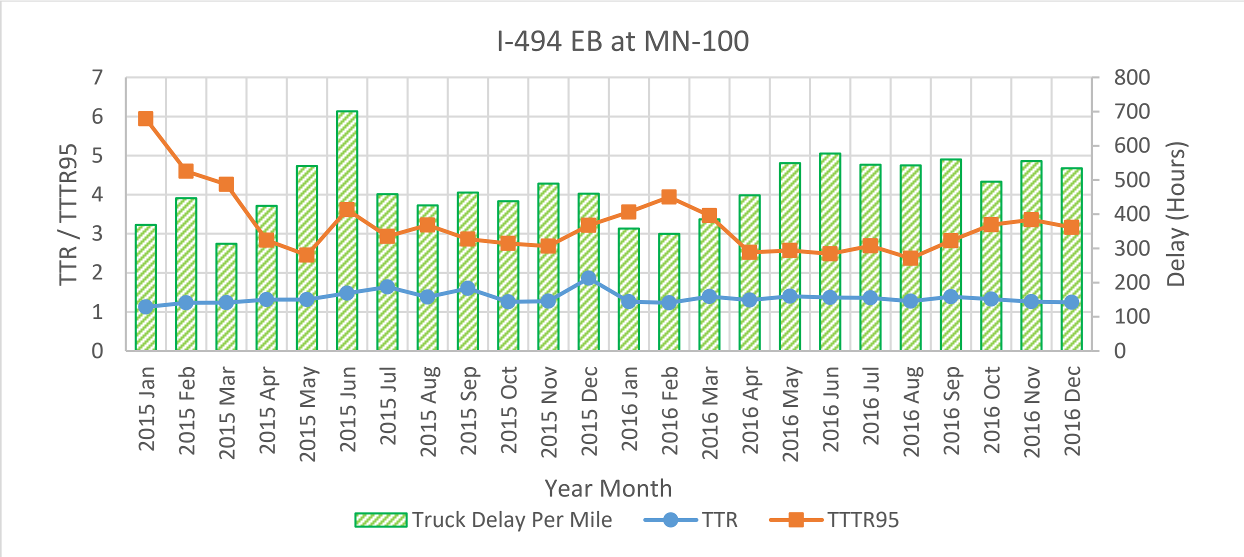


Figure 21: Average TTR, TTTR95, and Delay per Mile at I-494 EB at MN-100.

Figure 22 is a photo from MnDOT RTMC camera at I-494 and MN-100 in Bloomington in the PM peak period on a weekday. The I-494 EB traffic is very busy during the PM peak period near the MN-100 interchange area.

Figure 22: Screenshot of MnDOT RTMC Camera at I-494 and MN-100.

4.5 SITE #5 - I-694/94 WB WEST OF US-169

The location of I-694 WB west of US-169 interchange in Maple Grove is illustrated in Figure 23. The 2016 HCAADT and AADT for I-94 EB traffic at this location (TMC 118P04153) were 10,000 and 118,000, respectively. This location has the highest commercial truck volume as compared to the other sites discussed in this chapter. Commercial trucks make up 8.5% of all vehicles traveling through this location. Recurring traffic congestion occurred in peak hours on a regular basis. Point A (as illustrated in Figure 23) is a weaving location for traffic coming from I-494 NB to I-94 toward St. Cloud. Horizontal and vertical curves for traffic leaving I-694 WB to I-494 SB (point D, splitting to I-494 SB and I-94 WB) could affect the traffic flow upstream. Speed limit between point A and C is 65 MPH. In addition, multiple paths of traffic weaving in (from US-169, I-494 NB, and Hemlock Lane) and out (to I-494 SB and Hemlock Lane) generate several potential points of disruption in this area (between A and C as illustrated in Figure 23). Traffic congestion queue on I-694/94 WB often grows beyond point C.

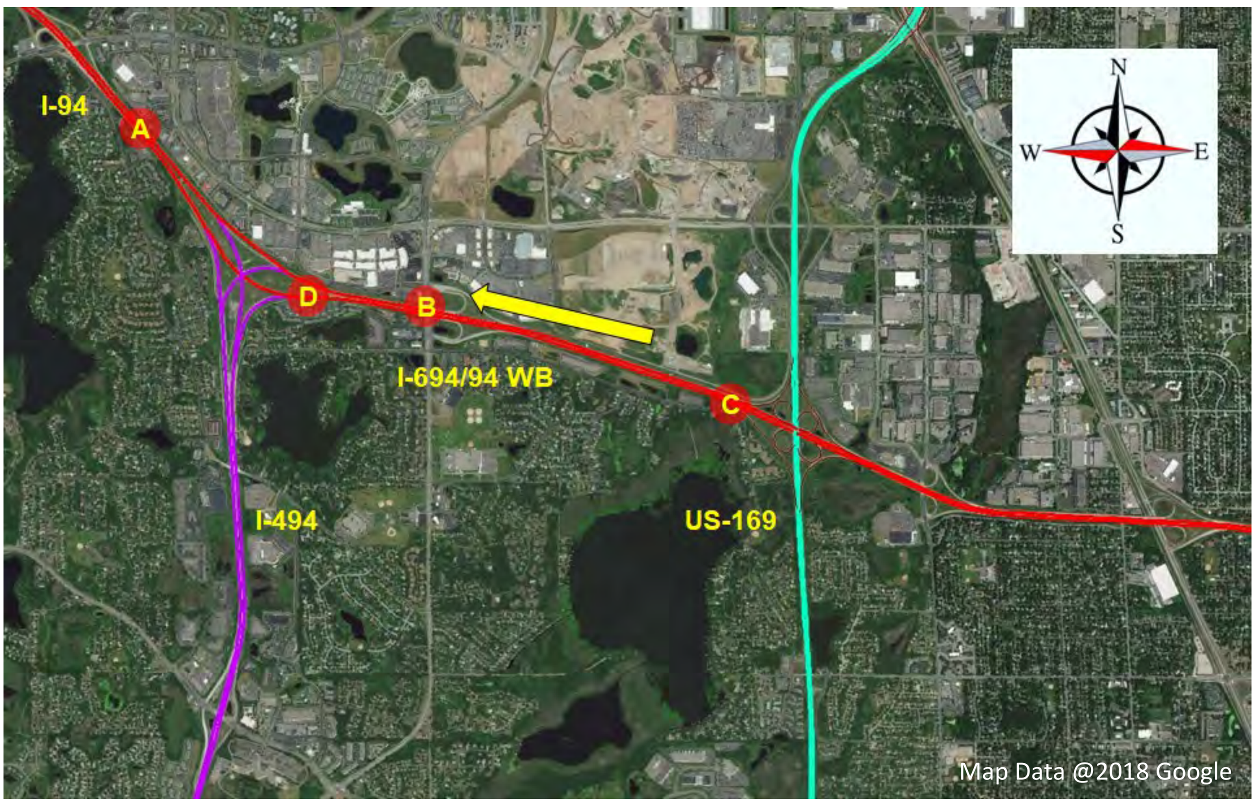


Figure 23: Aerial Map of I-694 at US-169 in Maple Grove, MN.

Insufficient capacity and multiple weaving points at this location are the key causes of recurring congestion. The truck mobility (TTR), reliability (TTTR95) and delays are plotted in Figure 24. The average TTR at this location is 1.35 with a standard deviation of 0.26. On average, truck travel time on a weekday PM peak period is 35% longer than the travel time of a passenger vehicle.

The average TTTR95 is 4.09 with a standard deviation of 1.44. The truck travel time reliability measures from May to Sep. 2016 were significantly lower (1.8) than the TTTR95 in the other months (see Figure 24). The research team found that I-494 was partially closed for rehabilitation between I-394 and the I-94/I-494/I-694 interchange from mid-April 2016 through November 2016. In fact, the I-694 WB to I-494 SB ramp (point D in Figure 23) was closed for a period of time. Upstream traffic on I-694/94 WB was affected by the construction during the period. The reliable truck travel time may be caused by the downstream construction from mid Apr. to Nov. 2016.

The column chart in Figure 24 displays the daily average truck delay in the PM peak by month at this location. In 2015 & 2016, the average truck delay in the PM peak at this location ranges from 149 to 580 hours on a weekday. Truck congestion increased to almost twice as much the delay before the construction. However, the truck travel time reliability measure (TTTR95) decreased (more reliable) when the traffic became reliably slow during the I-494 rehabilitation period.

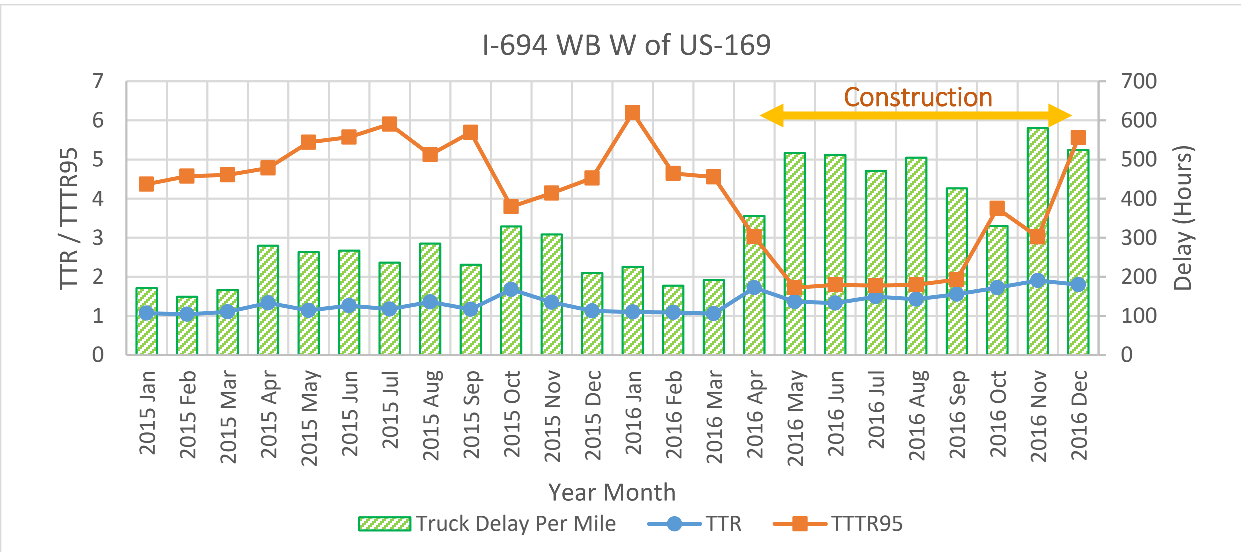


Figure 24: Average TTR, TTTR95, and Delay per Mile at I-694 WB W of US-169.

4.6 SITE #6 - I-394 EB WEST OF I-94

The location of I-394 EB west of I-94 interchange in Minneapolis is illustrated in Figure 25. The 2016 HCAADT and AADT for I-94 EB traffic at this location (TMC 118P04354) were 3,400 and 134,000, respectively. This location has the lowest commercial truck volume as compared to the other locations discussed in this chapter. Commercial trucks make up only 2.5% of all vehicles traveling through this location. Recurring traffic congestion occurred in peak hours on a regular basis. Point A (as illustrated in Figure 25) is a merging location for traffic coming from I-394 EB (general & HOV lanes) to I-94 EB toward St. Paul. Horizontal and vertical curves between A and B on a single lane off-ramp really restrict the traffic flow upstream. Speed limit at off-ramp (between point A and B) is 30 MPH. In addition, multiple paths of traffic weaving in (from MN-100 and Penn Ave.) and out (to I-94 WB and Downtown Minneapolis) generate several potential points of disruption in this area (between B and D as illustrated in Figure 25). Traffic congestion queue on I-394 EB often grows beyond point D in the PM peak hours.

Insufficient capacity and roadway geometry near this location are the key causes of recurring congestion. The truck mobility (TTR), reliability (TTTR95) and delays are plotted in Figure 26. The average TTR at this location is 1.34 with a standard deviation of 0.25. On average, truck travel time during a weekday PM peak period is 34% longer than the travel time of a passenger vehicle. The average TTTR95 is 7.6 with a standard deviation of 2.2. Truck travel time in this area is very unreliable with large variations throughout the 24-month study period. The unreliable truck travel time may be caused by the dynamic nature of congested traffic and driver behaviors. Many impatient drivers like to cut in the single lane off-ramp at the beginning of I-94 EB & WB off-ramp split (location B in Figure 25). The column chart in Figure 26 displays the daily average truck delay in the PM peak by month at this location. In 2015 & 2016, the average truck delay in the PM peak at this location ranges from 137 to 566 hours on a weekday.

Figure 25: Aerial Map of I-394 and I-94 in Minneapolis, MN.

Figure 27 is a photo from MnDOT RTMC camera at I-394 and Penn Ave in Minneapolis during PM peak period on a weekday. The I-394 EB traffic is very busy during a regular weekday PM period.

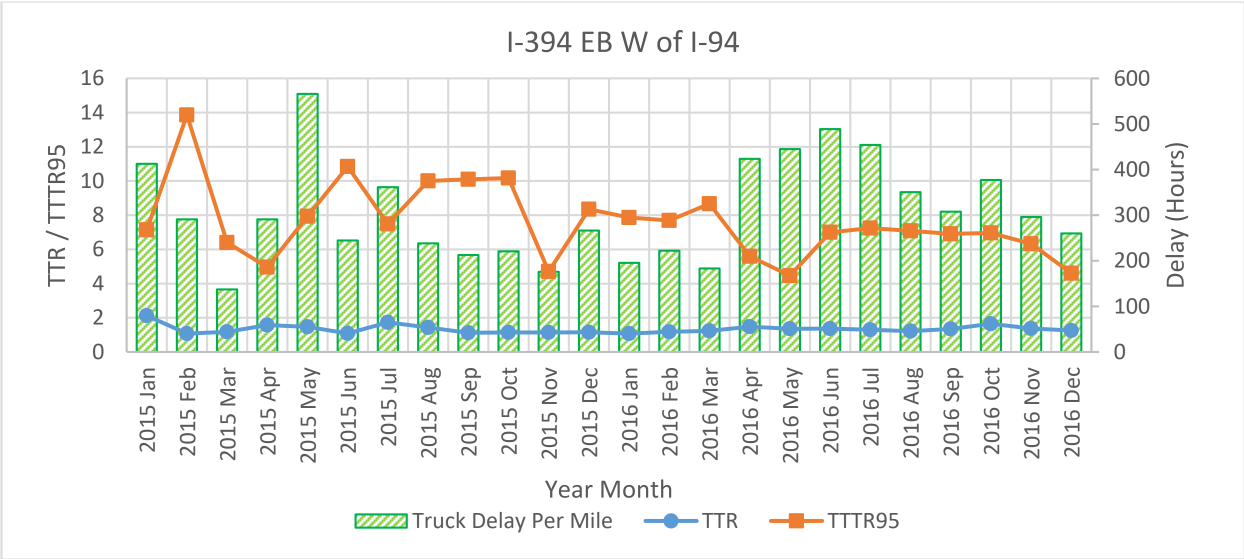


Figure 26: Average TTR, TTTR95, and Delay per Mile at I-394 EB W of I-94.

Figure 27: Screenshot of MnDOT RTMC Camera at I-394 and Penn Ave.

5.0 MITIGATION STRATEGIES

In 2017, the NCHRP published a report that provides guidelines for identifying, classifying, evaluating, and mitigating truck bottlenecks. Options for mitigating truck bottlenecks were recommended for recurring and nonrecurring congestions [31 & 32]. The author's previous effort [33] focused on the data analysis to identify truck bottlenecks. This project leverages the previous effort to investigate potential causes of truck bottlenecks and develop mitigation strategies on major truck highway corridors in the TCMA.

Traditionally, adding more physical capacity to existing roadways has been the option and an important strategy to alleviate traffic congestion. However, it is increasingly difficult and expensive to add capacity in metropolitan areas due to the right-of-way, construction costs, and many other factors [34]. Another option is to use ITS technologies (e.g., real-time traveler information, variable speed limits, managed lanes, ramp metering, etc.) to operate existing roadway capacity more efficiently.

Among the identified bottlenecks described in the previous chapter, we noticed an increasing number of vehicles weaving in and out of the bottleneck areas as traffic demand increases in peak periods. The increasing frequency of vehicle weaving or lane changing causes the mainline traffic to slow down. The disruption of traffic flow significantly impacts the heavy commercial vehicles that usually require a longer time to accelerate and decelerate. We also noticed that passenger vehicles on the adjacent lanes near a heavy commercial vehicle often make lane changes to take advantage of a gap in front of the truck in stop-and-go traffic conditions. This phenomenon often causes an additional delay for the trucks.

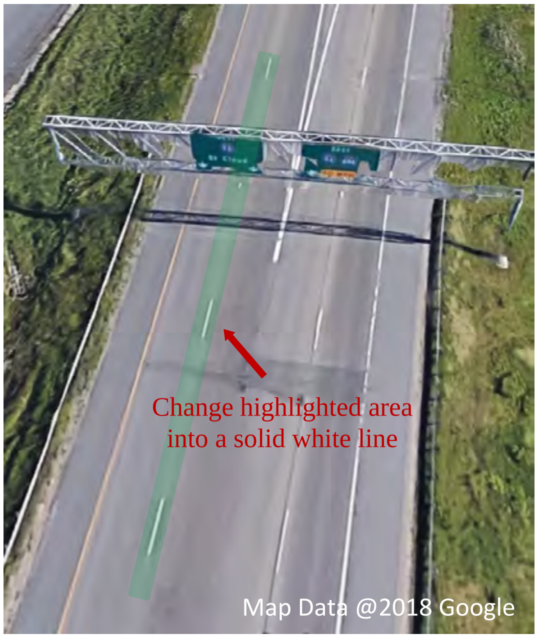
As a short-term and less expensive solution, we suggested using a solid white line on the main roadway to discourage drivers from lane changing near the interchange bottlenecks. Hourdos et al. [35] extended a double white line at an on-ramp merge point to reduce the number of shockwaves on the mainline. Figure 28 & 29 illustrate an example of changing the dashed line into a solid white line at a highway weaving location with 2-lane exit lanes on the left shoulder. The purpose is to discourage motorist to make lane changes at the weaving point.

Figure 28: Example of Solid White Line at a Highway Interchange.

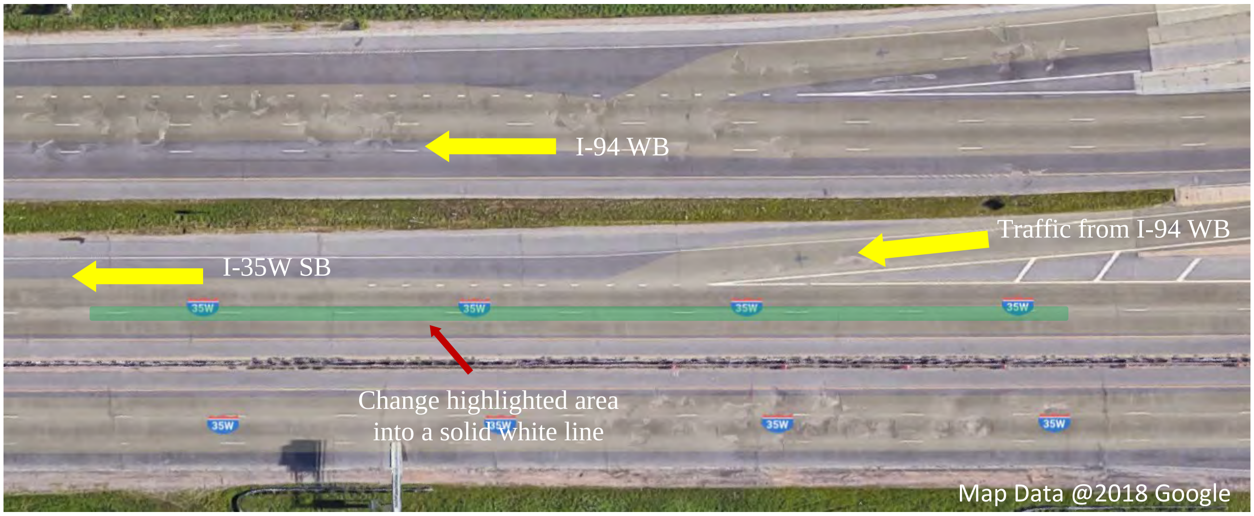
In addition, concrete barriers can be effective in separating the on/off-ramp traffic from the mainline and combining 2 conflict points (merging and diverging) into one merging point. For example, a Jersey barrier, as shown in Figure 30(a), was built to separate 2 on-ramp merging traffic and extend the merging point to the mainline about half-mile downstream at I-94 EB in Rogers, MN. Similarly, a low profile concrete barrier, as shown in Figure 30(b), was placed to separate on/off-ramp traffic at I-35W NB and I-494 interchange area.

Traffic signs and real-time traveler information can be placed at locations prior to approaching the bottlenecks (See Figure 31). For example, MnDOT has painted solid white lines for lane control at a few merging and diverging areas on highways and work zones in addition to using solid white lines inside the Lowry tunnel in Minneapolis.

The mid/long-term solution requires capacity expansion, reduce number of merging and diverging points near a bottleneck, and deploying ITS technology to provide timely traveler information to reduce congestion at bottlenecks. Although, it is debatable that the solid white lines are often ignored by motorists. The recommended mitigation strategies require the cooperation from the motorists. The public agency will need to continue monitor performance and track progress as an ongoing effort to provide safe and efficient services for the public.



(a)



(b)

Figure 29: Illustration of Changing Dashed Lines into a Solid White Line.

(a) I-94 EB at Highway 101 in Rogers, MN

(b) I-35W NB at I-494 Interchange in Bloomington, MN
Figure 30: Example of Barrier to Separate On/Off-Ramp Traffic from Mainline

Figure 31: Example of Real-time Traveler's Information Prior to a Bottleneck.

6.0 SUMMARY

Freight transportation provides a significant contribution to our nation's economy. The USDOT has identified and recommended critical performance measures, methodologies and standards for data collection, potential issues related to deployment, and usability of performance measures in addressing issues at local, state, and federal levels.

A reliable and accessible freight network enables business in Twin Cities to be competitive in the Upper Midwest region. Many urban roadways are facing challenges with traffic volumes being over capacity during peak periods. As a result, time and money are lost due to traffic congestion. Operational and design constraints such as interchange, steep grade, signalized intersection, work zone, merging, lane drop and others, could contribute additional delays for commercial vehicles.

The research team worked with stakeholders to prioritize a list of key truck corridors in the Twin Cities Metro Area (TCMA). Monthly NPMRDS data were processed to measure travel time reliability and estimate truck delay at the corridor level and then to identify system impediments during peak hours. Performance measures, including truck mobility ratio, travel time reliability, and delay, were defined and computed using 24 months of NPMRDS data.

On average, roadways with signalized or un-signalized intersections have a higher percentage of truck-to-car travel time ratio (TTR). On average, trucks travel an average of 10%more slowly than cars on freeways. As listed in Table 4, trucks on the US and interstate highways have about a 10% longer travel time than cars. On state highways, the TTR reaches 1.2 and 1.4 in the AM and PM peak periods, respectively. Trucks travel significantly slower than cars on county roads. The TTR on county roads is around 1.5 during mid-day and spikes to 1.7 and 1.9 in the AM and PM peak periods, respectively. The increase of TTR on county roads may largely be due to the number of intersections in a TMC segment and delays at signalized intersections.

For example, the average truck travel time on 34% of county road 30 in Hennepin County is over 50% longer than the average passenger vehicle travel time in the PM peak. In the PM peak hours, the average truck travel time on 6.8% of the I-94 roadway in the TCMA is over 50% longer than the average passenger vehicle travel time. Similarly, the average truck travel time on 6.6% of I-394 roadway is over 50% longer than the average passenger vehicle travel time.

A reliability measure was processed and analyzed to evaluate the truck travel time reliability. The results indicate that the truck travel time in the PM peak period is less reliable than the travel time in the AM peak period. Similar to the TTR measure, roadways with signalized or un-signalized intersections are generally less reliable than freeways. At the corridor level, the TTTR95 measure is much higher than the RI95 measure. The variability of TTTR95 is also higher than the RI95 measure. This is mostly caused by the long-tail distribution of truck travel time from the NPMRDS data.

For example, the 95th percentile truck travel time on 80% of CR-42 roadway is over twice as long as the average truck travel time in the PM peak. In the PM peak hours, the 95th percentile truck travel time on 75.5% of MN-65 roadway is over twice as long as the average truck travel time. Similarly, the 95th percentile truck travel time on 52.7% of I-394 roadway is over twice as long as the average truck vehicle travel time.

We identified six truck bottlenecks in the TCMA during the PM peak period to further investigate the potential causes of the congestion. Among the six bottlenecks, I-94 WB at I-35W in Minneapolis has the highest truck delay per mile in the PM peak on an average weekday. Average truck delay in the PM peak in this segment is 570 hours per mile or 775 hours in total. We found insufficient capacity, increasing demand, roadway geometry, and density of weaving points in a roadway segment are the key causes of traffic congestion among the identified bottlenecks.

We recommend painting solid white lines on the main roadway to discourage drivers from changing lane near the bottlenecks as a less expensive solution. Traffic signs and real-time traveler information could also be placed at locations prior to approaching the bottlenecks. Ongoing performance monitoring using NPMRDS or other sources of traffic data is needed to support transportation planning and operation.

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APPENDIX A

HOURLY TRUCK VOLUME DISTRIBUTION

Hourly truck volume distributions (Figure A-1 to A-5) were computed from truck volume data collected at five locations in the Twin Cities Metro Area (TCMA) using loop signature technology at existing loop detection stations. As shown in Figure A-2, significantly higher trucking activity (over 10%) occurred in the AM and PM peak hours in the US-169 NB direction near the TH-282 area.

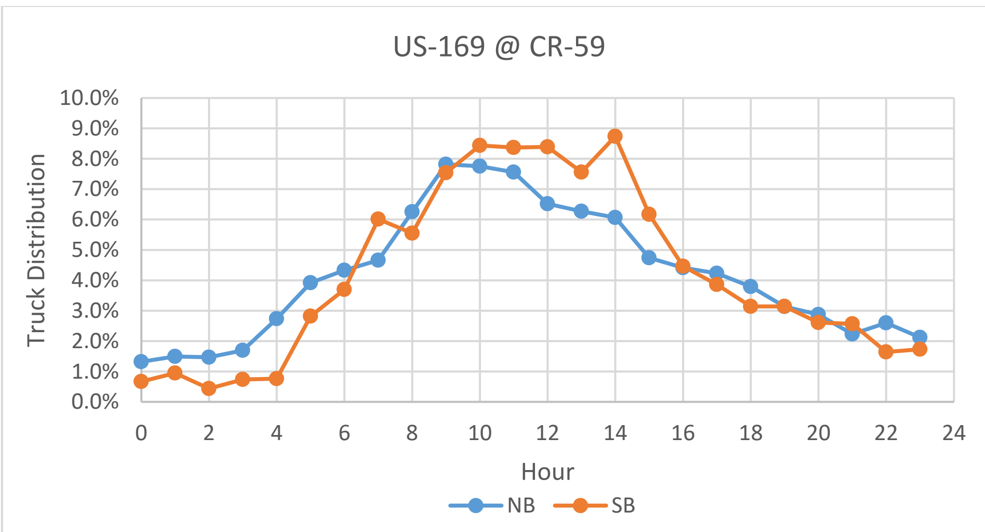

Figure A-1: Hourly Truck Volume Distribution on US-169 at CR-59.

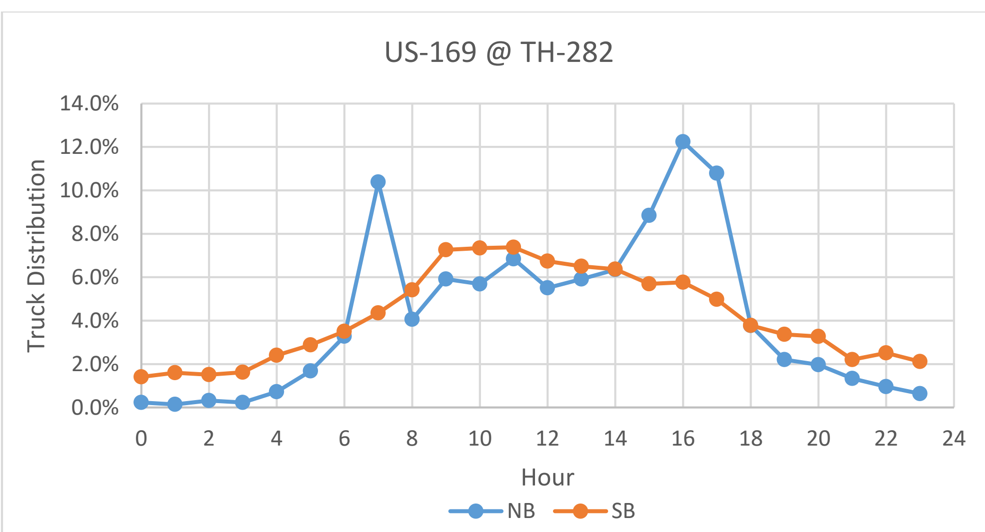

Figure A-2: Hourly Truck Volume Distribution on US-169 at TH-282.

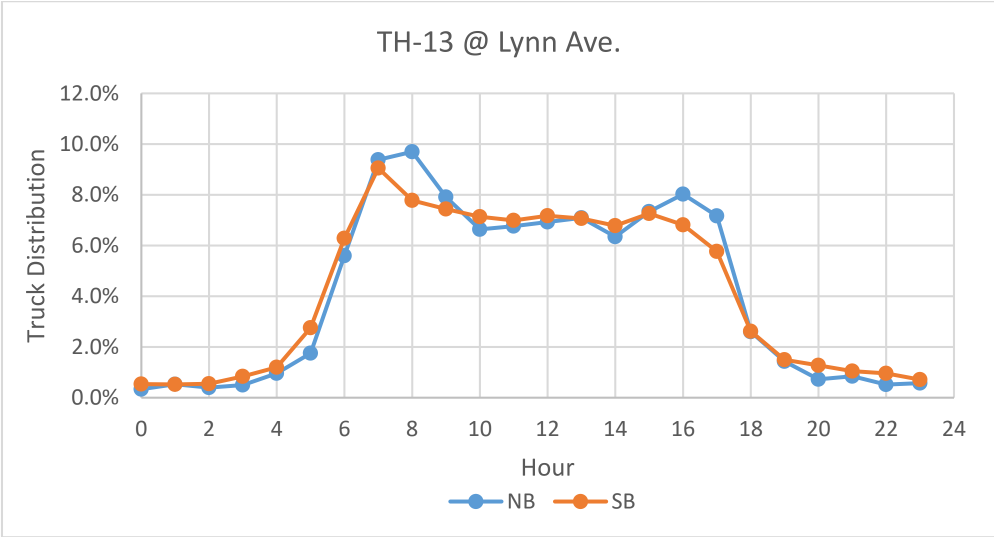

Figure A-3: Hourly Truck Volume Distribution on TH-13 at Lynn Ave.

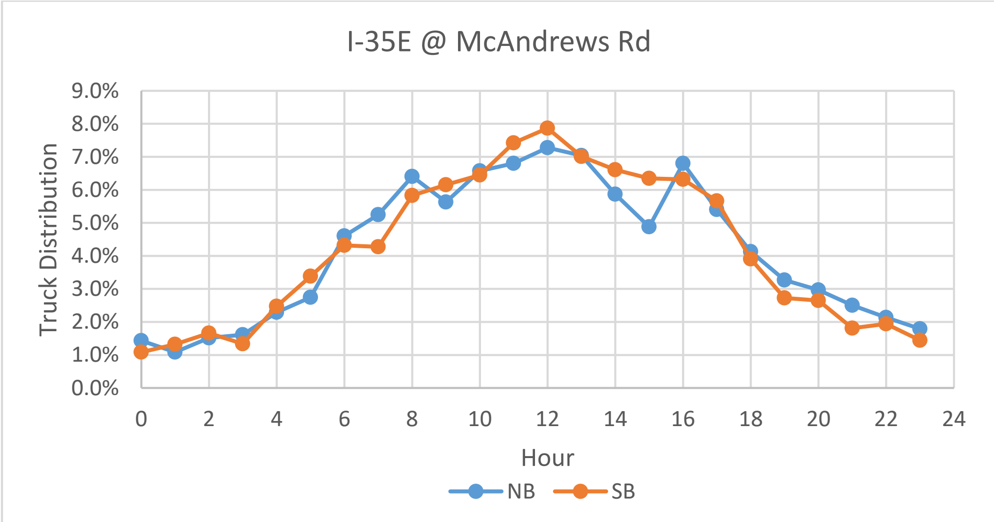

Figure A-4: Hourly Truck Volume Distribution on I-35E at McAndrews Rd.

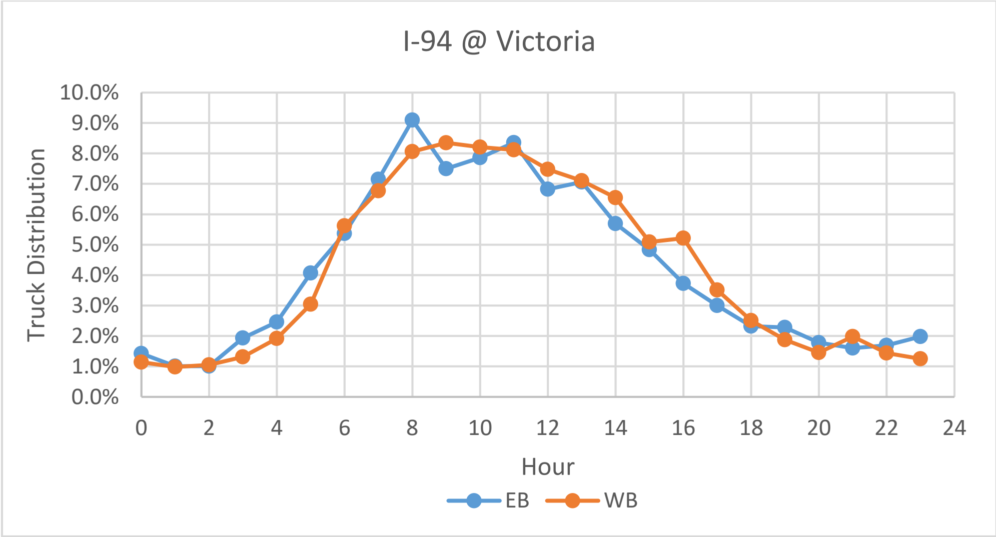

Figure A-5: Hourly Truck Volume Distribution on I-94 at Victoria St.

We also obtained 12 months of WIM data from MnDOT to examine the hourly truck volume distribution. Figure A-6 displays the hourly truck volume distribution at four WIM stations in the TCMA. WIM station 36 is located on MN-36 in the City of Lake Elmo in Washington County. WIM station 37 is located on I-94 WB in the City of Otsego in Wright County. WIM 40 is located on US-52 in the City of West St. Paul in Dakota County. And WIM station 42 is located in the City of Cottage Grove in Washington County.

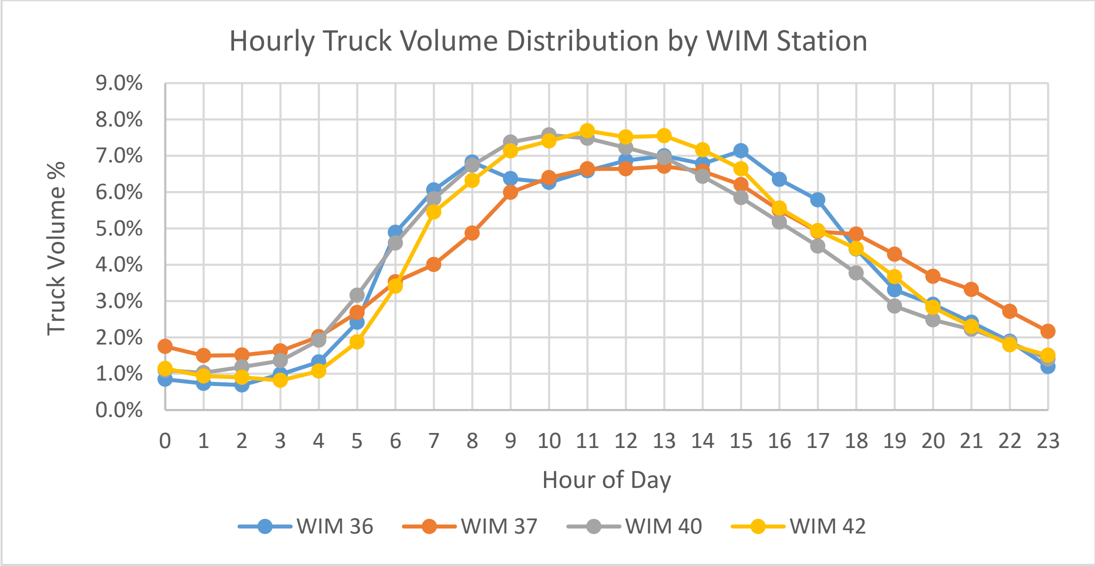

Figure A-6: Hourly Truck Volume Distribution at Four WIM Stations.