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Continued Updating the Lane Closure Guide for Urban Highways in the Kansas City, Kansas, Metropolitan Area

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16 Abstract

Temporary work zones in the United States continue to be an important and necessary aspect of preserving, expanding, and maintaining the roadway infrastructure network. However, work zones present a unique variable in that depending on the type of work being performed, they may require a reduction in roadway capacity if one or more lanes are closed temporarily. A reduction in capacity may lead to non-recurring congestion and safety concerns. A previous study conducted by the research team established a lane closure guide for the Kansas City metropolitan area where 1,500 passenger cars per hour per lane (pcphpl) was the established threshold for closing a lane based on the Highway Capacity Manual (HCM). The objective to this follow-up study was to determine if the 1,500 pcphpl threshold was appropriate based on historical work zones and KC Scout traffic operations center data. Data were extracted for work zones, and the 85th percentile and maximum sustained flow were investigated. An analysis of data found significant errors in the data where the sensor data indicated a work zone was not present during the specified time period. Multiple QA/QC checks were performed to ensure data was accurate. Based on the analyses, it is recommended that a ground-truthing methodology be used to ensure that sensors are recognizing a highway lane is closed and background traffic noise is not being collected by the sensors.

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

NOTICE

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Abstract

Temporary work zones in the United States continue to be an important and necessary aspect of preserving, expanding, and maintaining the roadway infrastructure network. However, work zones present a unique variable in that depending on the type of work being performed, they may require a reduction in roadway capacity if one or more lanes are closed temporarily. A reduction in capacity may lead to non-recurring congestion and safety concerns. A previous study conducted by the research team established a lane closure guide for the Kansas City metropolitan area where 1,500 passenger cars per hour per lane (pcphpl) was the established threshold for closing a lane based on the Highway Capacity Manual (HCM). The objective to this follow-up study was to determine if the 1,500 pcphpl threshold was appropriate based on historical work zones and KC Scout traffic operations center data. Data were extracted for work zones, and the 85^{th} percentile and maximum sustained flow were investigated. An analysis of data found significant errors in the data where the sensor data indicated a work zone was not present during the specified time period. Multiple QA/QC checks were performed to ensure data was accurate. Based on the analyses, it is recommended that a ground-truthing methodology be used to ensure that sensors are recognizing a highway lane is closed and background traffic noise is not being collected by the sensors.

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Chapter 1: Background

Temporary work zones on interstates and U.S. highways have a significant influence on the traveling public, where days the work zone is present, roadway geometry, and volume-to-capacity ratio of the work zone approach also influence travel-demand levels (Lee & Noyce, 2007). Hallmark, Mudgal, Stout, and Wang (2011) noted that rear-end and sideswipe crashes occur more frequently as traffic flow through the work zone is reduced. Non-recurring roadway congestion due to work zones in large urban areas can also pose significant delay and long queues, which in many cases can be unavoidable. Guerrini (2014) stated that in 2013, congestion on roadways (including roadways with work zones) cost an estimated $124 billion in economic loss, along with increased driver frustration and aggressive driver behavior (Heaslip, 2007).

Heaslip (2007) stated that during peak roadwork season approximately 20 percent of the U.S. highway system is under construction in some form. The author also said this construction activity accounts for nearly 24 percent of non-recurring delays. All state highway agencies design, schedule, and conduct highway projects that involve work zones along active roadways and bridges during both peak and non-peak travel times. The Manual on Uniform Traffic Control Devices (MUTCD) defines long-term work zones as being present greater than three days, and a short-term work zone as having a duration greater than an hour yet within a single day (FHWA, 2009).

Maintenance and rehabilitation also include a range of construction activities, from less extensive work such as striping and patching, to large construction projects such as replacing a bridge or adding additional travelling lanes. Depending on the type of roadwork activity, a lane of traffic must be closed to the travelling public. Larger construction projects may close a lane for an extended period of time, while smaller projects may only close a lane for less than 12 hours. Both durations of lane closures cause a reduction in highway capacity, causing queues and delays. However, if a project requires a short-term lane closure, timing of the closure greatly changes the impact to traffic congestion.

The capacity of highway segments for both normal conditions and work zone conditions have been extensively investigated. Results of this research have been incorporated into the

Highway Capacity Manual (HCM) (TRB, 2016). However, each state highway agency can develop procedures based on the HCM to estimate work zone capacity based on research, including field experience, existing or historical work zones, or data collected from the field.

A review of literature was conducted to evaluate previous findings related to updates of the lane closure guide in work zones. Most previous research, dissertations, and peer-reviewed journal articles have focused on short-term work zones, while other literature has emphasized long-term work zones and studies on queue length and diversion rates that applied to capacity. Previous research has primarily determined methods of calculating capacity, most often in relation to short-term work zones. Short-term work zones, which are typically in place less than three days, restrict traffic flows on the roadway. Therefore, knowing the capacity of a proposed work zone results in better timing of lane closure to reduce traffic delays and congestion.

Dudek and Richards (1982) conducted a study to determine traffic capacity on Texas freeways with a total of 37 work zones. The research team developed capacity ranges for six lane configurations ranging from 2-to-1 to 5-to-2. Although traffic volumes for each lane configuration were similar, configurations with the largest volumes were three-lane and four-lane freeways with two or more open lanes. Configurations of two-lane and five-lane freeways with more than half of the lanes closed showed volumes of at least 100 vehicles per hour per lane (vphpl) less than previous configurations. In addition, the research group studied a 3-to-1 lane configuration that was 210 vphpl lower than any other configuration, and they developed a method to estimate the number of vehicles in the queue and the length of queue.

Krammes and Lopez (1994) determined new capacity values for short-term freeway work zones in Texas. They collected data from 33 work zones from the years 1987 and 1991 and studied five lane configurations ranging from 2-to-1 to 5-to-3. They compared their data to a previous study conducted in Texas (Dudek & Richards, 1982) to determine if the values used to estimate work zone capacity were valid. Their results suggested that a new value of 1,600 passenger car per hour per lane (pcphpl) was appropriate for a base capacity for work zones. They also found that ramps in a work zone affect capacity, since drivers divert to other routes if the speed of traffic flow decreases. In addition, they determined that the Highway Capacity Manual (HCM) passenger car equivalent conversion factor of 1.7 for heavy vehicles, while slightly low, is a reasonable approximation.

Kim, Lovell, and Paracha (2000) developed a new methodology to estimate work zone capacity with a multiple regression model. Video cameras were used to collect data at 12 work zones in Maryland. The researchers investigated variables of traffic volume in work zones, including lane configuration, location of closed lanes (right, left, and center), and the effect of heavy vehicles, lane width, and work zone length. They initially hypothesized that these factors influence traffic volume, and they concluded that the number of closed lanes, grades, and percentage of heavy vehicles influence the work zone capacity. The research team also used multiple regression to estimate work zone capacity in North Carolina and Indiana where data had been collected during previous studies, and they used their model, three existing models, and the HCM to compare their results to the actual data. Results showed that their model more accurately estimated capacity than the other existing models.

Al-Kaisy and Hall (2003) studied six long-term freeway reconstruction sites and one site with recurrent congestion in Ontario, Canada. The research team utilized video and loop detectors to collect data over different days and times, and they used a multivariate linear regression model to formulate a capacity model and calculate volume (vphpl) for each site. They determined that no general model could be developed due to unique variables at each site, although they developed models that were particular or similar to those sites. For example, they developed a multiplicative model and an additive model.

Sarasua, Davis, Clarke, Kottapally, and Mulukutla (2004) developed a method to determine traffic volume (vphpl) that could pass through a short-term interstate work zone with acceptable levels of delay. This was Phase 2 of a study in which they used data from 23 work zones in South Carolina from Phase 1, completed in 2003, and 12 additional sites during Phase 2. Lane closures for Phase 1 were 2-to-1 lane closures, while Phase 2 included 3-to-1 and 3-to-2 lane closures. Methods such as video surveillance cameras, radar detection of speed, and manual queue length measurement were used to collect data, and the duration of the data collected ranged from less than 1 hour to 2.5 hours. One of the major findings of Phase 2 was that closure of a second lane reduces capacity by almost 150 pcphpl.

Sarasua, Davis, Chowdhury, and Ogle (2006) proposed two methods for capacity estimation at short-term work zones in South Carolina. The first approach used curve fitting to establish speed-density-flow relationship in work zones and derived capacity as maximum flow from the speed-flow curve. Results showed that parabolic speed-flow curves overestimated capacity compared to observed capacities. To resolve this issue, a capacity of 85th percentile volume was proposed which resolved the issue of overestimating.

Notbohm, Drakopoulos, and Dehman (2009) conducted capacity analysis on two long-term work zones in Milwaukee, Wisconsin. One zone had 4-to-2 lane configuration, and the other zone had 2-to-1 configuration. Project data were from the WisTransPortal website from detectors that were already in place. The research team pulled capacity data in 5-minute increments for a period of 50 days. They determined that long-term work zones have a negative impact on traffic capacity, with congestion typically lasting 13–14 hours. Peak conditions for work zones began earlier than regular hours and ended much later than regular time. They found that volumes within 90% of peak hour volumes were present for longer periods, but speed reductions were similar in both work zones at 33 mph.

Bham and Khazraee (2011) used mean breakdown and queue discharge to determine work zone capacity. Breakdown flow is the flow rate at which traffic flow is likely to "break down" or where the traffic speed greatly decreases. Cameras at one work zone in Missouri documented 11 breakdown events; the breakdown flow rate was estimated using data from five 1-minute intervals immediately prior to the breakdown. A comparison of this rate to the maximum queue discharge rate showed that congested traffic can occasionally flow at rates greater than the breakdown flow rate. Mean queue discharge rate was lower than the average breakdown flow rate.

Edara, Kianfar, and Sun (2012) analyzed different methods to compute work zone capacity. Data from four work zones near Columbia, Missouri, on I-70 were collected using video cameras to capture traffic approaching and leaving the work zone taper. Each work zone had right lane closures, 2-to-1, in one direction, and data were collected on four different nights. Capacity, sustained flow, and automated rescaling were calculated using queue discharge flow (QDF) rate and 85th percentile traffic flow. The researchers concluded that, although QDF was the better measure for sustainable capacity of a work zone, QDF is harder to determine than the other methods, and it provides the most conservative capacity estimates of all the methods. Their study found that 15-minute sustained flow is preferable to the 85th percentile, particularly since demand and length of study influenced the 85th percentile.

Weng and Meng (2013) published an overview of ways to estimate work zone capacity and traffic delay. Although the research team was in China, they utilized research and traffic data from Texas and North Carolina. When summarizing the existing research, they divided the analyses into three categories: parametric approaches, non-parametric approaches, and simulation approaches. Parametric approaches use data to derive their models, typically with various versions of regression modeling. Non-parametric approaches develop decision trees or other types of logic approaches, while simulation approaches use some version of simulation to estimate work zone capacity. The research team then categorized these approaches depending on estimation accuracy (low or high), ease of use (simple or complex), data requirements (large or small), or computational resources required (low or high).

Du and Chien (2014) developed an analytical model to optimize work zone length as well as a guideline for use of road shoulders. The study was conducted in New Jersey, but it did not utilize any collected data. Instead, the research team developed a series of equations and a model to quantify the delay and cost impact of work zones. Setting an optimum work zone length requires length variability of the work zone and is more applicable to short-term projects such as resurfacing or minor repairs. They analyzed the requirements to use road shoulders as an additional traffic lane in order to increase traffic volume through a work zone. If certain requirements are met, road shoulders can cost-effectively increase capacity and reduce the impact of work zones, thereby benefitting long-term work zones. A case study was conducted to show how the methodology would work under real conditions using traffic volume data from a study conducted in 2008.

Dissanayake and Ortiz (2015) conducted a study to estimate the capacity of rural highways with work zones in Kansas. Road tubes were used to collect data from three state highways in both directions, resulting in six sets of data. Similar to other studies that compared sites to find averages, this study was challenged by the number of variables and their impact on capacity. Sites for this study were selected based on their similarities to allow the research team to estimate capacity more accurately. All sites had similar duration, number of open lanes (2-to-1), work activity, position of closed lane, the length of lane closure, traffic control devices, and weather conditions. The maximum observed 15-minute flow rate and the platooning method were used to compute capacity, with results showing that the maximum observed 15-minute flow rate provided a more conservative estimate and was of more value for estimating capacity. The recommended capacity was 1,500 pcphpl. Most research on work zone capacity has been performed on short-term work zones, with results showing that variables such as lane configuration can cause work zone capacity to vary significantly, requiring the use of engineering judgment with each configuration. Although equations and methods have been developed to estimate the impact of short-term work zones on capacity, long-term work zones have a different impact on capacity. Site-specific models must be developed to predict the capacity impact of long-term work zones, especially for certain freeways where the whole freeway is very similar. Consequently, multiple models must be developed for use within each area, which will help identify the optimal time for construction projects.

Maze, Schrock, and Kamyab (2000) studied the rate of queue growth during times of traffic congestion on a rural freeway with a work zone in Iowa. The research team used trailers with cameras on 30-ft booms to collect data; they noted the presence of congestion on four days. The highest volume and the mean of the 10 highest volumes were calculated using vehicle per hour (vph) and passenger car per hour (pcph). They found that lane closure capacities were 1,400–1,600 pcph for rural Iowa freeways and queue lengths moved backwards and forwards at swift rates, presenting a safety hazard. They also found that dates and times for congestion were consistent and thus predictable.

Kwon and Park (2016) conducted a study in Minneapolis, Minnesota, to estimate diversion rates and capacity reduction in freeway work zones. Data were collected from 12 sites, with data from six sites used for calculations. Detector stations within the work zones were used to collect 15-minute flow rates and density data. The selected sites contained major parallel roads and ramps located near or within the work zone. The objective of the study was to develop a model to estimate the diversion rate for a work zone. Diversion of traffic volume not only reduces volume through the work zone, but it also increases volume on parallel roads. The researchers developed a model, but their model was applicable only to 2-to-1 work zones. Further studies were recommended to develop models for other lane configurations.

The one common theme among most research was the specificity of each study. Research teams developed models to estimate capacity, but each model was unique to each work zone. Lane configuration was the primary variable shown to affect capacity throughout all the studies. Models developed for certain lane configurations worked for similar conditions with identical lane configurations. However, based on data availability and data quality, 85^{th} percentile volume as capacity and the maximum sustained flow rate method were used to estimate capacities in this study.

Chapter 2: Research Objectives

The capacity of major roadways during work zone activities contributes to the safety and mobility of the driving public as well as the safety of the workers inside the work zone. Non-recurring congestion and significant traffic queue delays can be mitigated by having a better understanding of work zone capacity by keeping the appropriate number of lanes open during work zone activities. By not controlling non-recurring congestion, long queues may result in increased crashes (including end of queue crashes), road user delay costs, increased fuel consumption, and unwanted publicity from the general public. The Highway Capacity Manual (HCM) provides guidelines on the adjustment of capacity during short-term and long-term work zones through previous research studies noted in the review of literature (TRB, 2016). According to the HCM guideline, it is recommended that adjustments to capacity be based on local data and previous experiences. However, the HCM guideline may be used directly if there is no scope of data acquisition. The 2010 version of the Highway Capacity Manual recommended 1,500 passenger cars per hour per lane (pcphpl). However, many research studies have questioned the accuracy of this value and thus the most recent version of the HCM stresses that capacity be based on local conditions.

To investigate work zone capacity in the Kansas City metropolitan area as a follow-up to a previous research study (Fitzsimmons, Nye, & Dissanayake, 2018) to develop the Kansas Department of Transportation lane closure guide, the primary objective of this study was to estimate the capacity of the short-term work zones using KC Scout data and known historical work zones. To obtain capacity information estimation, two methodologies were proposed based on previous research: 85th percentile traffic flow and maximum sustained flow. A secondary objective of the study was to investigate the quality of work zone data provided by KC Scout traffic operations center.

The 85th percentile traffic flow is a commonly used threshold in traffic studies for speed estimation. Previous studies have reported 85th percentile traffic flow as a better indicator of existing traffic conditions and easily obtainable estimation for work zone (Edara et al., 2012).

Freeway capacity is generally defined as the maximum sustained 15-minute flow rate that can be accommodated by a uniform freeway segment under prevailing traffic, roadway, and control conditions. Maximum sustained flow rates were calculated for three time intervals: 5-minutes, 10-minutes, and 15-minutes. Later chapters describe these methodologies and the data collection process in detail.

Chapter 3: Data

The Kansas Department of Transportation (KDOT) provided a list of nine work zone locations and relevant data for this study in the Kansas City metropolitan area from 2018. Table 3.1 details the selected locations. Six of the projects were from eastbound I-435 and the remaining three were from westbound I-435. Eight of the projects had road closures due to pavement marking, and a temporary barrier was set up in other segments.

Table 3.1: Description of Selected Projects

Project	Date	Location	Lane Closed	Closure Time	Closed Segment	Work Type
1	03/06/18	EB I-435	2 LL	9:00 a.m. to 3:00 p.m.	I-35 to Metcalf	Pavement Marking
2	03/07/18	EB I-435	3 LL	9:00 a.m. to 3:00 p.m.	I-35 to Metcalf	Pavement Marking
3	03/08/18	EB I-435	2 RL	9:00 a.m. to 3:00 p.m.	Quivira to Antioch	Pavement Marking
4	03/09/18	EB I-435	2 RL	9:00 a.m. to 3:00 p.m.	Quivira to Metcalf	Pavement Marking
5	03/10/18	EB I-435	Reduce to 1 lane	4:00 a.m. to 8:00 p.m.	I-35 to Indian Creek	Pavement Marking
6	03/12/18	WB I-435	2 LL	9:00 a.m. to 3:00 p.m.	Metcalf to Quivira	Pavement Marking
7	03/13/18	WB I-435	2 LL	11:00 a.m. to 3:00 p.m.	Antioch to Quivira	Pavement Marking
8	03/14/18	WB I-435	2 LL	9:00 a.m. to 1:00 p.m.	Antioch to Quivira	Set Temp Barrier
9	03/31/18	EB I-435	1 Lane	4:00 a.m. to 8:00 p.m.	I 35 to Metcalf	Pavement Marking

Note: LL= Left lanes; RL= Right lanes

Lane closures in Project 3, Project 4, Project 5, and Project 9 also included ramp sections; this information was discarded from the analysis because only data from segments with highway lane closures were used for analysis. The following figures show the location of each project area. Figure 3.1 shows the segment with lane closure on eastbound I-435 on March 6, 7, and 31, 2018. On March 6, two left lanes were closed from 9:00 a.m. to 3:00 p.m. for pavement marking, while three left lanes were closed on the same segment from 9:00 a.m. to 3:00 p.m. on March 7. On March 31, the segment was reduced to one lane from 4:00 a.m. to 8:00 p.m.

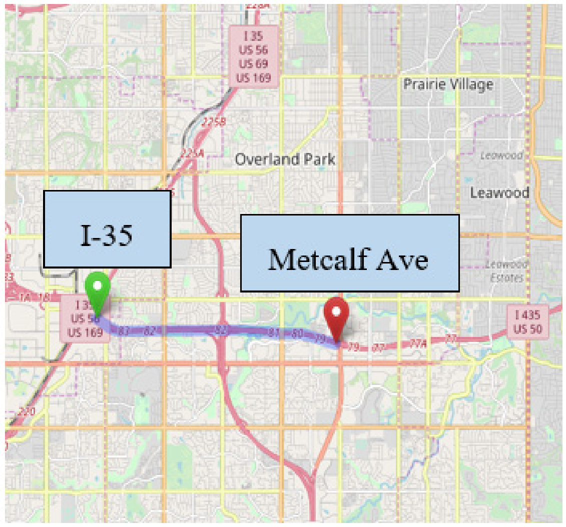


Figure 3.1: Project 1, Project 2, and Project 9

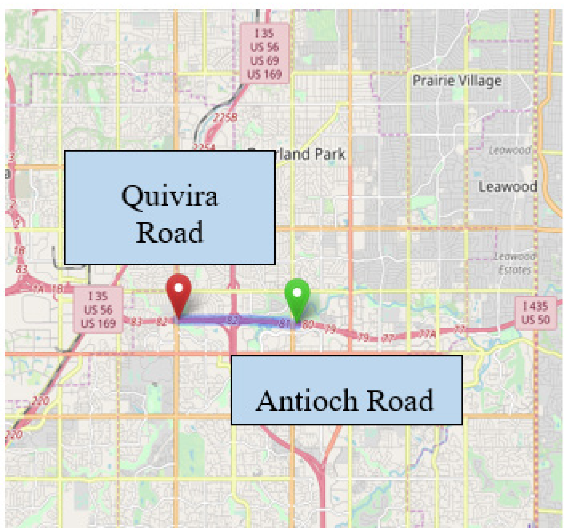


Figure 3.2: Project 3, Project 7, and Project 8

Figure 3.2 shows that the segment was closed on March 8, 13, and 14, 2018, for Project 3, Project 7, and Project 8. Two lanes were closed on eastbound I-435 from Quivira Road to Antioch Road, and for the other two projects, two lanes on westbound I-435 were closed from Antioch Road to Quivira Road. The lanes were closed for 6 hours (from 11:00 a.m. to 3:00 p.m.) during

Project 3 and 4 hours (from 11:00 a.m. to 3:00 p.m. and from 9:00 a.m. to 1:00 p.m.) for Project 7 and Project 8, respectively.

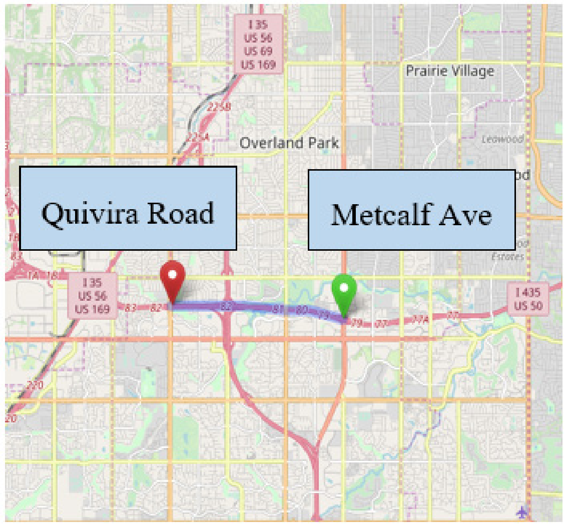


Figure 3.3: Segment 4 and Segment 6

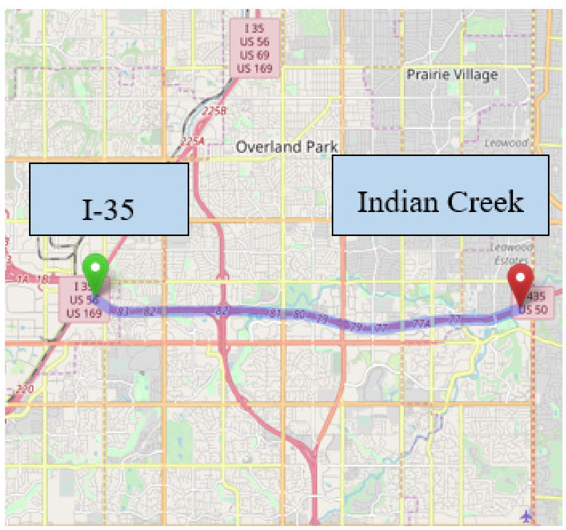


Figure 3.4: Segment 5

As shown in Figure 3.3, the lane closure was on I-435 from Quivira Road to Metcalf Avenue and vice versa. The eastbound two right lanes were closed from 9:00 a.m. to 3:00 p.m. on March 9, 2018, and the two left lanes on Metcalf Avenue to Quivira Road on westbound I-435 were closed from 9:00 a.m. to 3:00 p.m. Figure 3.4 shows the lane closure for Project 5, in which the segment between I-35 and the Indian Creek Bridge was reduced to one lane on eastbound I-435 on March 10, 2018, from 4:00 a.m. to 8:00 p.m. for pavement marking.

TMC data used in this project originates from the Kansas City Traffic Management Center, or KC Scout. KC Scout is a network of data-collection sensors and cameras as a joint venture between the Missouri Department of Transportation (MoDOT) and KDOT to monitor traffic in the Kansas City metropolitan area, both on the Kansas and Missouri sides of the city. The KC Scout system was designed to assist in incident management and subsequent non-recurring congestion due to crashes, stalled vehicles, or special generators, as well as provide assistance to emergency medical services. KC Scout primarily uses Wavetronix side-fire radar sensors located on poles along each of the major highways in the Kansas City metropolitan area as shown in Figure 3.5.

Figure 3.5: Map of KC Scout Wavetronix sensors on the Kansas side of Kansas City

As shown in Figure 3.5, as of 2018, 170 sensors—operational on interstates and highways in the Kansas City, Kansas, area—monitor both directions of travel. A total of 154 of the 170 sensors were used for this research project. Sensors collect vehicle data on lane occupancy, average speed, and volume for each lane, with a resolution of 30-second intervals. KC Scout mainly uses this data for motorist travel time; however, meta-data is achieved continuously and stored in the MoDOT regional office in Lee's Summit, Missouri. The system is periodically calibrated by both state highway agencies to ensure accurate data collection by the sensors.

Data retrieval from the KC Scout is performed using a secure login to its servers. The user interface allows the user to select sensor locations and query information such as date range, day(s) of the week, and aggregation level.

Although Table 3.1 lists the number of lanes closed for each segment and project, the existing number of lanes along the segment varied from 3 to 5 lanes in each direction. Therefore, the number of lanes present before the road closure in each segment were identified from the KC Scout data portal to determine the number of lanes open during the lane closure. The query output from the KC Scout portal provided the number of lanes present within each sensor area, and the identification of lanes closed specifically during the closure. The number of open lanes during the road closure were calculated by subtracting the number of closed lanes from the total number of lanes. Table 3.2 through Table 3.10 provide data related to the number of lanes closed during the road closure for each segment. It should be noted that in the following tables and discussion the symbol "@" represents the spatial location of the sensor associated with an interstate and cross street (or interchange). For example, in Table 3.2 "I-435 E @ Before Lackman" means a Wavetronix sensor is located on a pole along Interstate 435 in the East direction prior to the Lackman Road Interchange.

Table 3.2: Description of Project 1 Lane Closure

Date	Location	Closed Segment	Start Time	9:00 a.m.
3/6/2018	EB I-435	I-35 to Metcalf	**End Time**	3:00 p.m.
	# of Lanes Closed	**Sensor Name**	**Number of Lanes before Constr.**	**Number of Lanes during Constr.**
	2	I-435 E @ Before Lackman	5	3
	2	I-435 E @ Pflumm Road	5	3
	2	I-435 E @ East of Pflumm Road	4	2
	2	I-435 E @ Before Quivira Road	4	2
	2	I-435 E @ Quivira Road	3	1
	2	I-435 E @ Before Quivira	3	1
	2	I-435 E @ Past Quivira Road	3	1
	2	I-435 E @ 69 HWY	3	1
	2	I-435 E @ East of HWY 69	3	1
	2	I-435 E @ Indian Creek	3	1
	2	I-435 E @ Antioch	4	2
	2	I-435 E @ W of Metcalf	3	1
	2	I-435 E @ Metcalf	3	1

Table 3.3: Description of Project 2 Lane Closure

Date	Location	Segment	Start Time	9:00 a.m.
3/7/2018	EB I-435	I-35 to Metcalf	**End Time**	3:00 p.m.
	# of Lanes Closed	**Sensor Name**	**Number of Lanes before Constr.**	**Number of Lanes during Constr.**
	3	I-435 E @ Before Lackman	5	2
	3	I-435 E @ Pflumm Road	5	2
	3	I-435 E @ East of Pflumm Road	4	1
	3	I-435 E @ Before Quivira Road	4	1
	3	I-435 E @ Quivira Road	3	0
	3	I-435 E @ Before Quivira	3	0
	3	I-435 E @ Past Quivira Road	3	0
	3	I-435 E @ 69 HWY	3	0
	3	I-435 E @ East of HWY 69	3	0
	3	I-435 E @ Indian Creek	3	0
	3	I-435 E @ Antioch	4	1
	3	I-435 E @ W of Metcalf	3	0
	3	I-435 E @ Metcalf	3	0

Table 3.4: Description of Project 3 Lane Closure

Date	Location	Segment	Start Time	9:00 a.m.
3/8/2018	EB I-435	Quivira to Antioch	**End Time**	3:00 p.m.
	# of Lanes Closed	**Sensor Name**	**Number of Lanes before Constr.**	**Number of Lanes during Constr.**
	2	I-435 E @ Before Quivira Road	4	2
	2	I-435 E @ Quivira Road	3	1
	2	I-435 E @ Before Quivira	3	1
	2	I-435 E @ Past Quivira Road	3	1
	2	I-435 E @ 69 HWY	3	1
	2	I-435 E @ East of HWY 69	3	1
	2	I-435 E @ Indian Creek	3	1
	2	I-435 E @ Antioch	4	2

Table 3.5: Description of Project 4 Lane Closure

Date	Location	Segment	Start Time	9:00 a.m.
3/9/2018	EB I-435	Quivira to Metcalf	**End Time**	3:00 p.m.
	# of Lanes Closed	**Sensor Name**	**Number of Lanes before Constr.**	**Number of Lanes during Constr.**
	2	I-435 E @ Before Quivira Road	4	2
	2	I-435 E @ Quivira Road	3	1
	2	I-435 E @ Before Quivira	3	1
	2	I-435 E @ Past Quivira Road	3	1
	2	I-435 E @ 69 HWY	3	1
	2	I-435 E @ East of HWY 69	3	1
	2	I-435 E @ Indian Creek	3	1
	2	I-435 E @ Antioch	4	2
	2	I-435 E @ W of Metcalf	3	1
	2	I-435 E @ Metcalf	3	1

Table 3.6: Description of Project 5 Lane Closure

Date	Location	Segment	Start Time	4:00 a.m.
3/10/2018	EB I-435	I-35 to Indian Creek Bridge	**End Time**	8:00 p.m.
	# of Lanes Closed	**Sensor Name**	**Number of Lanes before Constr.**	**Number of Lanes during Constr.**
	4	I-435 E @ Before Lackman	5	1
	4	I-435 E @ Pflumm Road	5	1
	3	I-435 E @ East of Pflumm Road	4	1
	3	I-435 E @ Before Quivira Road	4	1
	2	I-435 E @ Quivira Road	3	1
	2	I-435 E @ Before Quivira	3	1
	2	I-435 E @ Past Quivira Road	3	1
	2	I-435 E @ 69 HWY	3	1
	2	I-435 E @ East of HWY 69	3	1
	2	I-435 E @ Indian Creek	3	1

Table 3.7: Description of Project 6 Lane Closure

Date	Location	Segment	Start Time	9:00 a.m.
3/12/2018	WB I-435	Metcalf to Quivira	**End Time**	3:00 p.m.
	# of Lanes Closed	**Sensor Name**	**Number of Lanes before Constr.**	**Number of Lanes during Constr.**
	2	I-435 W @ Metcalf	4	2
	2	I-435 W @ W of Metcalf	4	2
	2	I-435 W @ Antioch Road	5	3
	2	I-435 W @ Indian Creek	3	1
	2	I-435 W @ East of HWY 69	4	2
	2	I-435 W @ 69 HWY	3	1
	2	I-435 W @ After HWY 69	3	1
	2	I-435 W @ Before Quivira	3	1
	2	I-435 W @ Quivira Road	5	3
	2	I-435 W @ After Quivira Road	6	4

Table 3.8: Description of Project 7 Lane Closure

Date	Location	Segment	Start Time	9:00 a.m.
3/13/2018	WB I-435	Antioch to Quivira	**End Time**	3:00 p.m.
	# of Lanes Closed	**Sensor Name**	**Number of Lanes before Constr.**	**Number of Lanes during Constr.**
	2	I-435 W @ Antioch Road	5	3
	2	I-435 W @ Indian Creek	3	1
	2	I-435 W @ East of HWY 69	4	2
	2	I-435 W @ 69 HWY	3	1
	2	I-435 W @ After HWY 69	3	1
	2	I-435 W @ Before Quivira	3	1
	2	I-435 W @ Quivira Road	5	3
	2	I-435 W @ After Quivira Road	6	4

Table 3.9: Description of Project 8 Lane Closure

Date	Location	Segment	Start Time	9:00 a.m.
3/14/2018	WB I-435	Antioch to Quivira	**End Time**	1:00 p.m.
	# of Lanes Closed	**Sensor Name**	**Number of Lanes before Constr.**	**Number of Lanes during Constr.**
	2	I-435 W @ Antioch Road	5	3
	2	I-435 W @ Indian Creek	3	1
	2	I-435 W @ East of HWY 69	4	2
	2	I-435 W @ 69 HWY	3	1
	2	I-435 W @ After HWY 69	3	1
	2	I-435 W @ Before Quivira	3	1
	2	I-435 W @ Quivira Road	5	3
	2	I-435 W @ After Quivira Road	6	4

Table 3.10: Description of Project 9 Lane Closure

Date	Location	Segment	Start Time	4:00 a.m.
3/31/2018	EB I-435	I-35 to Metcalf	**End Time**	8:00 p.m.
	# of Lanes Closed	**Sensor Name**	**Number of Lanes before Constr.**	**Number of Lanes during Constr.**
	1	I-435 E @ Before Lackman	5	4
	1	I-435 E @ Pflumm Road	5	4
	1	I-435 E @ East of Pflumm Road	4	3
	1	I-435 E @ Before Quivira Road	4	3
	1	I-435 E @ Quivira Road	3	2
	1	I-435 E @ Before Quivira	3	2
	1	I-435 E @ Past Quivira Road	3	2
	1	I-435 E @ 69 HWY	3	2
	1	I-435 E @ East of HWY 69	3	2
	1	I-435 E @ Indian Creek	3	2
	1	I-435 E @ Antioch	4	3
	1	I-435 E @ W of Metcalf	3	2
	1	I-435 E @ Metcalf	3	2

Sensor locations were categorized based on the number of lanes reduced during the project period, as described in the previous tables: 3-to-1, 4-to-1, 4-to-2, 5-to-1, 5-to-2, 5-to-3, and 5-to-4. Among all these groups, the 3-to-1 group had the highest number of observations, with 48 sensors on different dates during the project period. Table 3.11 shows all the projects in this category.

The other categories had fewer observations for analysis. As a result, only data from 3-to-1 lane road closure locations were used to estimate capacities. However, all sensors from this group were not used for analysis because some of the sensors did not provide data on those dates or had incomplete data during the period. Among the 48 observations, three sensors were identified from each project which had consistent data for all the projects. Finally, I-435 E @ Quivira Road, I-435 E @ Before Quivira, and I-435 E @ Past Quivira Road were selected for eastbound directions as they appear on all eastbound projects. Similarly, the dates were selected based on the availability of the data on the sensor on the project day.

After extracting the data from the KC Scout portal, only March 6, March 8, and March 10 provided complete data for the selected sensors. Similar approaches were used to select the sensors and the dates for westbound projects. Sensors on westbound I-435 with complete data were I-435 W @ Indian Creek, I-435 W @ 69 HWY, and I-435 W @ After HWY 69 for March 13 and 14, 2018. The selected sensors are highlighted in green in Table 3.11. After the preliminary investigation, a total of 15 sensor locations were selected on five lane closure days. Data acquired from those sensors were used to estimate capacities during lane closures.

The KC Scout portal provides analysis data for each sensor because this project did not collect data on the field. Input variables included sensor location, date, time, and type of data required (count, speed, 5-min, 15-min, etc.). The output tables provided data for dates and times based on the input query, including data for the entire roadway and for each lane. Traffic counts, vph, and counts for vehicle categories, average speed, and occupancy were collected at 5-minute intervals. The following vehicle categories of data were collected for each lane:

1. VC1 = number of motorcycles during interval,
2. VC2 = number of passenger cars during interval,
3. VC3 = number of recreational vehicles and buses during interval, and
4. VC4 = number of tractor-trailers during interval.

Table 3.11: All Sensor Locations with 3-to-1 (Two-Lane) Reductions

Date	Location	Segment	Time start	Time end	Sensor Name
3/6/2018	EB I-435	I-35 to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ Quivira Road
3/6/2018	EB I-435	I-35 to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ Before Quivira
3/6/2018	EB I-435	I-35 to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ Past Quivira Road
3/6/2018	EB I-435	I-35 to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ 69 HWY
3/6/2018	EB I-435	I-35 to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ East of HWY 69
3/6/2018	EB I-435	I-35 to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ Indian Creek
3/6/2018	EB I-435	I-35 to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ W of Metcalf
3/6/2018	EB I-435	I-35 to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ Metcalf
3/8/2018	EB I-435	Quivira to Antioch	9:00 a.m.	3:00 p.m.	I-435 E @ Quivira Road
3/8/2018	EB I-435	Quivira to Antioch	9:00 a.m.	3:00 p.m.	I-435 E @ Before Quivira
3/8/2018	EB I-435	Quivira to Antioch	9:00 a.m.	3:00 p.m.	I-435 E @ Past Quivira Road
3/8/2018	EB I-435	Quivira to Antioch	9:00 a.m.	3:00 p.m.	I-435 E @ 69 HWY
3/8/2018	EB I-435	Quivira to Antioch	9:00 a.m.	3:00 p.m.	I-435 E @ East of HWY 69
3/8/2018	EB I-435	Quivira to Antioch	9:00 a.m.	3:00 p.m.	I-435 E @ Indian Creek
3/9/2018	EB I-435	Quivira to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ Quivira Road
3/9/2018	EB I-435	Quivira to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ Before Quivira
3/9/2018	EB I-435	Quivira to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ Past Quivira Road
3/9/2018	EB I-435	Quivira to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ 69 HWY
3/9/2018	EB I-435	Quivira to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ East of HWY 69
3/9/2018	EB I-435	Quivira to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ Indian Creek
3/9/2018	EB I-435	Quivira to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ W of Metcalf
3/9/2018	EB I-435	Quivira to Metcalf	9:00 a.m.	3:00 p.m.	I-435 E @ Metcalf
3/10/2018	EB I-435	I-35 to Indian Creek Bridge	4:00 a.m.	8:00 p.m.	I-435 E @ Quivira Road
3/10/2018	EB I-435	I-35 to Indian Creek Bridge	4:00 a.m.	8:00 p.m.	I-435 E @ Before Quivira
3/10/2018	EB I-435	I-35 to Indian Creek Bridge	4:00 a.m.	8:00 p.m.	I-435 E @ Past Quivira Road
3/10/2018	EB I-435	I-35 to Indian Creek Bridge	4:00 a.m.	8:00 p.m.	I-435 E @ 69 HWY

Date	Location	Segment	Time start	Time end	Sensor Name
3/10/2018	EB I-435	I-35 to Indian Creek Bridge	4:00 a.m.	8:00 p.m.	I-435 E @ East of HWY 69
3/10/2018	EB I-435	I-35 to Indian Creek Bridge	4:00 a.m.	8:00 p.m.	I-435 E @ Indian Creek
3/12/2018	WB I-435	Metcalf to Quivira	9:00 a.m.	3:00 p.m.	I-435 W @ Indian Creek
3/12/2018	WB I-435	Metcalf to Quivira	9:00 a.m.	3:00 p.m.	I-435 W @ 69 HWY
3/12/2018	WB I-435	Metcalf to Quivira	9:00 a.m.	3:00 p.m.	I-435 W @ After HWY 69
3/12/2018	WB I-435	Metcalf to Quivira	9:00 a.m.	3:00 p.m.	I-435 W @ Before Quivira
3/13/2018	WB I-435	Antioch to Quivira	11:00 a.m.	3:00 p.m.	I-435 W @ Indian Creek
3/13/2018	WB I-435	Antioch to Quivira	11:00 a.m.	3:00 p.m.	I-435 W @ 69 HWY
3/13/2018	WB I-435	Antioch to Quivira	11:00 a.m.	3:00 p.m.	I-435 W @ After HWY 69
3/13/2018	WB I-435	Antioch to Quivira	11:00 a.m.	3:00 p.m.	I-435 W @ Before Quivira
3/14/2018	WB I-435	Antioch to Quivira	9:00 a.m.	1:00 p.m.	I-435 W @ Indian Creek
3/14/2018	WB I-435	Antioch to Quivira	9:00 a.m.	1:00 p.m.	I-435 W @ 69 HWY
3/14/2018	WB I-435	Antioch to Quivira	9:00 a.m.	1:00 p.m.	I-435 W @ After HWY 69
3/14/2018	WB I-435	Antioch to Quivira	9:00 a.m.	1:00 p.m.	I-435 W @ Before Quivira
3/31/2018	EB I-435	I-35 to Metcalf	4:00 a.m.	8:00 p.m.	I-435 E @ Quivira Road
3/31/2018	EB I-435	I-35 to Metcalf	4:00 a.m.	8:00 p.m.	I-435 E @ Before Quivira
3/31/2018	EB I-435	I-35 to Metcalf	4:00 a.m.	8:00 p.m.	I-435 E @ Past Quivira Road
3/31/2018	EB I-435	I-35 to Metcalf	4:00 a.m.	8:00 p.m.	I-435 E @ 69 HWY
3/31/2018	EB I-435	I-35 to Metcalf	4:00 a.m.	8:00 p.m.	I-435 E @ East of HWY 69
3/31/2018	EB I-435	I-35 to Metcalf	4:00 a.m.	8:00 p.m.	I-435 E @ Indian Creek
3/31/2018	EB I-435	I-35 to Metcalf	4:00 a.m.	8:00 p.m.	I-435 E @ W of Metcalf
3/31/2018	EB I-435	I-35 to Metcalf	4:00 a.m.	8:00 p.m.	I-435 E @ Metcalf

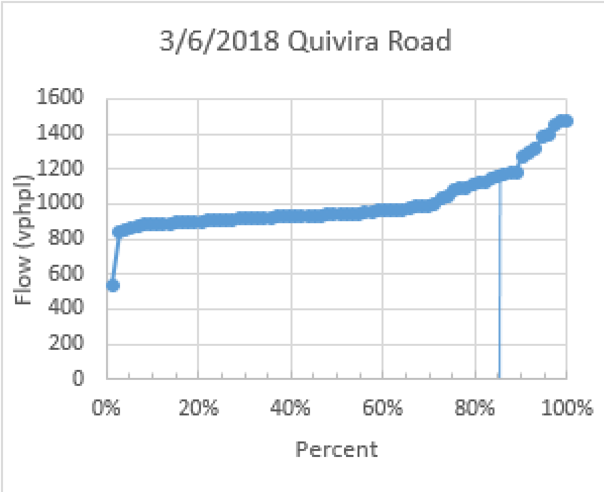
Chapter 4: Analysis

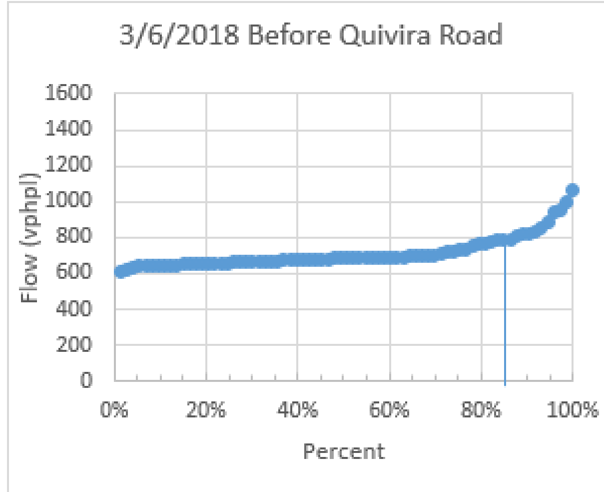
Based on the literature review and available data, two methods were used to estimate work zone capacities: 85th percentile traffic flow and maximum sustained flow.

4.1 85th Percentile Traffic Flow

As discussed, Sarasua et al. (2006) proposed the 85th percentile value as an appropriate estimate of capacity due to extensive use of this threshold value in transportation and other statistical applications. Use of a specified percentile when estimating capacity provides a margin of safety that prevents regular traffic variation from creating capacity problems as flow approaches threshold volume. The 85th percentile traffic flow values were computed for 15 selected sensors. All the 5-minute flows were sorted into ascending order, and cumulative percentiles were computed. For example, for twenty 5-minute flows, the least flow rate was lowest, representing the 5th percentile, and the highest value represented the 100th percentile. Percentile and traffic flow can be used to compute any percentile of the flow rate as it is plotted.

All 5-minute traffic flow values for each project were ranked in ascending order by converting vph to vphpl by dividing by the number of lanes. Figure 4.1 through Figure 4.5 show 85th percentile traffic flow of all sensors with lane reduction of 3-to-1. Figure 4.1 shows traffic flow per lane (vphpl) on March 6, 2018, for the lane closure period. The highest traffic flow was observed on the Quivira Road sensor. The 85th percent traffic flow observed @ Quivira Road, @ Before Quivira Road, and @ Past Quivira Road sensors were 1,156, 788, and 984 vphpl, respectively.





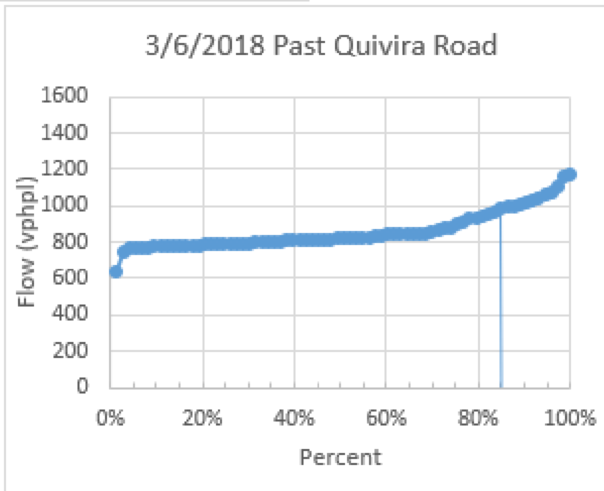


Figure 4.1: 85th Percentile Flow from Project 1

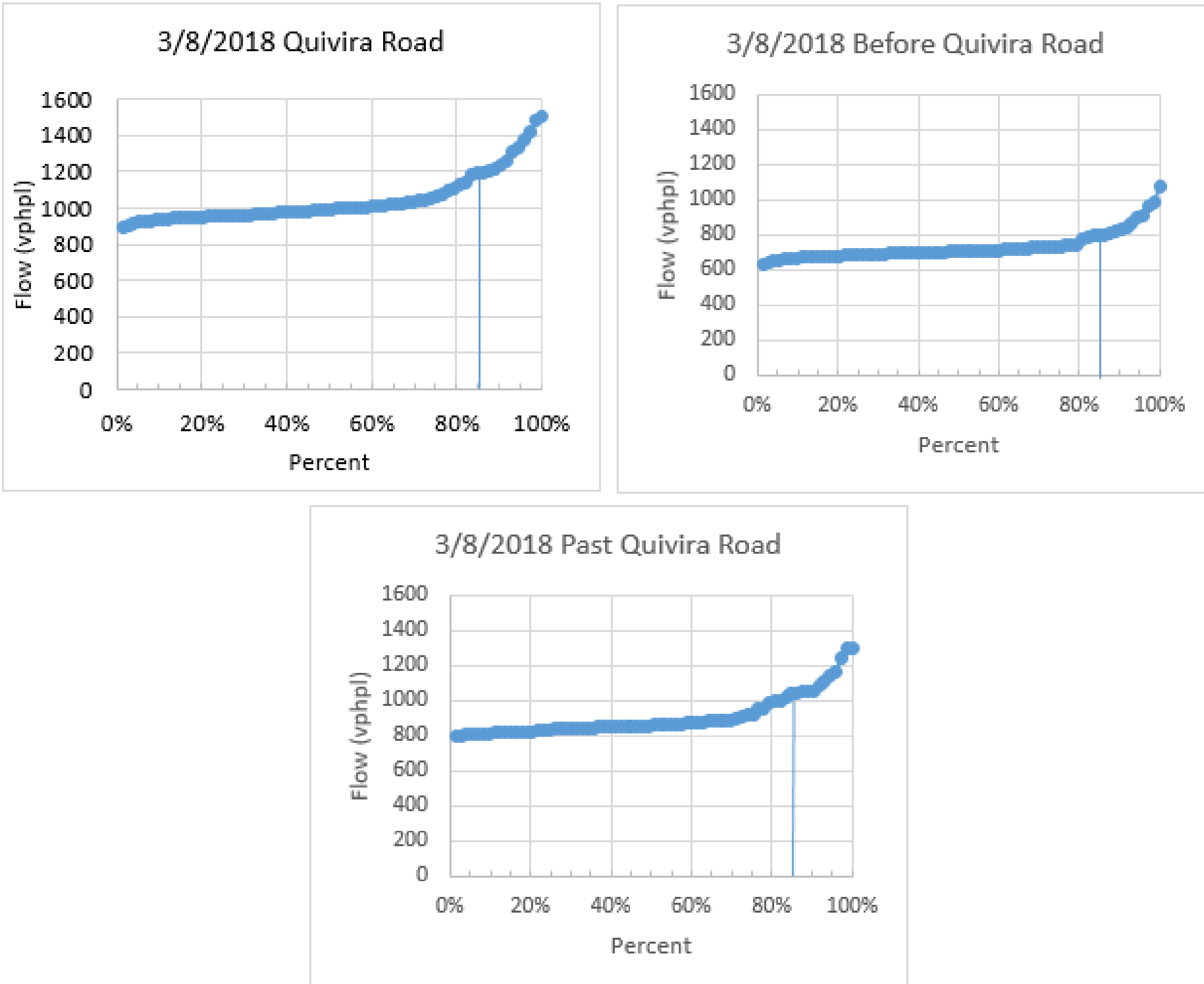


Figure 4.2: 85th Percentile Flow from Project 3

The observed 85th percentile traffic flow on the @ Quivira Road, @ Before Quivira Road, and @ Past Quivira Road sensors were 1,191, 792, and 1,037 vphpl, respectively. Similar to Project 1, the highest flow in Project 3 was observed in the @ Quivira Road sensor. Data from the other two sensors showed much lower 85th percentile flow during the same period.

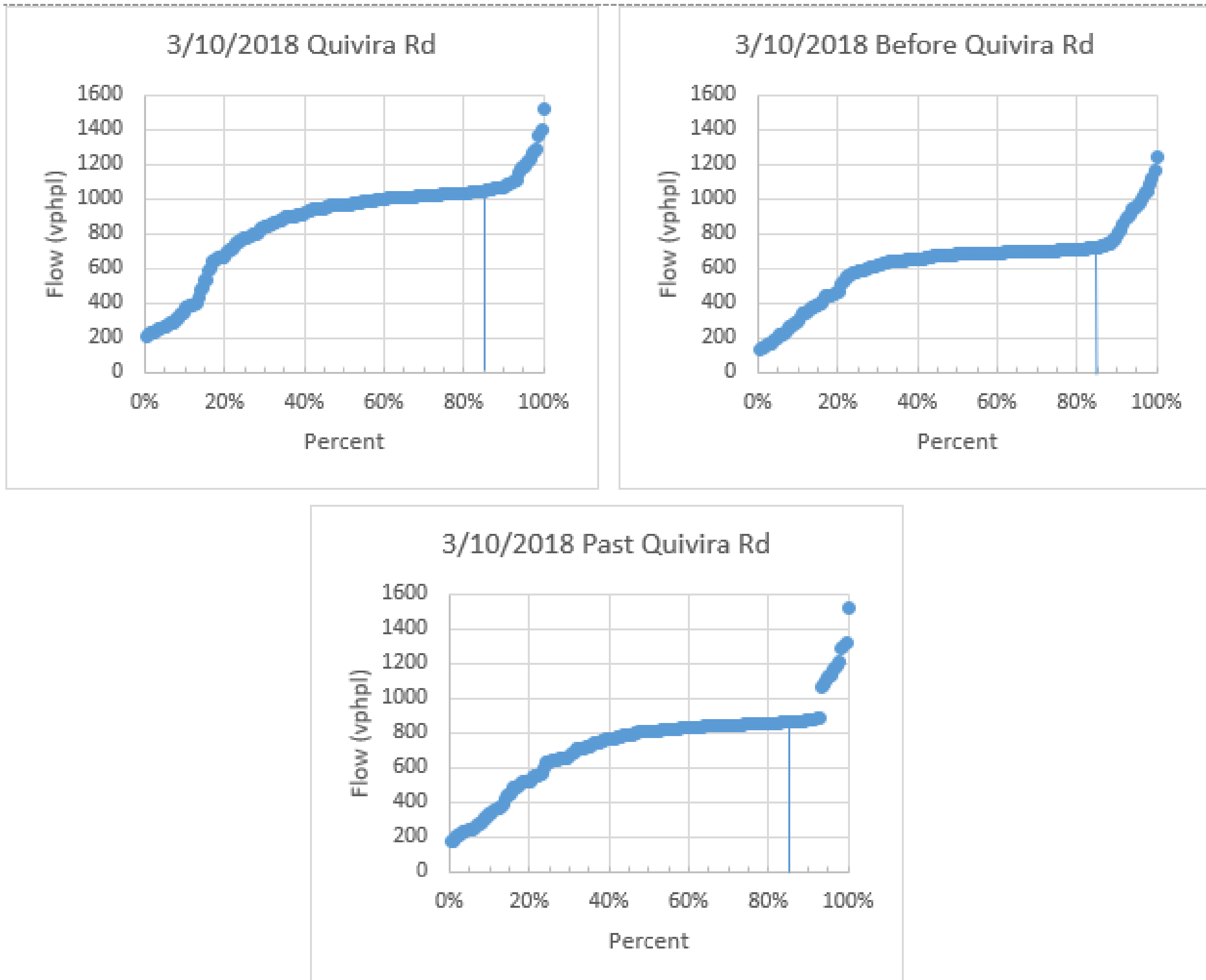


Figure 4.3: 85th Percentile Flow from Project 5

Figure 4.3 shows the 85th percentile traffic flow for the same sensors on March 10, 2018, during the lane closure. Similar to the other projects, the @ Quivira Road sensor had the highest 85th percentile traffic flow with 1,050 vphpl. The lowest observed traffic flow was approximately 200 vphpl on all sensors. All three sensors showed a sharp increase in flow around the 90th percentile.

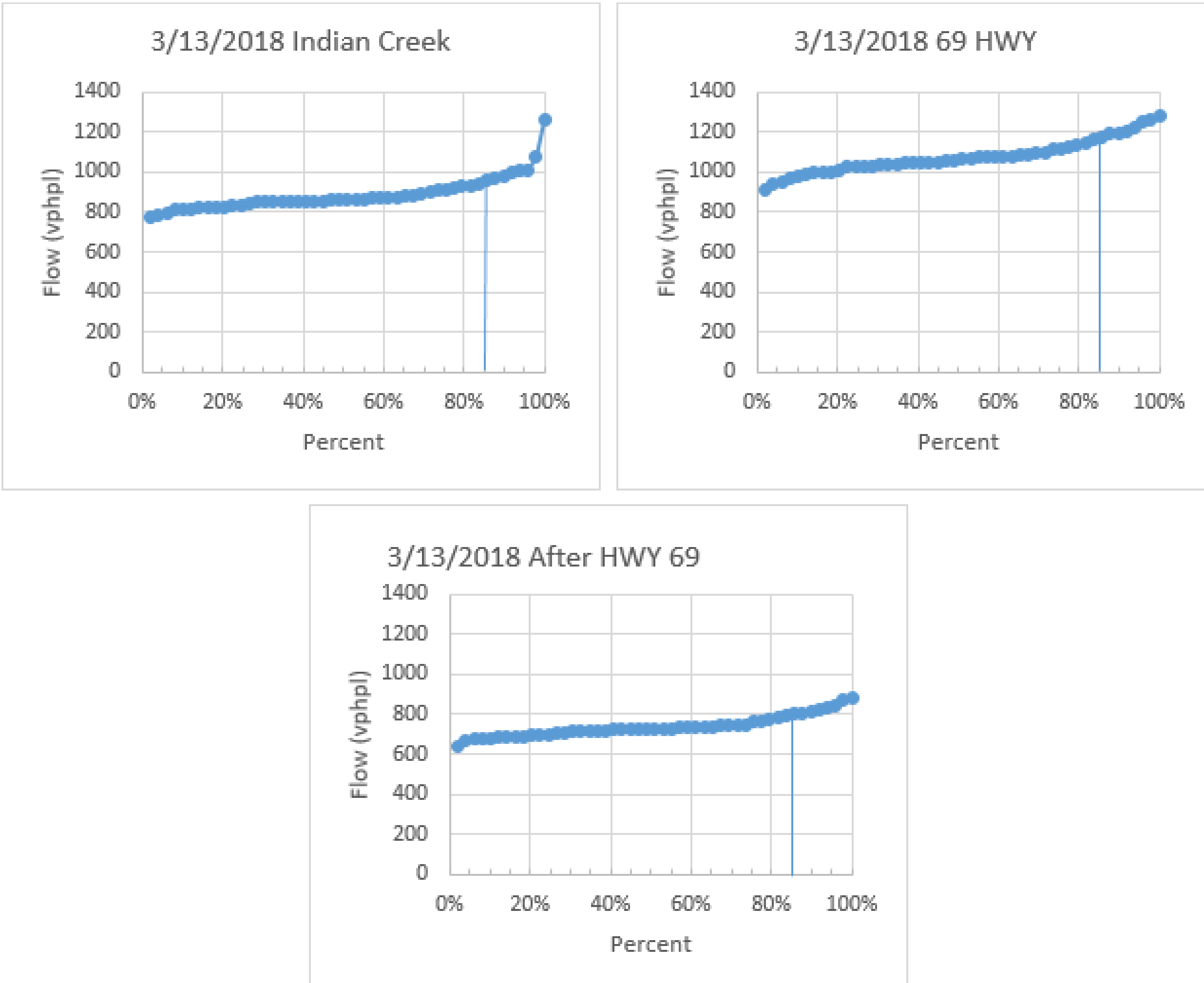


Figure 4.4: 85th Percentile Flow from Project 7

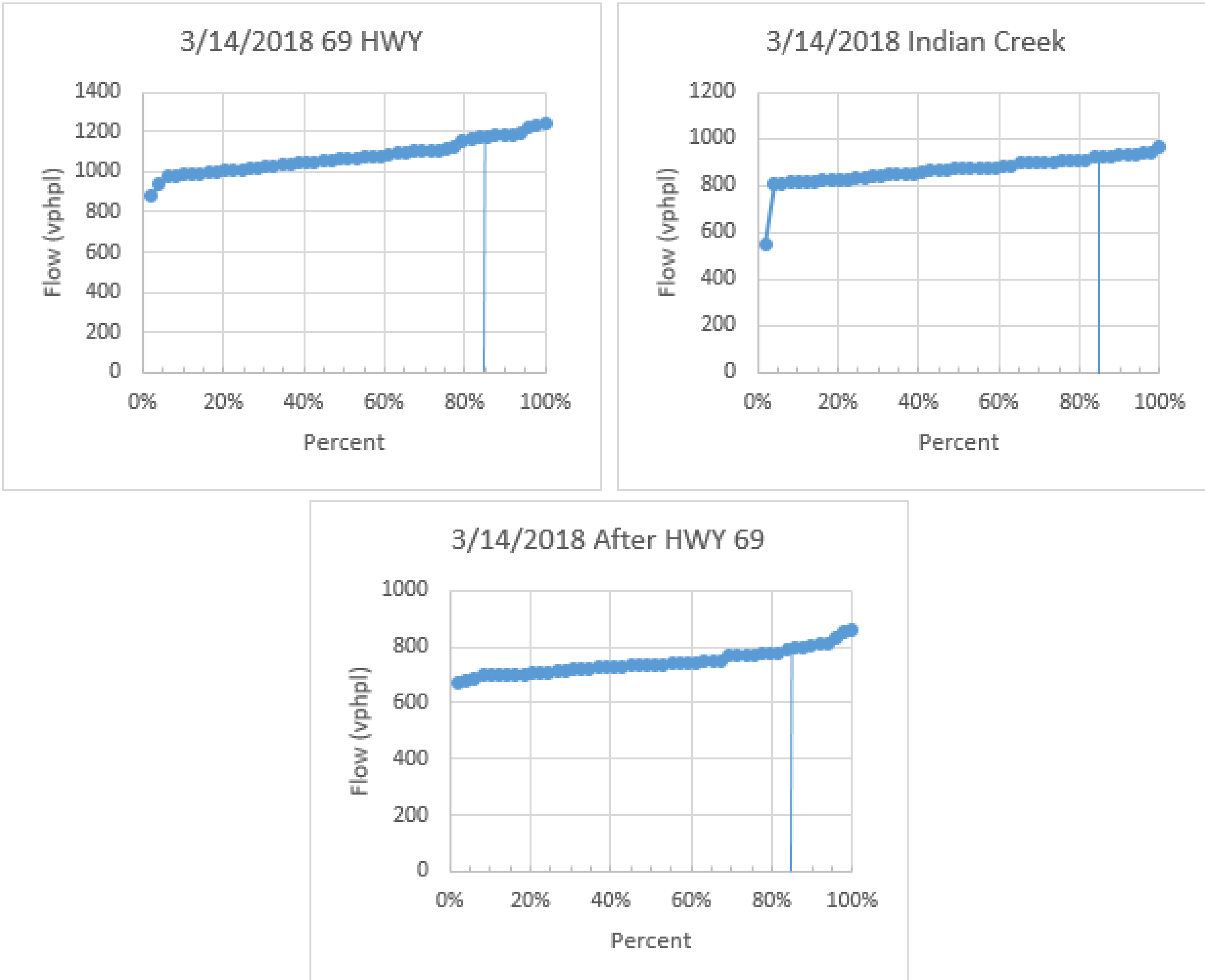


Figure 4.5: 85th Percentile Flow from Project 8

The highest traffic flow was observed on the @ 69 HWY sensor on westbound I-435 projects. Figure 4.4 and Figure 4.5 illustrate the projects on westbound I-435 on March 13–14, 2018. Both projects had the highest 85th percentile flow of 1,166 and 1,178 vphpl, respectively.

Table 4.1 summarizes the 5th percentile traffic flow of all the selected sensors. Traffic flow (vphpl) was also converted to pcphpl using the conversion factor of 1.2 for recreational vehicles and 1.5 for heavy vehicles.

Table 4.1: 85th Percentile Flows for All Projects and Segments

Date	Location	85th percentile flow	
		vphpl	pcphpl
March 6, 2018	Quivira Road	1,156	1,165
	Before Quivira Road	788	800
	Past Quivira Road	984	998
March 8, 2018	Quivira Road	1,191	1,200
	Before Quivira Road	792	804
	Past Quivira Road	1,037	1,051
March 10, 2018	Quivira Road	1,050	1,054
	Before Quivira Road	724	729
	Past Quivira Road	861	867
March 13, 2018	Indian Creek	951	965
	69 HWY	1,166	1,175
	After HWY 69	796	798
March 14, 2018	Indian Creek	923	936
	69 HWY	1,178	1,194
	After HWY 69	796	808
	Average	960	970
	Standard Deviation	164	165

4.2 Maximum Sustained Flow

Freeway capacity is generally defined as the maximum sustained 15-minute flow rate that can be accommodated by a uniform freeway segment under prevailing traffic, roadway, and control conditions (Sarasua et al., 2006). The traditional way of measuring capacity based on field data is to calculate the maximum observed flow rate. This study calculated maximum sustained flow rates based on three time intervals: 5 min, 10 min, and 15 min. Moving time windows were used by grouping 5-minute traffic counts, and maximum observed flow rates were then computed by aggregating counts within that interval. Flow rates were calculated in vphpl and later converted to pcphpl by multiplying by the passenger car equivalents (PCEs) as suggested by the HCM. Maximum sustained flow rate values obtained for 15 sensors are shown in Table 4.2.

Table 4.2: Maximum Sustained Flow Rate as Capacity for All Projects and Segments

Date	Location	5-min		10-min		15-min	
		vphpl	pcphpl	vphpl	pcphpl	vphpl	pcphpl
March 6, 2018	Quivira Road	1,480	1,570	1,421	1,526	1,417	1,522
	Before Quivira Road	1,060	1,165	916	1,064	914	1,062
	Past Quivira Road	1,175	1,356	1,133	1,314	1,135	1,316
March 8, 2018	Quivira Road	1,507	1,613	1,448	1,554	1,454	1,560
	Before Quivira Road	1,072	1,198	939	1,089	947	1,097
	Past Quivira Road	1,301	1,441	1,175	1,365	1,172	1,362
March 10, 2018	Quivira Road	1,520	1,547	1,275	1,302	1,181	1,208
	Before Quivira Road	1,242	1,293	1,040	1,089	1,018	1,067
	Past Quivira Road	1,515	1,569	1,308	1,349	1,115	1,156
March 13, 2018	Indian Creek	1,261	1,420	1,040	1,199	995	1,154
	69 HWY	1,279	1,450	1,235	1,425	1,237	1,427
	After HWY 69	879	1,000	861	982	858	979
March 14, 2018	Indian Creek	941	1,124	940	1,123	936	1,119
	69 HWY	1,234	1,440	1,208	1,414	1,200	1,406
	After HWY 69	850	982	842	974	831	963
	Average	1,221	1,344	1,119	1,247	1,094	1,227
	Standard Deviation	227	208	197	197	189	193

As shown in Table 4.2, the maximum sustained flow rate decreased as the interval time increased. Highest maximum sustained flow was observed for 5-minute flow in all cases, and 85th percentile flows were lower than the 15-minute maximum sustained flow values in all cases. Because demand can influence the 85th percentile flow, a frequently congested location typically has higher 85th percentile flow than a less frequently congested location.

Results obtained from these two methods were not reliable, however, due to issues with data quality. Sensor data acquired from the KC Scout portal did not reflect work zone scenarios present at the time of the data collection.

Chapter 5: Project Challenges

Data quality was the primary challenge of this project. Sensor data extracted from the KC Scout portal during the lane closure period was similar to any other day with no lane closures; no impact was observed in the data pattern. Therefore, traffic flow data from the @ Quivira Road sensor during the day of lane closure (March 6, 2018), as well as seven days before the lane closure for the same day of the week (February 27, 2018) and seven days after the lane closure (March 13, 2018), were collected and plotted, as shown in Figure 5.1. Data were collected from 9:00 a.m. to 3:00 p.m. The 85th percentile traffic flow for all three days were 1,129, 1,156, and 1,128, respectively. According to the project description, two left lanes were closed during that period, but the sensor data did not show any effect of the lane closure event. A similar approach was applied to the @ Past Quivira Road sensor, and a similar pattern was noticed for all three days of the data, as shown in Figure 5.2.

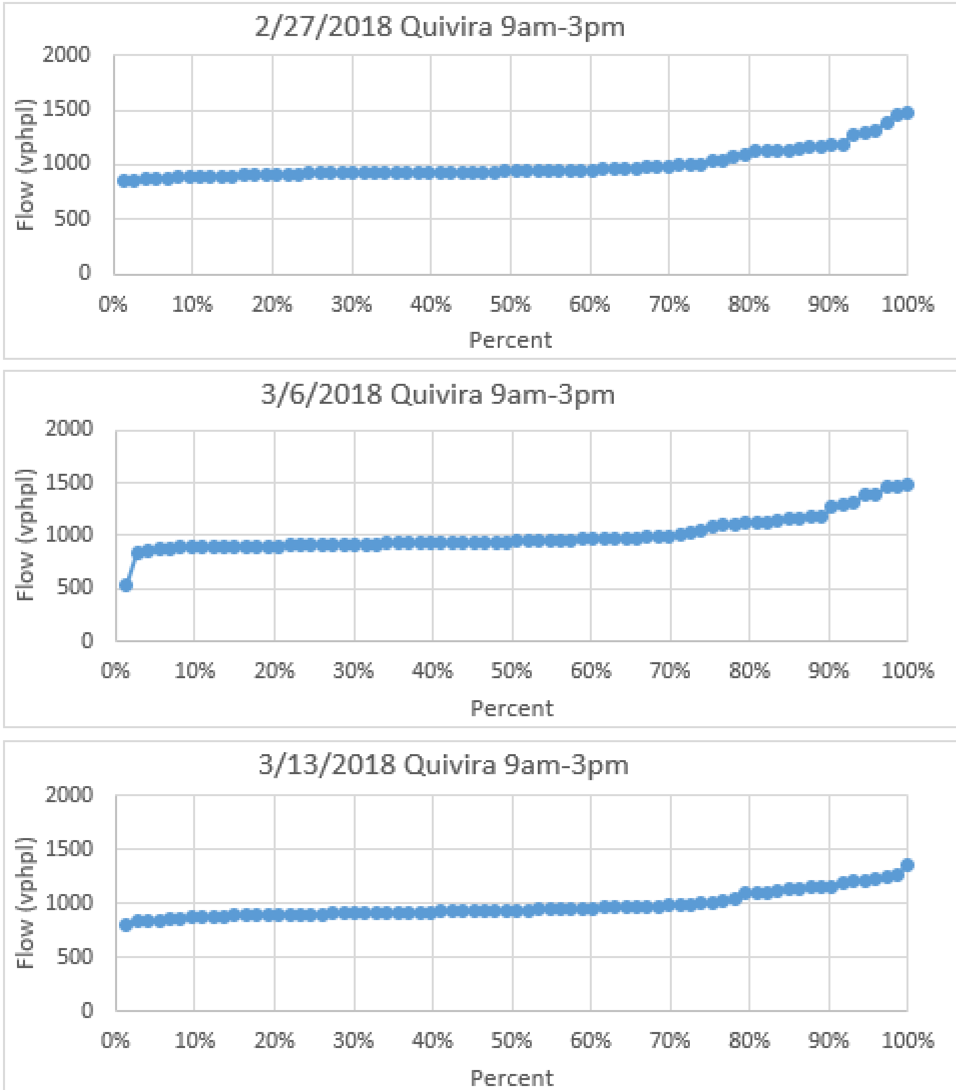


Figure 5.1: Traffic Flow Pattern of @ Quivira Road Sensor Before, During, and After Lane Closure

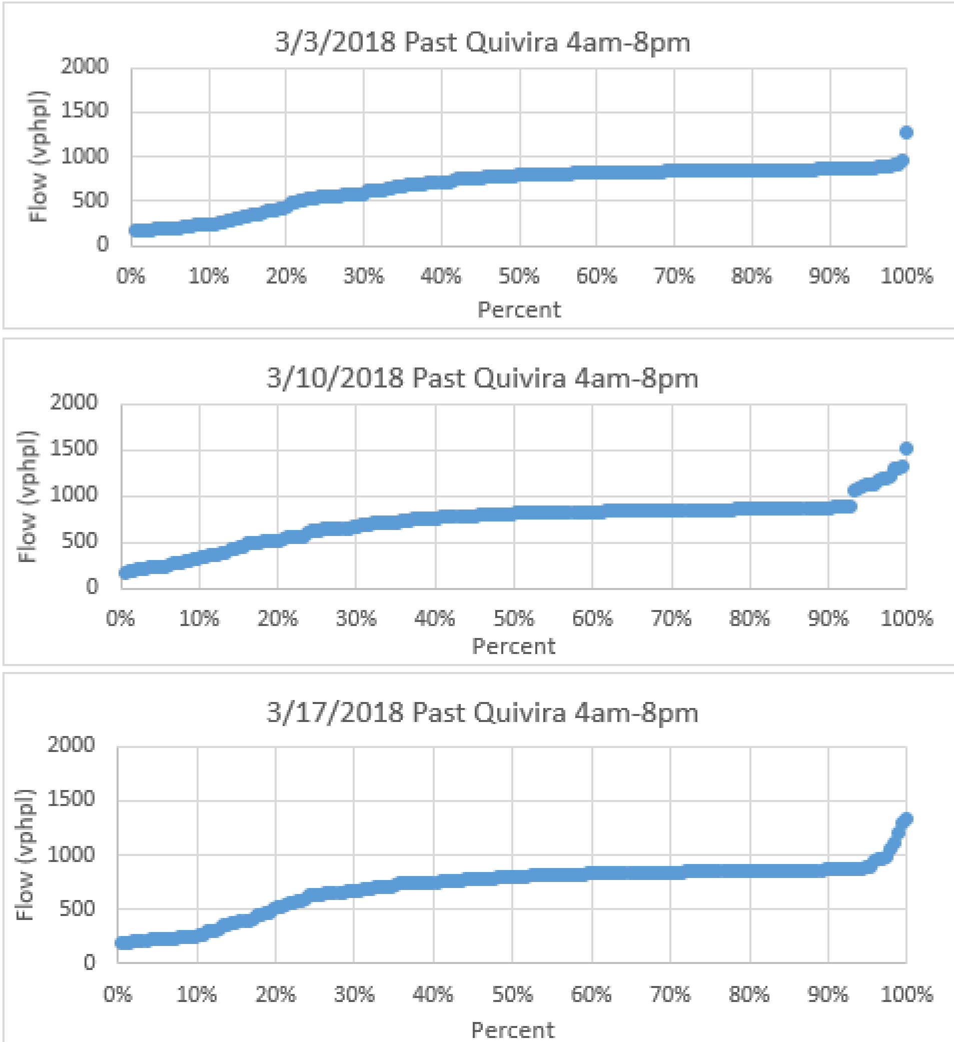


Figure 5.2: Traffic Flow Pattern of @ Past Quivira Road Sensor Before, During, and After Lane Closure

The 24-hr data of the @ Quivira Road sensor was plotted with no visible difference between daily traffic pattern, as shown in Figure 5.3, and according to the data pattern, no reduction in traffic capacity occurred. The speed profile of the 24-hr traffic data was also plotted, as shown in Figure 5.4. Speed profiles from February 27 and March 6 were very similar for the 24-hr period.

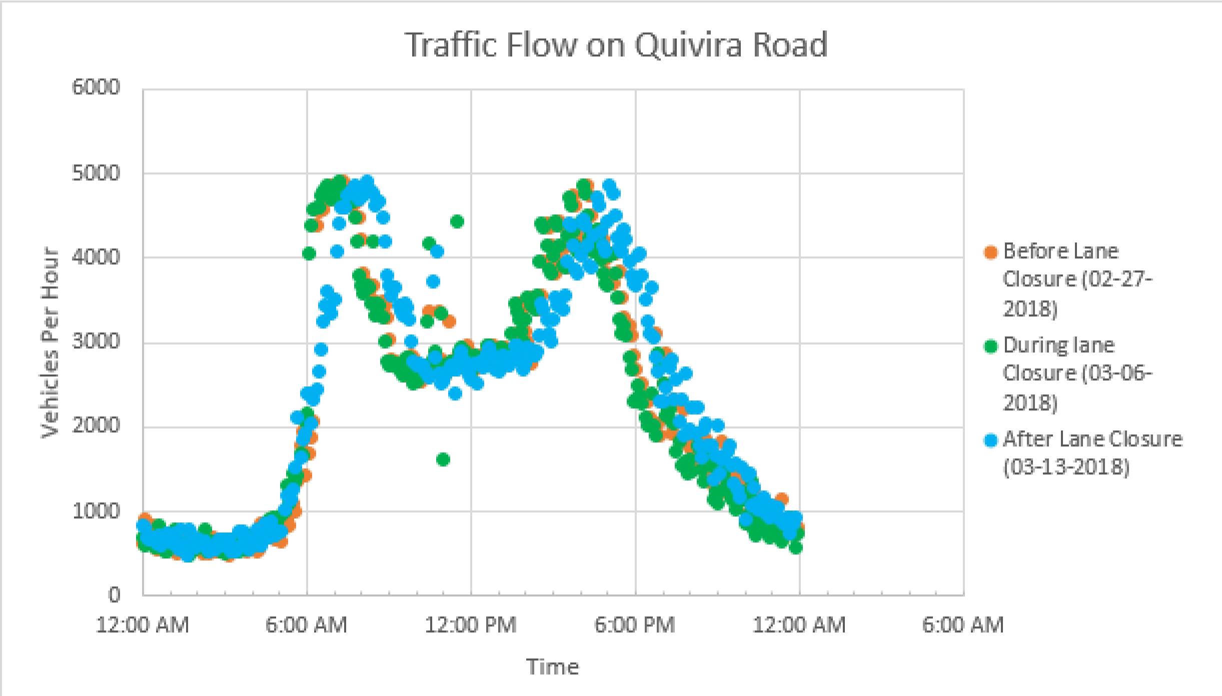


Figure 5.3: 24-Hr Traffic Flow of @ Quivira Road Sensor

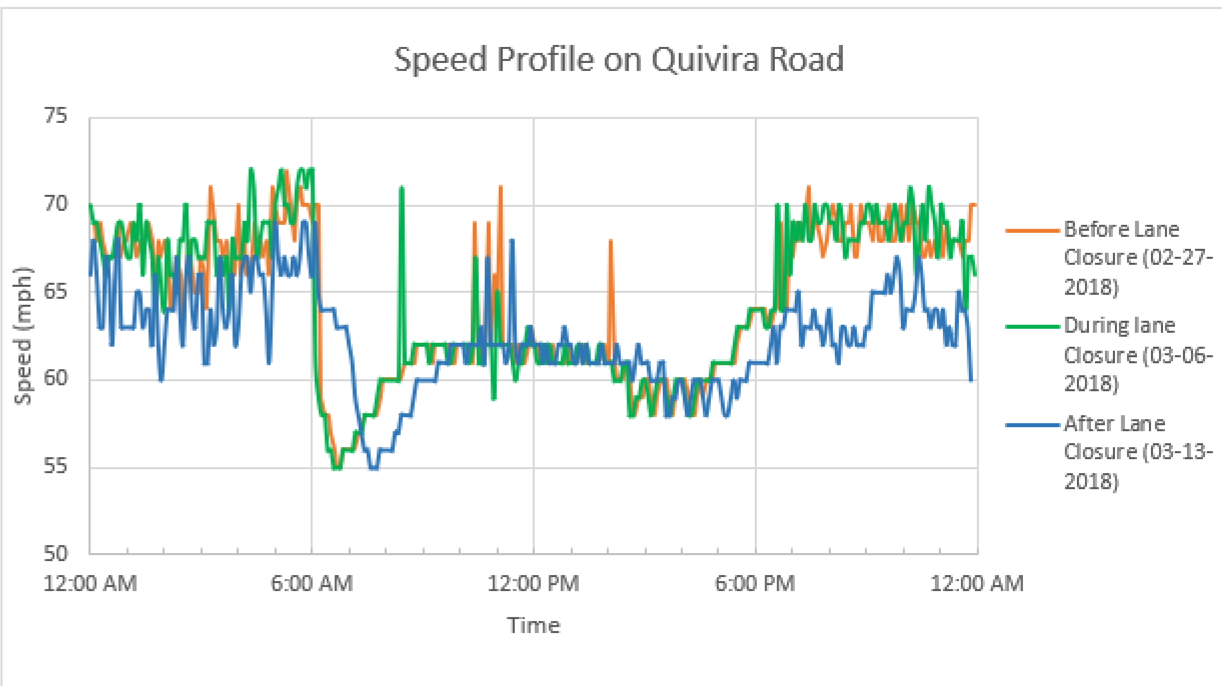


Figure 5.4: 24-Hr Speed Profile of @ Quivira Road Sensor

According to KC Scout portal data, traffic continued in all three lanes from 9:00 a.m. to 3:00 p.m. on March 6, 2018. Except for sharp drops in vph around 10:30, 11:00, and 11:30 (Figure 5.5), traffic flow on Lane 2 and Lane 3 was similar. However, no traffic should have been present on those lanes since they were closed during that period.

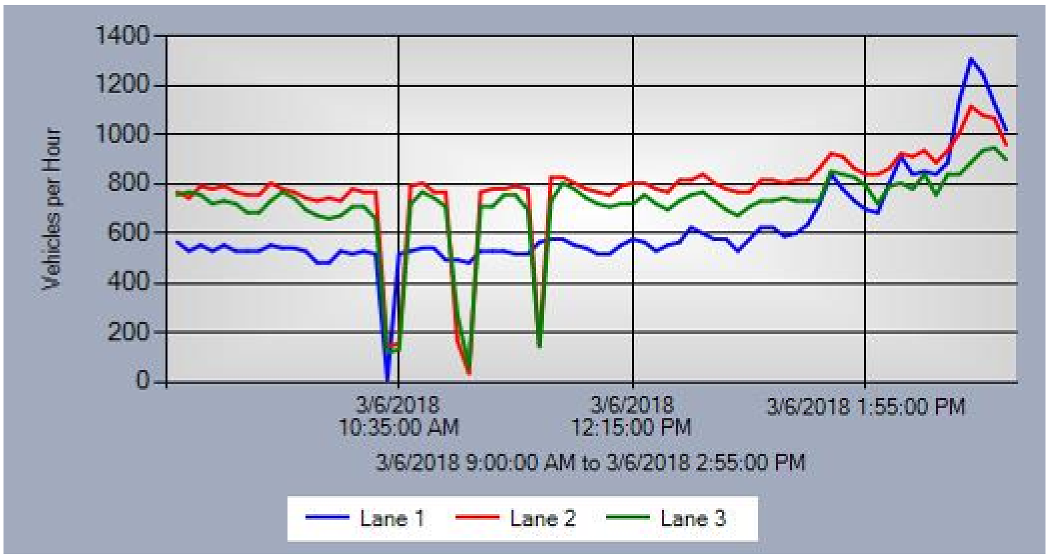


Figure 5.5: KC Scout Vehicles per Hour Data from @ Quivira Road Sensor During the Lane Closure

Similarly, speed flow data of the @ Quivira Road sensor were collected from the KC Scout portal, as shown in Figure 5.6. The speed profiles showed a similar pattern to the vph data. Speed increased on Lane 2 and Lane 3 when there was a decrease in the number of vehicles on the road. However, Lane 2 and Lane 3 should not have had any speed data during that period since they were experiencing lane closures. A screenshot of the database file in Figure 5.7 shows traffic counts and vph for closed lanes in the data extracted from KC Scout for the @ Quivira Road sensor on March 7, 2018, starting at 9:00 a.m. when two of the lanes were closed.

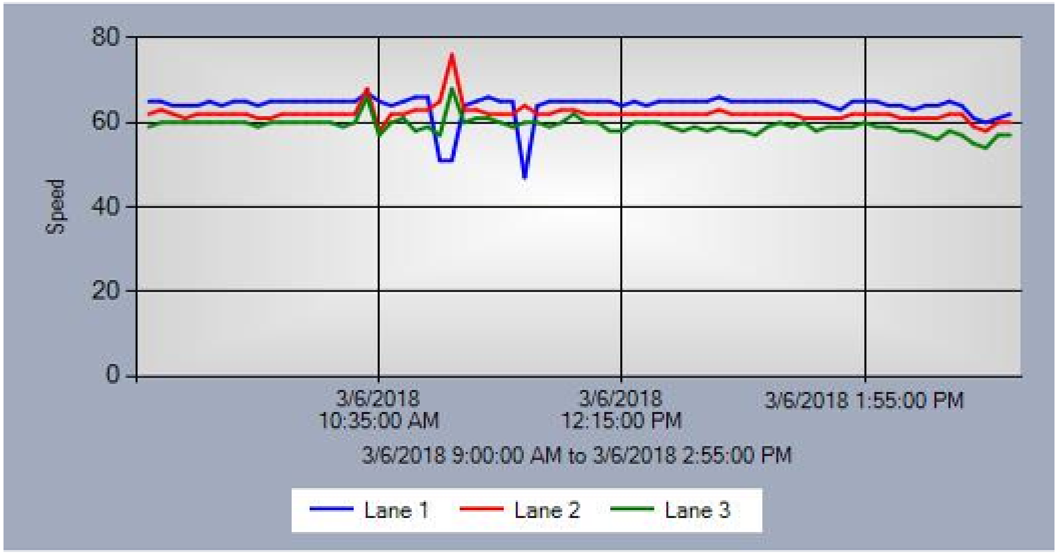


Figure 5.6: KC Scout Speed Flow Data from @ Quivira Road Sensor During the Lane Closure

Station	Timestamp	Interval	Lanes	Dir	Cnt	VPH	Occ	Cnt1	VPH1	Occ1	Spd1	Cnt2	VPH2	Occ2	Spd2	Cnt3	VPH3	Occ3
I-435 E @ Quivira road	3/7/2018 8:55:00 AM	FiveMin	3	E	250	3164	6.29	56	714	4.840	65	70	894	7.090	61	72	905	8.000
I-435 E @ Quivira road	3/7/2018 9:00:00 AM	FiveMin	3	E	234	2938	6.02	52	667	4.730	65	66	830	6.850	62	69	857	7.600
I-435 E @ Quivira road	3/7/2018 9:05:00 AM	FiveMin	3	E	225	2825	5.76	49	628	4.420	65	65	818	6.660	61	64	799	7.380
I-435 E @ Quivira road	3/7/2018 9:10:00 AM	FiveMin	3	E	222	2796	5.78	48	622	4.330	65	66	824	6.780	62	62	784	7.530
I-435 E @ Quivira road	3/7/2018 9:15:00 AM	FiveMin	3	E	233	2911	6	50	637	4.440	65	67	832	6.970	62	67	835	7.670
I-435 E @ Quivira road	3/7/2018 9:20:00 AM	FiveMin	3	E	228	2863	6.05	49	632	4.550	64	67	835	7.270	61	66	819	7.630
I-435 E @ Quivira road	3/7/2018 9:25:00 AM	FiveMin	3	E	224	2808	5.89	49	629	4.390	65	66	827	7.110	62	63	779	7.410
I-435 E @ Quivira road	3/7/2018 9:30:00 AM	FiveMin	3	E	219	2789	5.7	47	609	4.290	65	66	839	6.820	61	62	784	7.200
I-435 E @ Quivira road	3/7/2018 9:35:00 AM	FiveMin	3	E	223	2825	5.67	48	622	4.390	65	67	848	6.770	62	63	792	7.060
I-435 E @ Quivira road	3/7/2018 9:40:00 AM	FiveMin	3	E	233	2910	5.93	50	636	4.430	65	67	844	6.[illegible]	62	67	827	7.580
I-435 E @ Quivira road	3/7/2018 9:45:00 AM	FiveMin	3	E	234	2945	6.14	50	638	4.430	65	70	881	7.250	62	63	796	7.700
I-435 E @ Quivira road	3/7/2018 9:50:00 AM	FiveMin	3	E	234	2934	6.07	49	629	4.280	65	69	872	7.090	62	67	830	7.750
I-435 E @ Quivira road	3/7/2018 9:55:00 AM	FiveMin	3	E	219	2776	5.73	47	600	4.150	65	64	817	6.810	62	62	778	7.310
I-435 E @ Quivira road	3/7/2018 10:00:00 AM	FiveMin	3	E	213	2672	5.51	44	569	4.030	65	65	814	6.610	62	60	745	7.030
I-435 E @ Quivira road	3/7/2018 10:05:00 AM	FiveMin	3	E	207	2635	5.43	43	562	3.830	64	64	812	6.650	62	58	730	6.960
I-435 E @ Quivira road	3/7/2018 10:10:00 AM	FiveMin	3	E	218	2745	5.71	46	590	4.190	64	68	851	6.990	61	58	731	6.920
I-435 E @ Quivira road	3/7/2018 10:15:00 AM	FiveMin	3	E	223	2848	5.82	49	635	4.330	64	67	855	6.980	62	62	787	7.360
I-435 E @ Quivira road	3/7/2018 10:20:00 AM	FiveMin	3	E	228	2864	5.86	48	611	4.270	64	69	869	7.130	61	63	787	7.190
I-435 E @ Quivira road	3/7/2018 10:25:00 AM	FiveMin	3	E	221	2822	5.82	46	604	4.120	65	68	867	6.930	62	60	765	7.540
I-435 E @ Quivira road	3/7/2018 10:30:00 AM	FiveMin	3	E	224	2810	5.74	46	593	4.050	65	69	855	6.860	62	62	778	7.360
I-435 E @ Quivira road	3/7/2018 10:35:00 AM	FiveMin	3	E	223	2836	5.79	45	585	3.960	65	68	866	6.950	62	60	764	7.340
I-435 E @ Quivira road	3/7/2018 10:40:00 AM	FiveMin	3	E	234	2963	6.01	48	625	4.190	65	71	890	7.100	62	64	812	7.680
I-435 E @ Quivira road	3/7/2018 10:45:00 AM	FiveMin	3	E	232	2978	6.03	48	634	4.180	65	68	869	6.970	62	64	821	7.840
I-435 E @ Quivira road	3/7/2018 10:50:00 AM	FiveMin	3	E	183	3070	28.25	46	594	2.000	65	67	842	2.000	19	63	794	100.00
I-435 E @ Quivira road	3/7/2018 10:55:00 AM	FiveMin	3	E	219	2784	5.67	42	555	3.750	66	67	844	6.610	63	61	777	7.500
I-435 E @ Quivira road	3/7/2018 11:00:00 AM	FiveMin	3	E	216	2745	5.66	42	549	3.800	65	65	821	6.430	63	63	795	7.900
I-435 E @ Quivira road	3/7/2018 11:05:00 AM	FiveMin	3	E	218	2772	5.5	43	571	3.750	66	65	817	6.600	63	63	792	6.970
I-435 E @ Quivira road	3/7/2018 11:10:00 AM	FiveMin	3	E	223	2829	5.75	46	601	4.110	65	66	836	6.750	63	62	779	7.340
I-435 E @ Quivira road	3/7/2018 11:15:00 AM	FiveMin	3	E	224	2829	5.79	46	596	4.040	65	66	834	6.810	62	62	784	7.420
I-435 E @ Quivira road	3/7/2018 11:20:00 AM	FiveMin	3	E	233	2902	5.78	47	604	4.090	65	71	878	6.870	62	66	818	7.390

Figure 5.7: Extracted Data of @ Quivira Road Sensor from KC Scout Portal

Chapter 6: Discussion

Work zones along major roadways and highways in the United States will continue to be a necessary aspect of maintaining, expanding, and preserving our infrastructure. The nature of many work zone cases requires construction activities to occur during peak hour conditions where sometimes a significant amount of traffic will pass by or travel adjunct to an active work zone. A previous study was conducted to develop a lane closure guide for the Kansas City metropolitan area where the number of lanes open are specified based on actual traffic operations center data for each hour of the day (Fitzsimmons et al., 2018). However, when closing a lane on a roadway or highway, the capacity of the roadway can be reduced, oftentimes resulting in non-recurring congestion which can lead to long queues and a higher chance of a rear-end crash. The Highway Capacity Manual gives limited guidance on the required capacity for a roadway during work zone activities, often times referring to engineering judgement, local conditions, or an estimation of 1,500 pcphpl. In other words, if one, two, or more lanes are closed due to work zone activities, it is desired that 1,500 pcphpl be able to traverse the work zone area to maintain flow and safety.

The objective of this project was to estimate work zone capacity using KC Scout traffic operations data and known historical work zone sites provided by KDOT. The 85th percentile flow and the 15-minute maximum sustained traffic flow methods were applied to calculate these capacities, but as was discussed in Chapter 5, the results may not be reliable since the data quality was proven unreliable. In fact, during the study period, estimated work zone capacities may not have represented actual work zone scenarios. The primary issue was the availability of data on closed lanes. According to the provided list of work zones, lanes were closed in the study segments; however, during data collection, sensors from those closed lanes provided traffic, speed, and occupancy data. As a result, determination of actual traffic flow on the open lanes during the lane closure period was difficult and the research team concluded that the data provided by KC Scout was unreliable.

Sensor data were collected for the roadway segments one week before and one week after the lane closure events. The traffic pattern and speed profile were similar for during, before, and after the lane closure even though the work zone was expected to demonstrate a different speed profile and traffic volume than when the segment had had no lane closure. Although the underlying reason for this scenario was unknown, one hypothesis is that the sensors may not have been updated during the lane closure period, so they collected data from the roadway during the lane closures just like other days with no lane closures. Therefore, the sensors as well as the data collection process must be updated in work zone locations. Sensors should be updated so that they only collect data from open lanes in a work zone or, if the lanes are rerouted, the sensors should be adjusted to capture data from the rerouted lanes. Also, on-site data from work zones can be used to estimate work zone capacity. Future studies should collect data from the work zone site instead of using data from work zone sensors. KC Scout sensor data can be used as well after verifying that the data are reliable using a ground truthing method.

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