Evaluating and Updating the Kansas Department of Transportation’s Lane Closure Guide in the Kansas City Metropolitan Area Using Traffic Management Center Data

by

Benjamin Gilbert Nye

B.S., Kansas State University, 2016

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Civil Engineering
College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2017

Approved by:

Major Professor
Dr. Eric Fitzsimmons

Copyright

Abstract

Each year maintenance and rehabilitation occur on interstates and highways to repair damage, improve rideability, and increase safety. To perform many of these activities a short or long-term work zone is required. However, short and long-term work zones can have significant impacts on traffic flow, especially during peak travel times. To mitigate the impact of work zones, the Kansas Department of Transportation (KDOT) has developed a lane closure guide to assist KDOT personnel and contractors in determining times during the day that a lane can be closed to traffic. The existing lane closure guide was comprised of limited data sources and assumptions based on past traffic counts. The purpose of this research study was to evaluate the existing guide and update it using a consistent data source that reflects current roadway conditions.

During the evaluation of the existing lane closure guide, several inconsistencies with traffic counts, directional splits, and adjustment factors were found. To eliminate the consistencies, data from the Kansas City Traffic Management Center was used. During the procedure of updating the lane closure guide a repeatable data extraction process and a quality assurance/quality control process were utilized.

In addition to updating the KDOT lane closure guide, sensor data verification was performed on one KC Scout sensor on K-10 using road tubes. The data from the road tubes was then compared to the data extracted from KC Scout during the same time interval. The comparison found the road tubes and KC Scout counted statistically the same number of cars for the chosen interval. However, the comparison found the road tube’s average speed for chosen interval to be on average 10 percent higher than KC Scout, which was statistically significant.

Table of Contents

List of Figures

List of Tables

List of Equations

Acknowledgements

I would first like to thank my advisor, Dr. Fitzsimmons, for his continual support throughout the learning process of this thesis. Furthermore, I would like to thank Aaron Fritz and Kristi Ericksen from KDOT for their assistance and guidance. Finally, I would like to thank my coworkers for their help and encouragement during my time as a graduate student. Without everyone's presence, this accomplishment would not have been possible and am forever grateful.

Chapter 1 - Background

1.1 Background

The daily transportation of high volumes of people, goods, and services makes the consistent maintenance of city or state transportation infrastructure essential. Interstate routes and multilane highways ideally should be maintained at high levels of service with little to no traffic congestion during peak operational times. However, as cities and populations expand, a routinely serviced highway may experience increased traffic volumes and congestion, resulting in travel time delays and subsequent decreased levels of service. A study in 2013 estimated that "traffic congestion cost Americans $124 billion in direct and indirect losses" (Guerrini, 2014). Lane expansions, bypass routes, and other countermeasures are often used to reduce high traffic volumes and minimize roadway congestion.

Typically, maintenance and rehabilitation must occur for road infrastructure to perform as designed. During peak roadwork season (warmer months in the Midwest), approximately 20 percent of the U.S. highway system is under construction, accounting for 24 percent of nonrecurring delays (Heaslip, 2007). Maintenance and rehabilitation often require work on traveling lanes, and in some cases, lanes must be closed to prevent interference with the work and ensure operational space and safety for the construction crew and machinery. Figure 1 shows the *Manual on Uniform Traffic Control Devices* (MUTCD) guide to lane closures on a public roadway.

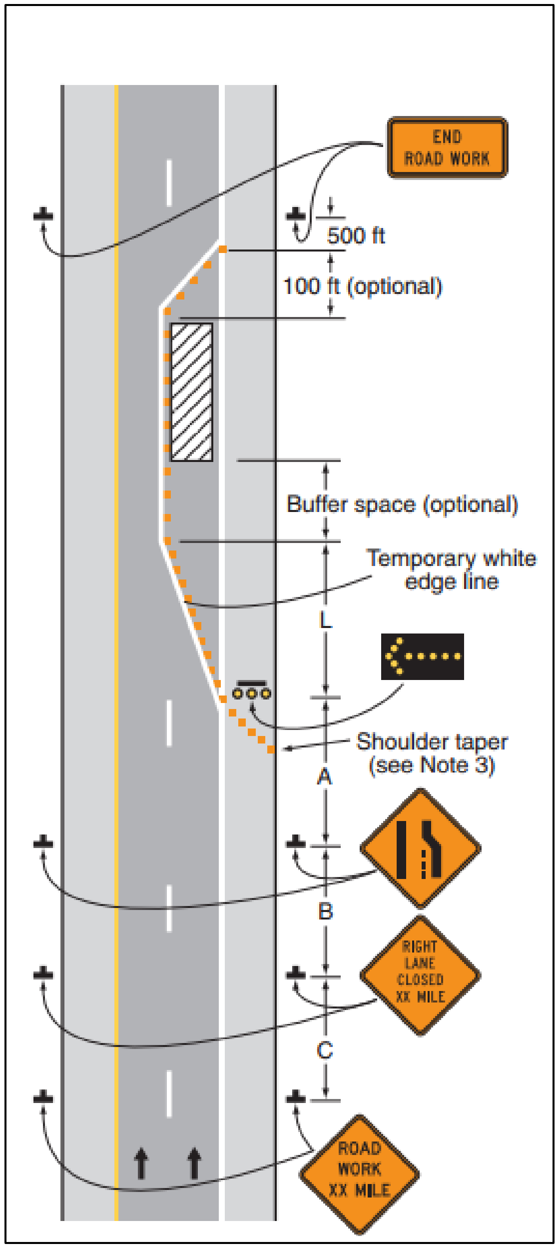


Figure 1 MUTCD Guide on Closing a Lane of Traffic on a Multilane Divided Highway (Federal Highway Administration, 2012, p. 699)

As shown in Figure 1, closure of the right lane involves advanced warning signs and a taper to move traffic out of the lane. Depending on the time of day and hourly traffic volumes, traffic queues and delays may occur due to reduced roadway capacity.

Two important factors minimize the impact of work zones on a roadway: work zone lane capacity and roadway hourly volumes. The *Highway Capacity Manual* (HCM) 2010 uses two methods to explain lane capacities throughout a work zone. One method, which utilizes a set of equations or a table with estimated values based on completed studies, reduces a base roadway lane capacity using variables such as heavy truck percentage, terrain type, and number of open lanes through a work zone. The second method requires a set of values for various work zone lane configurations based on previous research from several states. Although the HCM provides a general default value that can be used in all work zone situations, all values generically determine capacity; therefore, each state should use values tailored to their needs. The determination of hourly volumes for roadways varies state by state and city by city based on available data and data collection methodologies.

The SHRP2 – L08, another method that complements values used in the HCM 2010, adjusts work zone capacity based on a speed limit of 55 mph and a base capacity of 2,250 passenger cars per hour per lane (pcphpl). Depending on the number of lanes prior to and through the work zone, the factors applied to the base capacity range from 0.62 to 0.67 (FHWA, 2013).

1.2 Research Objectives

The primary objective of this research was to evaluate the current KDOT Lane Closure Guide to determine data reliability for when a lane on a multi-lane highway can be closed for temporary and mobile work zones. The research team also sought to determine other lane closure guidance available from state highway agencies. In addition, the research team was tasked by KDOT with updating the KDOT Lane Closure Guide using traffic management center operational data from Kansas City Scout (KC Scout) for the Kansas City, Kansas, metropolitan area.

Chapter 2 - Literature Review

A review of literature was conducted to identify previous studies that have investigated work zone capacity. Recent and relevant literature was found using online databases containing peer-reviewed journals and dissertations. In addition, a survey was sent to state highway agencies to determine work zone capacity values used in practice.

2.1 Capacity in Work Zones Methods

Although capacities of highway segments under normal flow conditions and work zone flow conditions have been widely studied, each state has guidelines to estimate work zone capacity based on location and importance of the area. Benekohal, Kaja-Mohideen, and Chitturi (2003) evaluated work zone operational constraints in Illinois by distributing surveys to various state departments of transportation (DOTs). The researchers also surveyed Illinois Department of Transportation (IDOT) districts regarding their use of incentive/disincentive and lane rental procedures in order to review ways IDOT reduces motorist delay. The survey found that incentive/disincentive and lane rental procedures reduce delay in work zones, but no consensus emerged for dollar amounts associated with those procedures. The researchers also surveyed other state DOTs regarding contract procedures, capacity, queue, delay, and road user costs; results indicated that most states use HCM methodology to calculate capacity. Additionally, QUEWZ, Quick Zone, and HCM techniques are often used to calculate queue length and delay, and QUEWZ and spreadsheets are used most often for road user cost calculations. Survey results also showed that 70 percent of DOTs attribute the loss of work zone sign credibility from failure to remove signs during non-construction periods, incorrect information, and overuse of signs (Benekohal, Kaja-Mohideen, & Chitturi, 2003).

Maze, Schrock, and Kamyab (2000) evaluated lane closure capacities and driver behavior in work zones in Iowa. Data were collected on Interstate 80 between U.S. 61 and Interstate 74 to determine traffic flow characteristics at the beginning and end of each work zone and the queue length at the onset of congestion. The researchers collected video of the work zone to determine traffic flow data. Based on the data collected, the highest converted volumes (to passenger car equivalents) ranged from 1,400 to 1,600 pcphpl. The researchers also found that vehicle queuing causes safety concerns because queues can move backwards and forwards quickly (Maze, Schrock, & Kamyab, 2000).

Sarasua, Davis, Chowdhurry, and Ogle (2005) developed a methodology to estimate interstate highway capacity for short-term work zone lane closures. The South Carolina Department of Transportation (SCDOT) requested a study of capacity through short-term work zones to update the lane closure policy for interstate highway work zones. The study was completed in two phases. The first phase determined threshold volumes for two-to-one lane closure configurations. Phase two focused on numerically derived relationships and analysis of three-to-two and three-to-one lane closure configurations. The researchers found insufficient data to conclude that work zone activity, intensity, and length positively or negatively influence work zone capacity; however, a double lane closure was shown to decrease work zone capacity by 150 pcphpl. The researchers concluded that work zones have capacities between 1,200 and 1,400 pcphpl, with low values showing a high percentage of heavy vehicles (Sarasua, Davis, Chowdhury, & Ogle, 2005).

Notbohm, Drakopoulos, and Deham (2006) completed a capacity analysis of two work zones on an urban freeway in Wisconsin. The first work zone had a four-to-two lane configuration, and the second work zone had a two-to-one lane configuration. The researchers defined the work zone capacity as "the maximum traffic flows observed over a one-hour period." The researchers observed trip diversions due to low traffic volumes entering the freeway as well as increased use of off-ramps and decreased use of on-ramps. Results indicated a four-to-two lane configuration ranged from 1,800 to 2,100 vehicles per hour per lane (vphpl) and a two-to-one lane configuration ranged from 1,550 to 1,900 vphpl (Notbohm, Drakopoulos, & Dehman, 2006).

Al-Kaisy and Hall (2003) used information collected from several work zones in Ontario, Canada, to create guidelines to estimate freeway capacity in a work zone. The researchers found the base capacity for long-term lane closures to be 2,000 pcphpl, which was lower than the HCM's recommendation of 2,400 pcphpl. Factors such as the percentage of heavy vehicles and driver population were applied to the 2,000 pcphpl base to determine a realistic capacity through the work zone. The application of various factors resulted in a capacity range of 1,500–1,900 vphpl (Al-Kaisy & Hall, 2003).

Du and Chien (2014) studied the feasibility of shoulder use for optimization of highway work zones. Feasibility was based on costs associated with decreased capacity and increased congestion as well as costs of temporary shoulders. For example, a wide shoulder that is strong enough to support traffic would have a minimum cost for use as a temporary lane. However, if the shoulder was too narrow or weak, the cost to upgrade the shoulder may not decreased costs. When the researchers considered various longitudinal roadway lengths and the number of lanes closed, they found that shoulder use could significantly reduce user delay costs, concluding that long distance work zones reduce capacity during peak hours as opposed to temporary or moving work zones (Du & Chien, 2014).

Edara, Kianfar, and Sun (2012) tested various capacity definitions on computed values: maximum sustained flow, rescaled cumulative flow curves, and 85th percentile flow. The obtained values were then compared to field data collected from short-term work zones in Missouri. The researchers surveyed 29 state DOTs to determine factors that influence work zone capacity information. Results showed that 74 percent of DOTs consider work zone configuration (number of open and closed lanes) and work zone length when determining capacity. Seventy percent of DOTs stated that lane width is a factor for determining capacity, 65 percent stated that the proportion of heavy vehicles is a factor, and only 9 percent use driver familiarity as a factor for determining capacity. Based on the four site locations, the average capacities were 1,149, 1,267, and 1,301 for queue discharge flows, 85th percentile flow, and 15-minute sustained flow, respectively. The values were similar to HCM's estimation of 1,240 used in Missouri but lower than values used by other state DOTs (Edara, Kianfar, & Sun, 2012).

Kwon and Park (2016) created a guideline to estimate traffic diversion rates and capacity reduction for work zones using data collected from work zones in the metro freeway network in Minnesota. However, this study only used information from two-to-one lane reductions, so results are applicable only to those types of work zones. An iterative process was used to find the convergence of diversion and resulting freeway delays. Study results suggested between 1,500 and 1,650 vphpl (Kwon & Park, 2016).

Dissanayake and Ortiz (2015) explored rural highway work zone capacity. The researchers selected six rural work zones for data collection with an average of six days' worth of data from each work zone. Two capacity estimation models were utilized: the maximum 15-minute flow rate method and the platooning method. Using the maximum observed 15-minute flow rate method, an average capacity of 1469 pcphpl was found, with a standard deviation of

141 pcphpl, and an average capacity of 1195 pcphpl was found with a standard deviation of 28 pcphpl using the platooning method. Based on the observed data and analysis, the researchers concluded that the maximum capacity of a work zone in rural Kansas could be 1500 pcphpl (Dissanayake & Ortiz, 2015).

Bham and Khazraee (2011) analyzed data from work zones on Missouri interstate highways to determine mean breakdown and queue-discharge rates that were then used to determine capacity. The researchers collected several days' worth of traffic data at a work zone near Pacific, Missouri, with a posted speed limit of 50 mph. The researchers identified 11 breakdown events using average speed profiles; breakdown flow rates ranged between 1194 vphpl and 1404 vphpl, with an average of 1295 vphpl. The researchers also found a mean queue discharge of 1199 pcphpl (1072 vphpl), which is below the 2000 HCM average capacity of 1600 pcphpl. The researchers concluded that the mean breakdown flow should be used to forecast the onset of congestion and that queue-discharge flow be set to estimate delays under congested conditions (Bham & Khazraee, 2011).

The literature on highway capacities showed a wide variance of total capacity in work zones. Capacity was found to depend on the number of closed lanes, location of the work zone, traffic type, and intangible factors.

2.2 Work Zone Capacity Simulation

One area with limited new research is the modeling of work zone capacity. Fei, Zhu, and Han (2016) analyzed traffic congestion caused by work zones. They proposed the use of cellular automata (CA) that uses meticulous motion description based on the R-STCA (symmetric two-lane cellular automata). The researchers replaced a cell 7.5 meters long with a cell 1.0 meter long. In the former approach, one vehicle would occupy one cell, but in the latter approach, a vehicle occupies seven cells. The researchers then classified each vehicle as fast or slow. A fast vehicle was represented by a car, and slow vehicles were represented by trucks and buses. Each classification contained two separate accelerations depending on whether or not the vehicle was moving. The simulation took into consideration lane merging and speed limits imposed by a work zone. After simulating a work zone using this model, the researchers concluded that the model's speed-flow diagram similar to with the speed-flow diagram obtained from empirical data. The researchers also concluded that the model could be used to optimize traffic flow in a work zone (Fei, Zhu, & Han, 2016).

2.3 Summary of Practice

In addition to a literature review of interstate work zone capacity, this study created and distributed a survey of practice to 34 state highway agencies, with 15 states submitting survey responses. The survey consisted of three questions:

- **Question 1 (Presence of Guidance):** Does your state highway association and/or traffic operations center have a guide, toolbox, or policy for closing single or multiple lanes during work zone activity, specifically on interstates or multi-lane highways?
- **Question 2 (Capacity for Work Zones):** If a lane is closed during work zone activity, what is the minimum flow rate for the open lane(s) through the work zone to maintain steady flow with minimal delay (for the Kansas Department of Transportation [KDOT] this value is 1500 pcphpl)?
- **Question 3 (Countermeasure Implementation):** Are any countermeasures implemented to reduce queue lengths and/or increase lane capacity through the work zone?

Approximately one-half (7) of the states that responded to the survey do no currently have a policy for closing a lane to traffic, and the states that responded affirmatively described vastly different policies. For example, the New York State Department of Transportation (NYSDOT) utilizes engineering judgment, or “seat of the pants” judgment, to determine when a lane of traffic can be closed. NYSDOT also considers completed work and the amount of overtime required to reduce costs. The SCDOT utilizes the Hourly Restrictions for Lane Closures on Interstate Routes (South Carolina Department of Transportation, 2017) guide for closing lanes on an interstate, as shown in Figure 2 **Hourly Restrictions for Lane Closures on Interstate Routes guide used by SCDOT**

I-20

LIMITS (MILEPOST TO MILEPOST)	COUNTIES	HOURLY LANE CLOSURE PROHIBITIONS (SINGLE)	HOURLY LANE CLOSURE PROHIBITIONS (DUAL)	DATE / LOCATION (COUNT STATION)
MP 0 (Georgia State Line) to MP 6 (US 25 / SC 121)	Aiken	Eastbound MON-WED: 7A-9P WED-THU: 7A-10P FRI: 7A-10P SAT: 8A-10P SUN: 9A-9P Westbound MON-WED: 6A-8P THU: 6A-9P FRI: 6A-10P SAT: 8A-8P SUN: 10A-9P	NA	July 2016 MP 0.55 (At Welcome Center) Station 23

Figure 2 Hourly Restrictions for Lane Closures on Interstate Routes guide used by SCDOT (South Carolina Department of Transportation, 2017)

Figure 2 shows an example of a lane closure restriction for I-20 starting at the Georgia state line to milepost 6.0. As shown, both eastbound and westbound directions had hourly restrictions for lane closures for each day of the week. This information is based on data collected at milepost 0.55 in July 2016. The Iowa Department of Transportation (IowaDOT) utilizes a website shown in Figure 3.

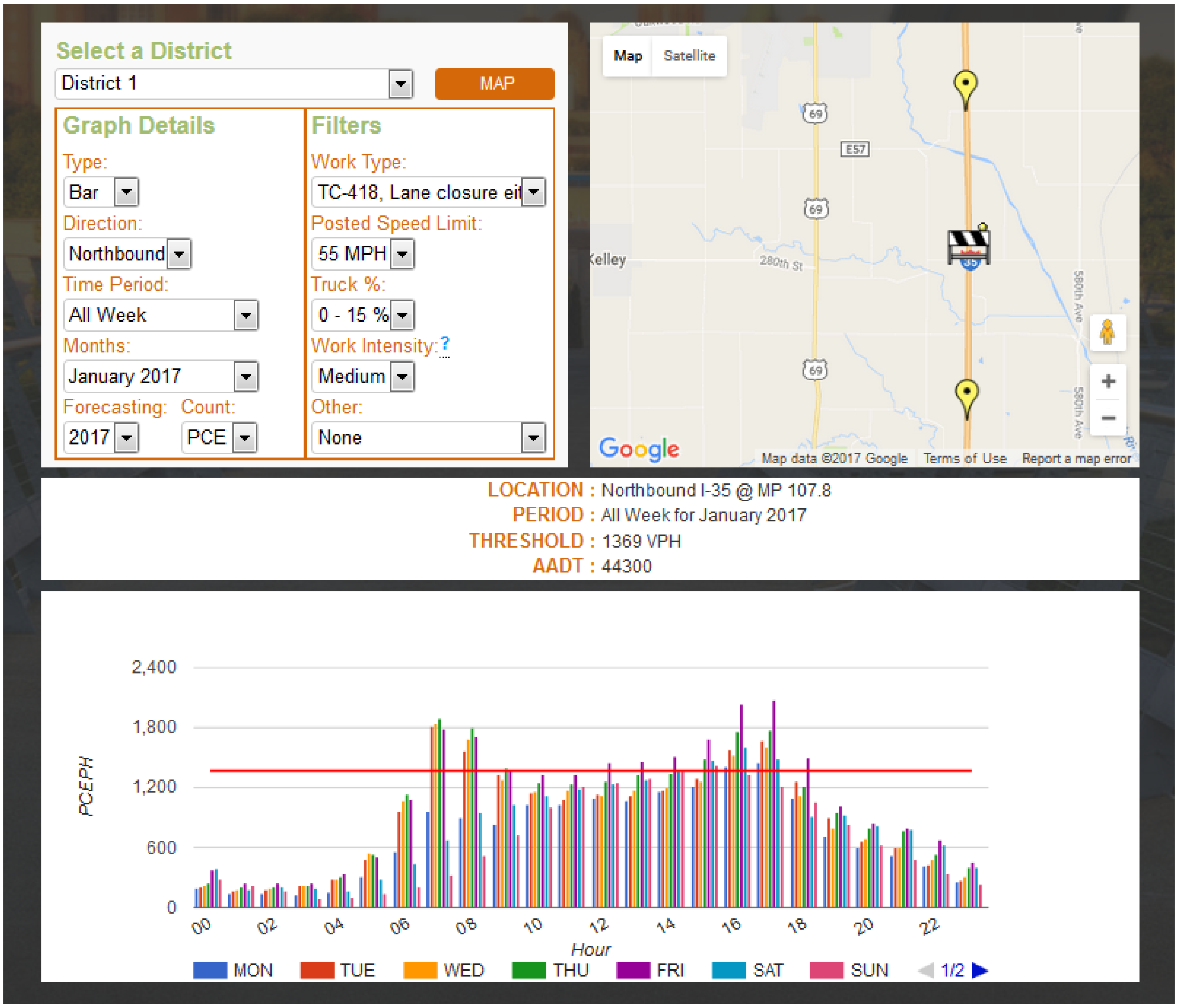


Figure 3 Iowa DOT Lane Closure Planning (IowaDOT, 2014)

Figure 3 shows traffic information for I-35 at milepost 107.8 in Iowa, including traffic volumes for each hour of the day for each day of the week during the month of January. The line across the bar graph indicates the threshold for the number of vehicles per hour for each lane. The graph, which indicates a peak in the morning (7:00–9:00 a.m.) and the evening (4:00–6:00 p.m.), shows that the amount of traffic exceeded the threshold determined by IowaDOT, suggesting that a lane of traffic should not be closed during these times.

Seven states noted on the study survey that they have a set value for minimum flow rate through work zones to maintain a steady flow. NYSDOT uses a value of 1,500–1,700 vphpl for interstate routes and 1,200 vphpl for multilane highways with traffic signals. The Nevada Department of Transportation (NDOT) uses a value of 1,600 pcphpl and a range of 1,400–1,600 vphpl depending on the volume of heavy vehicles. SCDOT and IowaDOT use a value of 1,200 vphpl for interstate routes. The Kentucky Transportation Cabinet uses 1,250 vphpl for long-term work zones and 1,000 vphpl for short-term work zones, and the Louisiana Department of Transportation and Development uses a value of 1,300 vphpl. The Michigan Department of Transportation is in the process of creating a manual with a specified minimum flow rate.

Responses for the last question regarding countermeasures revealed that only three states do not utilize countermeasures in work zones, and the remaining nine used one or more countermeasures to increase work zone capacity. Four states that use countermeasures use variable message signs (VMS) independently or in conjunction with intelligent work zone (IWZ) devices or intelligent transportation systems (ITS). The other two states either use or have the option of using a zipper merge system to improve capacity. State responses are shown in Table 1.

Table 1 Survey Responses from State Highway Agencies

	Question 1: Presence of Guidance	**Question 2: Capacity for Work Zones**	**Question 3: Countermeasure Implementation**
Arizona Department of Transportation (ADOT)	All closures or restrictions are handled by the Central Region Traffic Office and are in accordance with requirements listed in the MUTCD.	There are no written flow rate requirements; in urban areas work is done during off-peak/nighttime hours.	No specific countermeasures.
North Dakota Department of Transportation (NDDOT)	NDDOT does not have a formal policy for closing single or multiple lanes for work zones. North Dakota typically does not have large traffic volumes, so closing one lane is not usually an issue. NDDOT uses engineering judgment and occasionally requires work to be done at off-peak hours or at night. NDDOT typically shifts traffic onto the 10 ft. shoulder as a driving lane.	NDDOT has not conducted any calculations to determine delay in work zones for lane closures on multiple lane roadways.	NDDOT has a zipper merge layout to reduce queue lengths, but this layout has never been used in North Dakota. MnDOT uses a similar layout.

Delaware Department of Transportation (DelDOT)	DelDOT does not have written policies or guides for closing single or multiple lanes during work zone activities. Although DelDOT is working with the executive management team to formalize a review process for lane closure time restrictions, the developing policy/guidance is generic. DelDOT typically evaluates lane closure time restrictions on a case-by-case basis depending on the type of work occurring, time of day, and duration. DelDOT tries to use appropriate real-time traffic volumes to set limits for time restrictions based on available capacity, v/c ratio, queue lengths, and/or travel times.	DelDOT does not have a minimum flow rate or minimum MOE; capacities are evaluated on a case-by-case basis. Oftentimes, depending on the type and duration of work, traffic volumes are well over capacity, requiring DelDOT to use mitigation.	DelDOT uses transportation operations and public information strategies to reduce queue lengths and/or increase lane capacity through work zones. DelDOT only recently began using a queue detection system for transportation operations and has posted portable VMS at key points to divert traffic away from work zones. DelDOT uses real-time signal timing adjustments to accommodate increased queue lengths in signalized corridors.
New York State	NYSDOT utilizes a “seat of the pants” count-per-lane threshold review as their most accurate	Typical threshold values are 1500-1700 veh/lane/hour on Interstates, 1200 veh/lane/hour for multi-lane	NYSDOT typically provides advanced warning with VMS, which diverts traffic to reduce capacity and

Department of Transportation (NYSDOT)	program. NYSDOT uses 1500–1700 vphpl on interstates, 1200 vphpl for multi-lane highways with signals, and 650 veh/lane for flagging on two-lane highways.	highways with signals, and 650 veh/lane for flagging on two lane highways, which should be about the cut-off for creating queues.	impact. Maintaining a wide temporary lane decreases capacity but increases vehicle speeds next to workers. The use of inexpensive rubber-necking fencing also helps maintain drivers' focus on the road and not the work area.
South Dakota Department of Transportation (SDDOT)	SDDOT uses standard plates to establish lane closures on interstates and multilane highways. SDDOT also sets a maximum length of lane closure and a minimum distance between lane closures on these facilities. (See attached policy.)	SDDOT does not have a value for minimum capacity.	No specific countermeasures.
Iowa Department of Transportation (IowaDOT)	IowaDOT created a website to show traffic patterns and threshold values. IowaDOT is constantly working to improve this tool by adding more sensors, including a modification factor for truck percentage and a factor for terrain.	IowaDOT uses 1200 vehicles per hour (vph) for a single-lane closure on a two-lane single-direction facility (to accommodate truck percentages). IowaDOT also uses 3000 vph to close a single lane on a three-lane facility (with 1200 vph to	IowaDOT has a traffic-critical project program that uses IWZ to provide additional information to the traveling public.

		close two lanes on a three-lane facility).	
Michigan Department of Transportation (MDOT)	Yes, in the process of being updated. The new rule is 10 minutes of additional delay requires a transportation management plan (TMP). Although that value can be exceeded, the goal is to be at or below 10 minutes of delay.	Although MDOT does not have a set value, the new manual contains some draft numbers, which is a process and is set but the work zone and layout. Information about CO3 can be found at http://www.michigan.gov/mdot/0,4616,7-151-9625_54944-227053--,00.html	MDOT does not have them added into the numbers but is in the process of doing that. A zipper merge will increase capacity.
South Carolina Department of Transportation (SCDOT)	SCDOT has hourly lane closure prohibition restrictions. Information about these restrictions can be found on SCDOT's website (South	SCDOT's hourly lane closure prohibition restrictions are based on 1200 vphpl for interstate routes and 800 vphpl for primary and secondary routes.	SCDOT does not employ any countermeasures at this time.

	Carolina Department of Transportation, 2017).		
Tennessee Department of Transportation (TDOT)	TDOT does not have a policy for closing lanes in work zones. Each project is reviewed on a case-by-case basis.	TDOT does not have a minimum flow rate but determines if a project is significant based on the location (TMA area) or the expected delay using a Work Zone Safety and Mobility Manual. The TDOT website contains a chart, which was created using research from a local university, to determine if a delay greater than 30 minutes is expected (Tennessee Department of Transportation, 2017).	In areas determined to be significant or have long expected delays, the safety and mobility manual requires TDOT to determine countermeasures to help reduce the impact to motorists, such as utilizing TDOT's ITS system to warn and provide travel time information.
Nevada Department of Transportation (NDOT)	NDOT does not currently have any written policies regarding lane closures.	NDOT uses 1,600 pcphpl or 1,400–1,600 vphpl depending on the amount of heavy traffic.	NDOT has deployed several strategies. One strategy uses screening boards to reduce visual contact to the construction site to prevent driver distraction in order to increase speed and capacity. NDOT

			also relies on media (e.g., TV, radio, internet), dynamic message signs, and other traffic control devices to inform the traveling public and advise on alternate routes or detours.
Louisiana Department of Transportation & Development (Louisiana DOTD)	Louisiana DOTD has a written policy for closing a lane to traffic. The policy can be found at http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Traffic_Engineering/Misc%20Documents/Traffic%20Engineering%20Manual.pdf	Louisiana DOTD uses 1,300 vphpl.	The designer should consider the following to mitigate delays when lane closures are necessary: 1. Alternate route plan 2. Limit lane closures to off-peak weeknights and weekends 3. Limit maximum physical length of lane closure 4. Maintain existing number of lanes with lane narrowing and lane shifts 5. Merge left before a lane closure 6. Public information program identifying alternate routes through press releases

Oklahoma Department of Transportation (ODOT)	ODOT uses a lane rental specification.	ODOT does not use a minimum flow; typically, a lane rental is applied to interstates and other very high capacity U.S. or state highway facility.	ODOT uses incentive/disincentive to expedite finishing time and shorten the work zone duration.
Kentucky Transportation Cabinet	Although Kentucky does not have a formal document on lane closures, the state requires more time to develop a traffic management plan if the project is significant.	Kentucky uses a program created by the Kentucky Transportation Center based on the FHWA Work Zone Guide. For long-term work zones, 1,250 vphpl is used, and for short-term work zones, 1,000 vphpl is used.	Currently, Kentucky only specifies time periods for which work can be done. The use of a zipper merge has been discussed but has not been utilized.
Idaho Transportation Department (ITD)	ITD does not have a policy regarding the closure of lanes, and decisions are made on a project-by-project basis.	ITD does not use a minimum flow rate at this time.	ITD specifies that lane closures must meet requirements of MUTCD part 6, and a maximum delay is typically allotted to contractors.
Indiana Department of Transportation (INDOT)	INDOT has a policy for closing a lane and a webpage devoted to the policy. https://secure.in.gov/indot/3383.htm	The minimum flow rate depends on the number of existing lanes, lane width, and the number of lanes closed. Details can be found in the previously mentioned policy.	INDOT allows for a 10 percent increase in capacity when no work is occurring. For short-term work zones, INDOT tries to schedule work during off-peak hours to avoid queues.

Chapter 3 - Methodology

3.1 Lane Closure Guide

KDOT developed the current lane closure guide to assist KDOT design and construction engineers, consultants, and contractors when determining if a lane on a multi-lane divided highway can be closed for temporary or mobile work zones. The KDOT lane closure guide includes most interstates, U.S. highways, and Kansas highways in major cities (e.g., Wichita, Topeka, Lawrence, Manhattan) and the metropolitan area of Kansas City. The purpose of the current KDOT lane closure guide is to prevent temporary work zone lane closures from adversely affecting traffic flow by reducing available capacity during peak hours of the day, thus creating congestion that results in travel time delay. Figure 4 shows the general form of the KDOT lane closure guide, a Microsoft Access file that can be downloaded from the KDOT website.

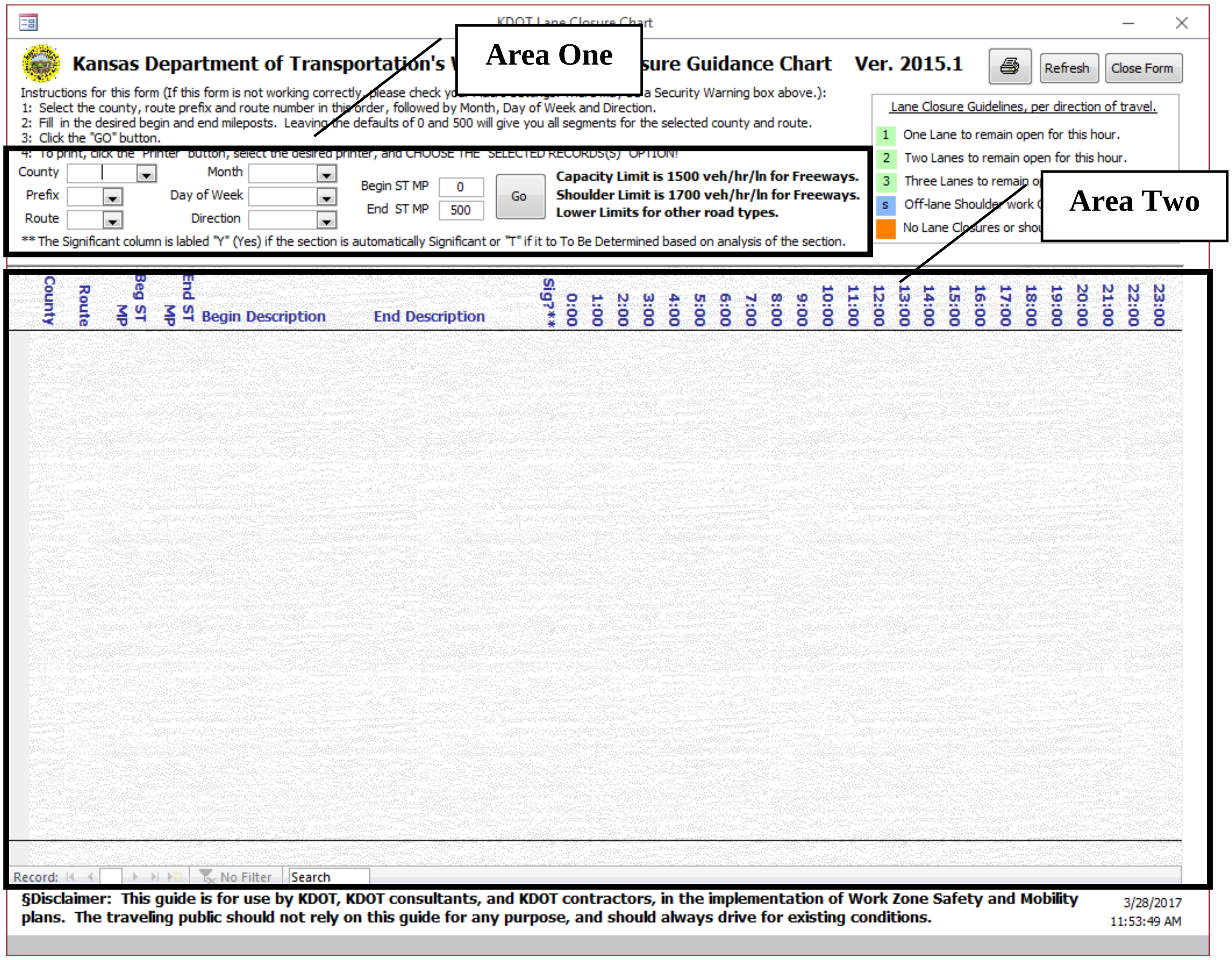


Figure 4 KDOT Lane Closure Guide

As shown in Figure 4, the KDOT lane closure guide has two main areas for the user to view. The first area (Area One) contains input and general information, and the second area (Area Two) contains output. The input area includes instructions for using the lane closure guide, user-selected drop-down menus for identifying counties, roadways (e.g., interstates, U.S. highways, state highways), months, days of the week, direction of travel and general information regarding KDOT-specified lane capacities for freeways.

When using the KDOT lane closure guide a user must first define basic information about the roadway with the potential lane closure, including the possibility of providing lateral space for workers and equipment. The user must also select the county (e.g., Douglas, Geary, Johnson, Riley, Sedgwick, Shawnee, or Wyandotte) where the temporary work zone will occur. Based on the county selected, the user must select the prefix for the interstate or highway in question (e.g., “I” for interstates, “K” for Kansas highways, and “U” for U.S. highways). As stated, arterial roadways and local roads are not included in the lane closure guide and therefore may not be selected by the user. Once the user selects an interstate or highway prefix, then a specific route can be selected. For example, Figure 5 shows the selection of I-70 in Wyandotte County. When a user has selected a roadway, then the month of the year, the day of week, and the direction of travel must be selected, as shown in Figure 6.

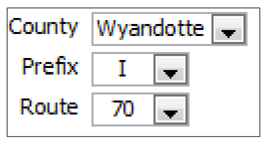


Figure 5 Example of I-70 in Wyandotte County

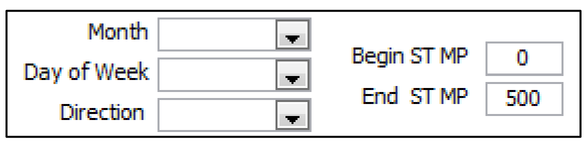
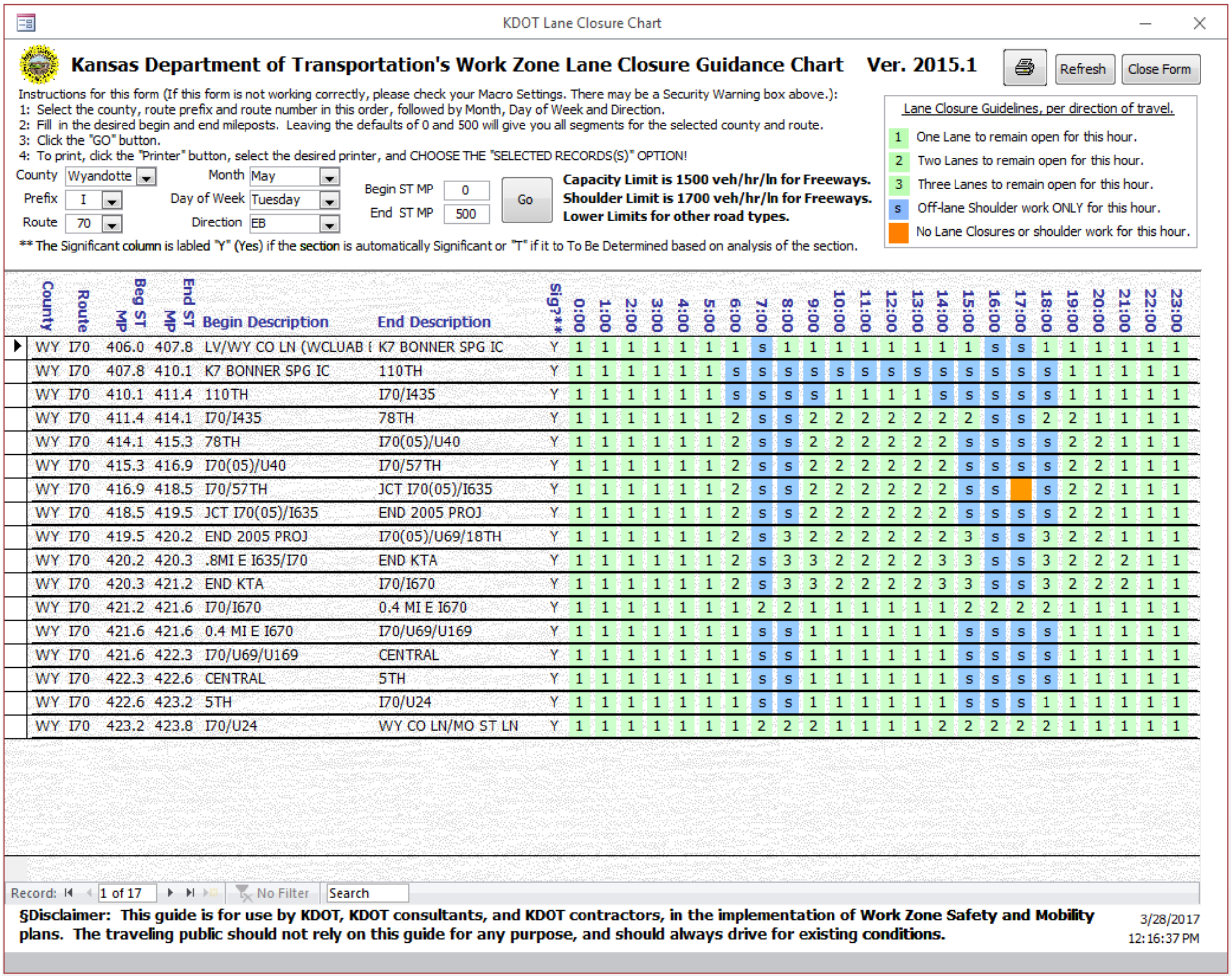


Figure 6 Month, Day of Week, Direction, and Milepost Selection

As shown in Figure 6, the combination of time variables applies various adjustment factors based on vehicle count data collected from the selected roadway. If a temporary work zone is planned for a project-defined segment of highway, a beginning milepost and an ending milepost can also be selected. However, if mileposts are left unselected, a default value of zero for the beginning milepost and 500 for the ending milepost will automatically be selected, meaning that the chart returns all available segments for the selected road within the selected county.

Once the user has selected all variables needed to evaluate a segment of roadway, the macro can be executed by selecting “Go,” as shown in Figure 4. Results of the program analysis display the county abbreviation, route, beginning and end mileposts, beginning and end descriptions, and hour segments representing times during the day, as shown in Figure 7.



KDOT Lane Closure Chart

Kansas Department of Transportation's Work Zone Lane Closure Guidance Chart Ver. 2015.1

Refresh | Close Form

Instructions for this form (If this form is not working correctly, please check your Macro Settings. There may be a Security Warning box above.):
1: Select the county, route prefix and route number in this order, followed by Month, Day of Week and Direction.
2: Fill in the desired begin and end mileposts. Leaving the defaults of 0 and 500 will give you all segments for the selected county and route.
3: Click the "GO" button.
4: To print, click the "Printer" button, select the desired printer, and CHOOSE THE "SELECTED RECORDS(S)" OPTION!

County: Wyandotte | Month: May | Prefix: I | Day of Week: Tuesday | Route: 70 | Direction: EB | Begin ST MP: 0 | End ST MP: 500 | Go

Capacity Limit is 1500 veh/hr/ln for Freeways.
Shoulder Limit is 1700 veh/hr/ln for Freeways.
Lower Limits for other road types.

Lane Closure Guidelines, per direction of travel.
1 One Lane to remain open for this hour.
2 Two Lanes to remain open for this hour.
3 Three Lanes to remain open for this hour.
s Off-lane Shoulder work ONLY for this hour.
No Lane Closures or shoulder work for this hour.

** The Significant column is labled "Y" (Yes) if the section is automatically Significant or "T" if it to To Be Determined based on analysis of the section.

County	Route	Beg ST MP	End ST MP	Begin Description	End Description	Sig?**	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
WY	I70	406.0	407.8	LV/WY CO LN (WCLUAB I	K7 BONNER SPG IC	Y	1	1	1	1	1	1	1	s	1	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1
WY	I70	407.8	410.1	K7 BONNER SPG IC	110TH	Y	1	1	1	1	1	1	s	s	s	s	s	s	s	s	s	s	s	s	s	1	1	1	1	1
WY	I70	410.1	411.4	110TH	I70/I435	Y	1	1	1	1	1	1	s	s	s	s	1	1	1	1	s	s	s	s	s	1	1	1	1	1
WY	I70	411.4	414.1	I70/I435	78TH	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	2	s	s	2	2	1	1	1	1
WY	I70	414.1	415.3	78TH	I70(05)/U40	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s	s	s	2	2	1	1	1
WY	I70	415.3	416.9	I70(05)/U40	I70/57TH	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s	s	s	2	2	1	1	1
WY	I70	416.9	418.5	I70/57TH	JCT I70(05)/I635	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s		s	2	2	1	1	1
WY	I70	418.5	419.5	JCT I70(05)/I635	END 2005 PROJ	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s	s	s	2	2	1	1	1
WY	I70	419.5	420.2	END 2005 PROJ	I70(05)/U69/18TH	Y	1	1	1	1	1	1	2	s	3	2	2	2	2	2	2	3	s	s	3	2	2	1	1	1
WY	I70	420.2	420.3	.8MI E I635/I70	END KTA	Y	1	1	1	1	1	1	2	s	3	3	2	2	2	2	3	3	s	s	3	2	2	2	1	1
WY	I70	420.3	421.2	END KTA	I70/I670	Y	1	1	1	1	1	1	2	s	3	3	2	2	2	2	3	3	s	s	3	2	2	2	1	1
WY	I70	421.2	421.6	I70/I670	0.4 MI E I670	Y	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	2	2	2	2	1	1	1	1	1
WY	I70	421.6	421.6	0.4 MI E I670	I70/U69/U169	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	s	1	1	1	1	1
WY	I70	421.6	422.3	I70/U69/U169	CENTRAL	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	s	1	1	1	1	1
WY	I70	422.3	422.6	CENTRAL	5TH	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	s	1	1	1	1	1
WY	I70	422.6	423.2	5TH	I70/U24	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	1	1	1	1	1	1
WY	I70	423.2	423.8	I70/U24	WY CO LN/MO ST LN	Y	1	1	1	1	1	1	1	2	2	2	1	1	1	1	2	2	2	2	2	1	1	1	1	1

Record: 1 of 17 | No Filter | Search

§Disclaimer: This guide is for use by KDOT, KDOT consultants, and KDOT contractors, in the implementation of Work Zone Safety and Mobility plans. The traveling public should not rely on this guide for any purpose, and should always drive for existing conditions.

3/28/2017 12:16:37 PM

Figure 7 Example Display for I-70 in Wyandotte County

Figure 7 shows an executed search when a user selected eastbound I-70 in Wyandotte County on a Tuesday in May. Because the user did not define a start and ending milepost, default values of 0 and 500 were used. Each row of text represents a defined segment of the roadway, or a section of roadway between two landmarks (e.g., existing interstate interchanges) on the roadway. For example, the first line displays the segment between milepost 406.0 and milepost 407.8 on I-70. Milepost 406.0 corresponds with the start of Wyandotte County, Kansas, and milepost 407.8 corresponds with the interchange of K-7 near Bonner Springs, Kansas. The displayed roadway segments total approximately 17.8 miles.

The top right section of the chart (Figure 7) shows the guidelines for closing a lane for each roadway segment (row of information). Each roadway segment includes colored boxes that correspond to the time of day based on 24 hours. Each box could be one of three possible colors: green, blue, or orange. The green box represents a one-hour period in which a lane may be closed. The green box also contains a number that represents the total number of lanes required to be open if a work zone requires a lane closure. If the box is blue, off-lane shoulder work only can be performed (or further out). An orange box means no work is permitted on the roadway or shoulder during that hour.

As shown in the first row of Figure 7, the roadway section (row 1) between mileposts 406.0 and 407.8, a segment of divided highway with two travel lanes in each direction, indicates that one lane must be open between the hours of midnight and 7:00 a.m., as represented by the "1" inside the green box. For the same roadway segment, only shoulder work may be performed for one hour starting at 7:00 a.m. However, at 8:00 a.m., one lane must remain open. Given another roadway (line 4) in Figure 7, a segment with three lanes in both directions beginning at milepost 411.4 and ending at milepost 414.1, user-defined inputs show that this segment requires two lanes to be open during most daylight hours, as demonstrated by green boxes with a value of 2. Line 7 of Figure 7 contains an orange box starting at 5:00 p.m., indicating to the user that no work zone activity may be performed for this hour and all lanes must remain open. However, starting at 6:00 p.m., off-lane work may be performed while maintaining a lane capacity of 1,500 pcphpl.

3.2 Lane Closure Guide Data

The user interface described in the previous section queries multiple data tables within the file based on user-defined parameters (e.g., county, roadway, milepost, etc.). An example of background data files within the Access file is shown in Figure 8.

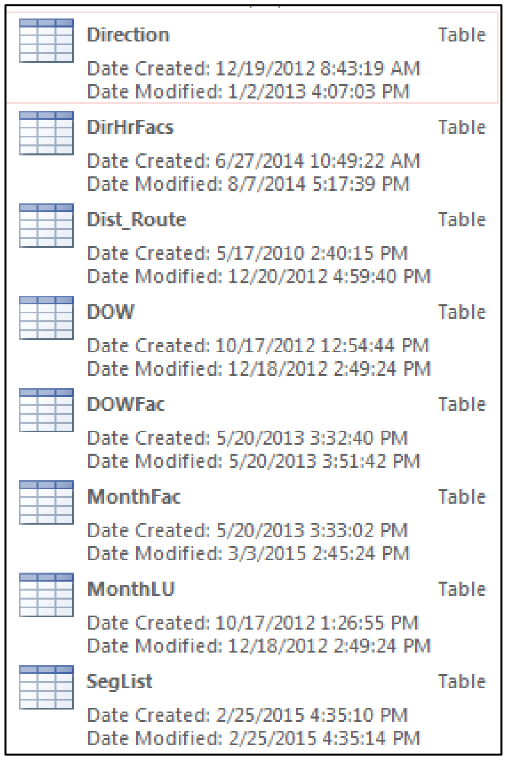


Figure 8 Tables Used Within the Lane Closure Guide

As shown in Figure 8, multiple data files are used within the lane closure chart. The county table (not shown in Figure 8) correlates a county number to the Kansas county name. For example, Douglas County, Kansas, was county number 23. The direction table (Direction in Figure 8) assigns a numerical value to a direction: a value of 1 for northbound, a value of 2 for eastbound, a value of 3 for southbound, and a value of 4 for westbound. The day of the week table (DOW file in Figure 8) assigns a numerical value to each day of the week. A value of 1 is assigned to Sunday, increasing to a value of 7 for Saturday. The month file (MonthFac in Figure 8) assigns a numerical value to each month. For example, a value of 1 is assigned to January and a value of 12 is assigned to December. Additionally, three other values are assigned in the MonthFac table, including a value of 13 for an average value of the months May through October and a value of 14 for an average value of the months November through April. A value of 15 was used for a year-long average (January through December).

The Microsoft Access file also contains two tables that correlate information in the Dist_Route and SegList tables. The Dist_Route table creates each route used within the lane closure guide and then assigns a prefix (e.g., “I” for interstate, “K” for Kansas highway, and “U” for U.S. highway) depending on the type of highway. The route is also assigned a direction and county number. For example, Route 10 would be assigned a “K” for a Kansas highway, a direction of EB, and a county number of 23. If a route exists within multiple counties, multiple entries are used for each route with differing county numbers.

The SegList table creates the segmentation for each route in the lane closure guide and assigns key information used for the query and subsequent calculations for each segment. Information used with the query includes beginning and ending milepost, county number, and direction indicator. The information used within each segment to calculate the total number of lanes required to be open includes the number of lanes, two-way volume, lane volume and shoulder volume, and destination of factors applied (e.g., month, day of week, direction/hour).

Each segment along a highway shows a different color box depending on how many lanes must remain open during a temporary work zone project. For this research project, each highway segment was assigned average annual daily traffic (AADT), defined as the average total number of cars traveling in both directions on that segment. AADT used in the KDOT lane closure guide was collected from various traffic data collection devices (manual counts, pneumatic road tubes, inductive loops, smart work zone devices, etc.) from KDOT traffic studies performed every five years. Several factors were applied to the AADT to determine highway segment hourly flow characteristics. Day of the week and month of the year factors were determined from KDOT-placed automated traffic recorders (ATR) for each highway in the Kansas City metro area, as shown in Figure 9.

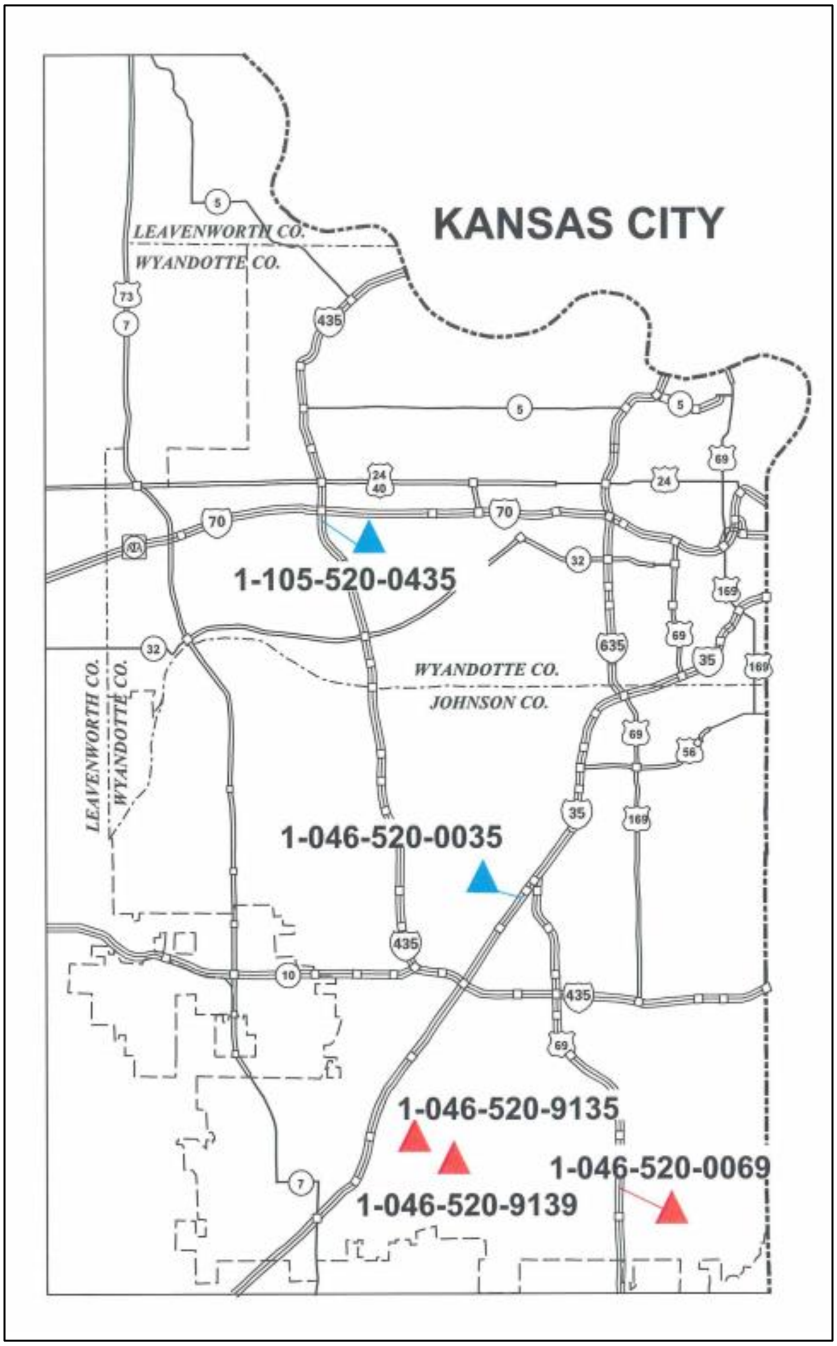


Figure 9 ATR Locations in Kansas City,
Kansas (Kansas Department of Transportation, 2007)

Factors were applied to the vehicle data for each highway segment. The first applied factor was a directional factor for each hour of the day. For example, on an unspecified highway, 56 percent of vehicles were traveling in the eastbound direction at 6:00 a.m., resulting in a factor of 0.56 being applied to the known AADT for the highway segment in the eastbound direction of travel. Additionally, a 0.44 factor (or 44 percent) was applied to the AADT for the westbound direction at 6:00 a.m. only. The westbound directional split could increase from 44 percent to 47 percent for the same highway segment during the 6:00 p.m. hour, resulting in a 0.53 factor (or 53 percent) assigned to the eastbound direction of travel. If the directional traffic split was unknown, a constant split value between 0.55 and 0.65 was used, depending on the type of highway, and applied to all hours of the day.

In addition to the directional split for a highway segment, a “k” factor was applied to each highway segment to determine the hourly percentage of traffic during a specific time based on the AADT. The “k” factor was a numerical value based on a scale of 0 to 100 percent of the AADT during that hour. For example, on an unspecified highway segment at 2:00 a.m., approximately 2 percent of the total AADT for that section was traveling. Therefore, the resulting “k” factor would be 0.02 for that hour.

The next two factors applied to an unspecified highway segment included the day of the week factor and the month factor. These two factors were determined by dividing the average daily traffic (ADT) for a period (such as ADT of all Wednesdays or ADT of all the days in January) with the AADT, as shown in Equations 1 and 2. For example, if the ADT for Friday was 82,000 and the AADT was 74,000, the day of week factor would be 1.11.

$$Month\ Factor = \frac{ADT\ (Month)}{AADT} \qquad \textbf{Eq. 1}$$

$$Day\ of\ the\ week\ factor = \frac{ADT\ (Day)}{AADT} \qquad \textbf{Eq. 2}$$

Once all the previously described factors were applied, a numerical value for the number of vehicles during the hour was determined. The determined values for the dataset, which ranged from approximately 1,000 to 6,000 vph, were used to determine how many lanes of traffic must remain open for the specified highway segment during the hour when a temporary work zone is in place. KDOT uses two capacity values to determine the number of lanes required to be open during a temporary work zone: 1,500 vphpl for work zones involving lane closure and 1700 vphpl for a work zone that does not require lane closure. For example, if two lanes run in one direction on a divided highway and one lane is shut down, the expected capacity of the open lane would be 1,500 vphpl; however, if both lanes are open and work is done on the shoulder, each lane would have a capacity of 1,700 vphpl.

The number of lanes required to be open was found by taking the number of vehicles per hour (vph) and dividing by 1,500 vphpl, as shown in Eq. 3. The resulting number was then rounded up. For example, if 3,300 vehicles were recorded during one hour, the total number of lanes required to be open would be 2.2, rounded up to three, indicating that three lanes must be open if a lane is closed (applicable only to highways with four or more lanes in one direction).

$$Number\ of\ Lanes\ Required\ to\ be\ Open = \frac{Vehicles\ Per\ Hour}{1{,}500\ vphpl} \qquad \textbf{Eq. 3}$$

However, if the portion of highway only has two lanes in the direction where work is being completed, no lane closures would be allowed during that hour. In order to determine if work not requiring a lane closure could be done, the 3,300 vph would then be divided by 1,700 vphpl, as shown in Eq. 4.

$$Number\ of\ Lanes\ Required\ to\ be\ Open = \frac{Vehicles\ Per\ Hour}{1{,}700\ vphpl} \quad \textbf{Eq. 4}$$

If a temporary work zone was set up on the shoulder of a specified highway segment (with two travel lanes in each direction and an hourly volume of 3,300 vehicles), a minimum of 1.94 lanes would be required to remain open, which rounds up to 2. Results from the output from the lane closure guide would show that work could be done on the shoulder without causing disruption to traffic. If the number of vehicles on a specified highway segment were to increase greater than 3,400 vph, however, no work may be done during that hour.

3.3 Kansas City Scout

The Kansas City Traffic Management Center (KC Scout) is a centralized network of data collection sensors and cameras connected via fiber optic cable. KC Scout was developed by a joint venture between the Missouri Department of Transportation (MoDOT) and KDOT to centrally control and monitor traffic around the Kansas City metropolitan area. Yearly funds from both state departments of transportation are used to staff the traffic management center as well as for equipment maintenance and upgrades. Similar to other traffic management centers around the United States, KC Scout is primarily used for incident management for events that cause non-reoccurring congestion.

KC Scout utilizes two types of technology to monitor and collect vehicular data: in-pavement counters and Wavetronixs sensors. In-pavement counters, as shown in Figure 10, are permanent inductive loops placed within the roadway pavement using a saw cut with wires extending to a counter on the side of the roadway. An inductive loop detects vehicles by monitoring for a change in resonance frequency (Marsh Products, 2000). Additionally, inductive loops are required for each lane of travel to determine the occupancy and volumetric data. Inductive loop sensors are typically located under bridges to avoid interference from weather, but over time these sensors may be susceptible to roadway rutting and snow plows. KC Scout has placed inductive loop sensors at limited number of locations.

Figure 10 Example of Inductive Loop (Smyth, 2015)

KC Scout primarily collects vehicle data using Wavetronix sensors, which are a multi-lane radar sensors typically mounted on a pole outside of a highway clear zone or in a protected area in the median. In addition to Wavetronix sensors, KC Scout often installs pan tilt zoom (PTZ) cameras to view roadway segments monitored by Wavetronix sensors. A single pole with a PTZ camera typically has one or two sensors. One sensor is used if the roadway has a small-width median or if the concrete barrier does not obstruct the inside lane. A second sensor is used with wide medians or if a concrete barrier obstructs the inside lane from the other side of the roadway. KC Scout manually configures radar units to identify roadway lanes and remove background interference such as traffic traveling above or below the highway on which the Wavetronix is programmed to collect data (e.g., highway interchanges). Wavetronix sensors are also able to identify vehicle types as specified by the Federal Highway Administration's

(FHWA) classification of vehicles. A KC Scout Wavetronix sensor on a pole is shown in Figure 11.

Figure 11 A Wavetronix Sensor Located at K-10 and Woodland

KC Scout traffic sensors (inductive loops and Wavetronix) collect highway data such as lane occupancy (percentage of time a vehicle is within sensor presence), average speed of vehicles during specific time interval, and volume of the roadway (total number of cars during specific time intervals). Sensor data is relayed to the KC Scout traffic management center building located in Lee's Summit, Missouri, every 30 seconds, and data are shown in real-time to KC Scout operators and highway patrol officers. The data are also archieved for historical data retrieval. The process to access KC Scout data is explained later in this report. KC Scout also regularly verifies sensor data accuracy, and MoDOT and KDOT have access to the KC Scout system at their respective headquarters as well as district offices located in the Kansas City metropolitan area.

3.4 Determination of Highways to Update

The current KDOT lane closure guide and KC Scout data coverage map were used to determine which highways to investigate for this research project. Table 2 shows the highways covered by the existing lane closure guide and KC Scout with total route miles.

Table 2 Highways Covered by the Existing Lane Closure Guide and KC Scout

Roads Covered in Lane Closure Guide	Roads with KC Scout Coverage	Route Miles
I-35	I-35	33.4
I-435	I-435	28.0
I-635	I-635	8.9
I-70	I-70	17.8
I-670	I-670	1.6
K-10	K-10	16.4
US-69	US-69	9.3
US-56	N/A	2.4

Figure 12 shows the current sensor coverage map for KC Scout as of 2016, which corresponds to highways and mileage shown in Table 2. Figure 12 also shows sensor locations in Missouri.

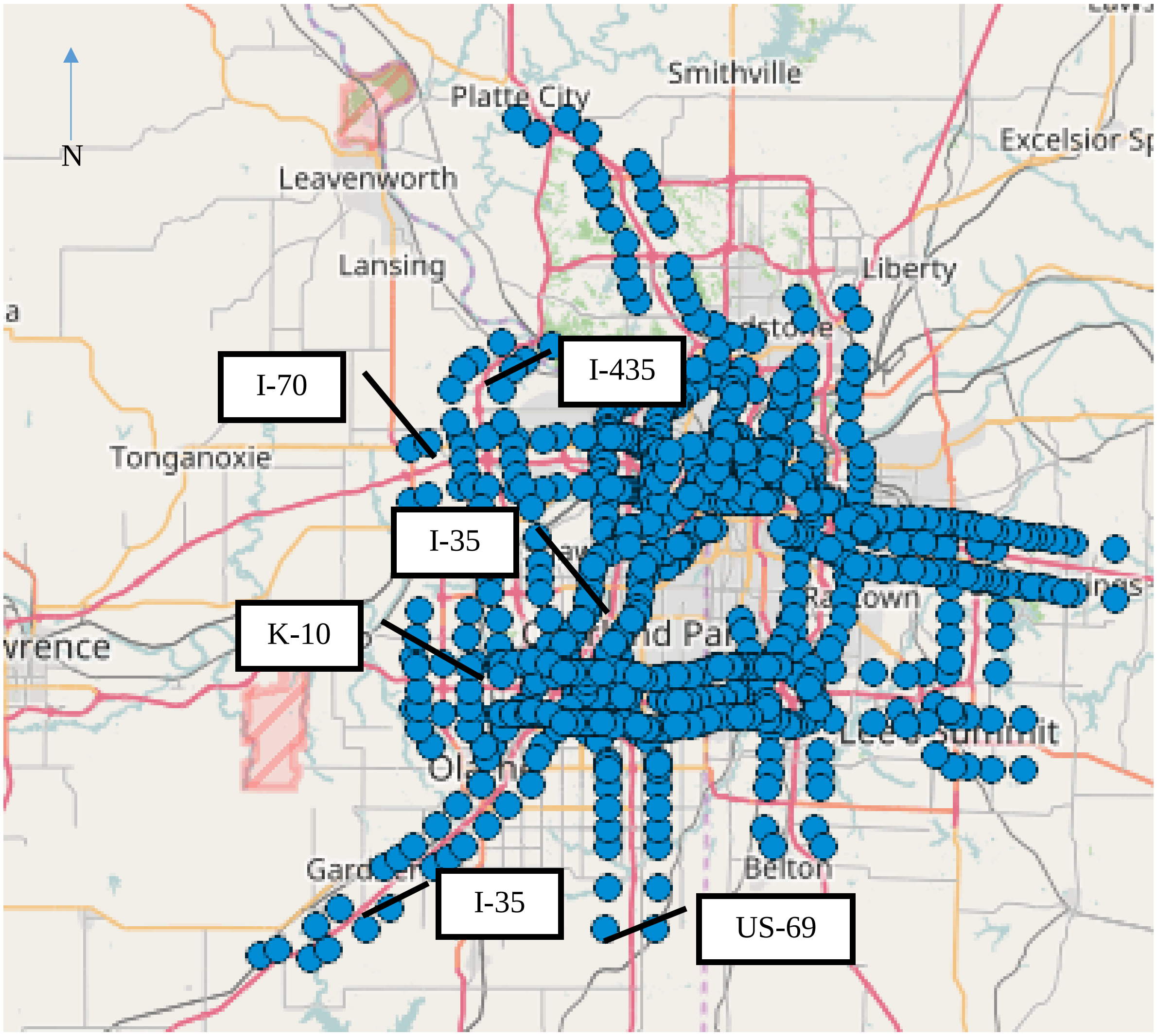


Figure 12 Sensor Locations in the Kansas City Area

All Kansas highways covered by the existing lane closure guide were selected to be updated with KC Scout data except for US-56. Using the KDOT lane closure guide as a starting point, each highway route was divided into segments, which were defined as the distances between interchanges on the highway route. Interchanges were used as the main basis for separating segments since interchanges are easily identifiable landmarks for KDOT personnel and contractors without requiring specific mileposts and the influence of interchanges. Because vehicles enter and exit highways at interchanges, each segment between interchanges could experience a significant difference in traffic volumes as compared to the segment upstream and downstream. Study results showed that segment lengths varied from 0.5 miles to 3 miles depending on interchange spacing and available sensors at and/or between interchanges. Segments were also defined at or between interchanges when the highway added or dropped lanes of travel. For example, on I-35 at 75th Street the number of lanes decreases from four to three under the interchange, as shown in Figure 13.

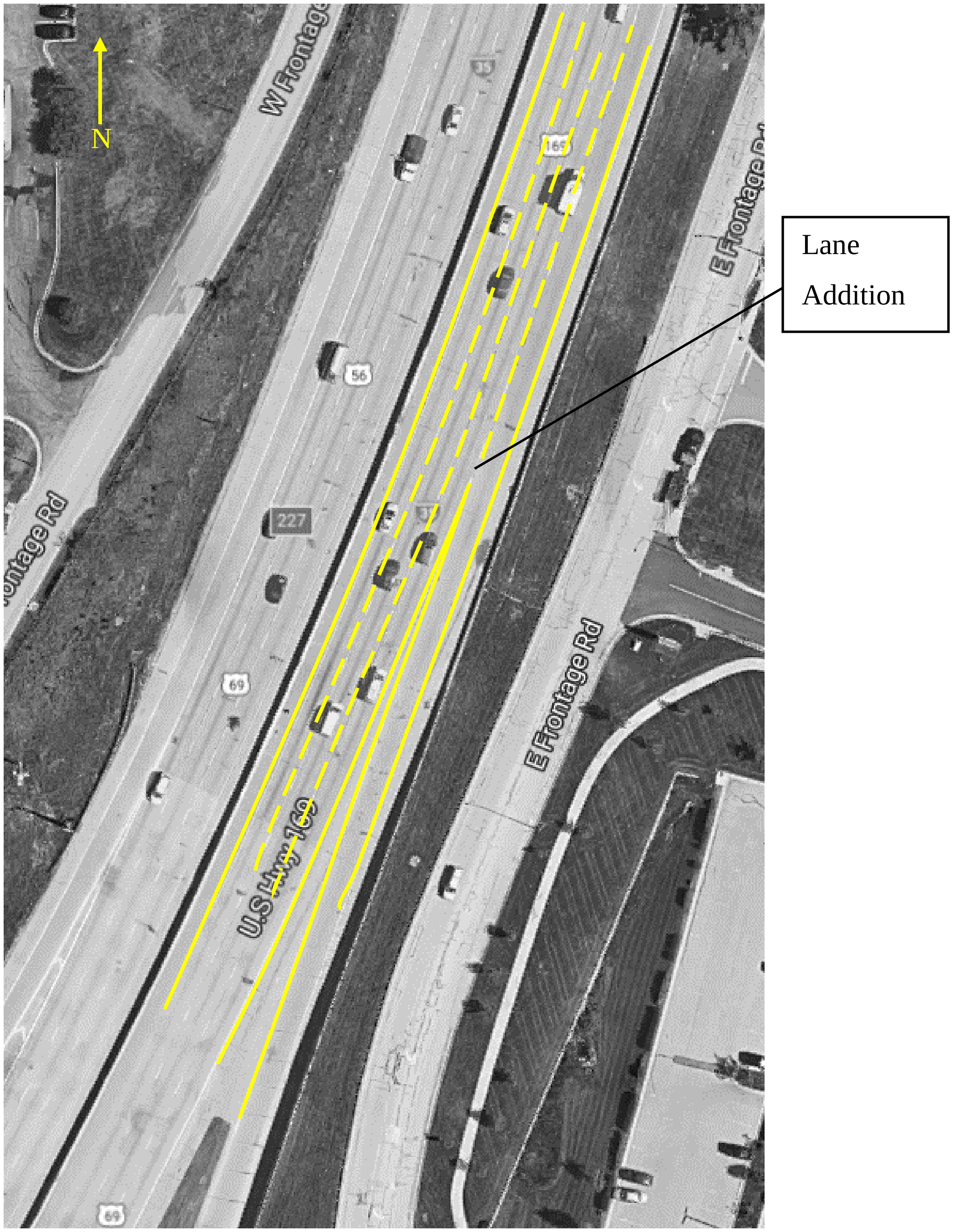


Figure 13 Interchange of I-35 and 75th Street with Lane Drops and Additions (Google Maps, 2017)

After each highway route was identified and classified into segments, a starting segment or milepost was defined based on an adjacent sensor location. For example, the starting location of I-35, which runs north and south through the Kansas City metropolitan area, was at the Miami/Johnson county line at the southernmost point of the KC Scout data coverage area.

Furthermore, I-435, an interstate beltway circling the Kansas City metropolitan area, had a starting location on the east side at the Missouri/Kansas state line, as shown in Figure 14 and Figure 15.

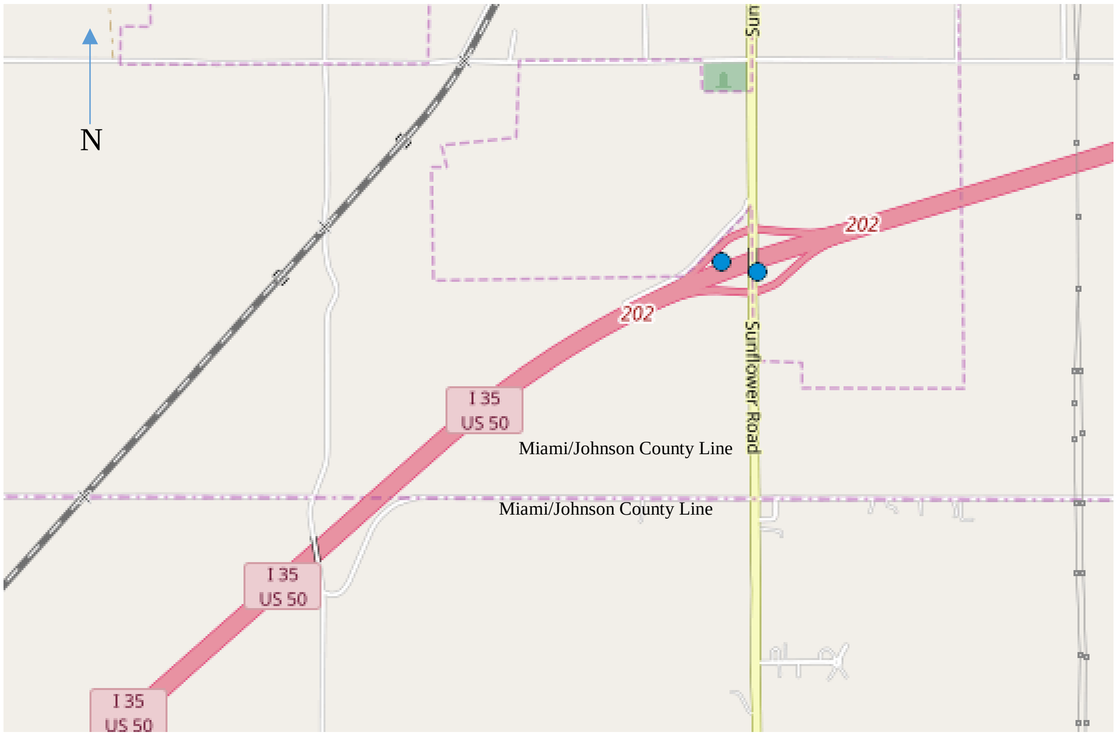


Figure 14 Selected Sensors for the First Segment of I-35 from the Miami/Johnson County Line and Sunflower Road (Kansas City Scout, 2017)

Once a starting location was established for a specific highway route, a KC Scout sensor within the identified segment was selected for both directions of travel. The KC Scout sensor was typically found at the beginning of the segment very close to the interchange. However, the research team found instances where the KC Scout sensor was closer to the end of the segment near the next interchange.

The process for identifying KC Scout sensors on highway route segments was repeated for each roadway segment in both directions. A single segment consisted of travel in both directions (e.g., north and south, east and west), and each segment had one sensor for each direction of travel (i.e., two sensors). However, if multiple sensors were present in one segment for each direction of travel, two criteria were used to identify and select which KC Scout sensor was most appropriate for data extraction. The two criteria were data availability and sensor location. An example of criteria application to the data extraction process is shown in Figure 15.

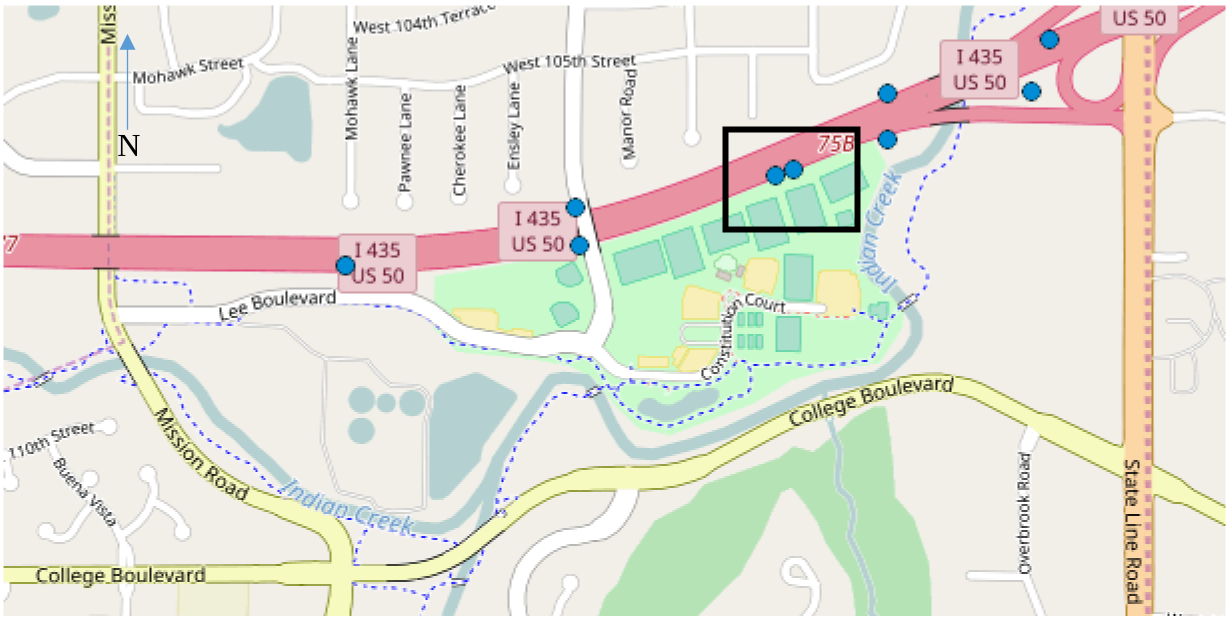


Figure 15 Multiple Sensors on One Segment of I-435 between State Line Road and Mission Road (Kansas City Scout, 2017)

Figure 15 shows a segment of I-435 in Johnson County, Kansas, between State Line Road and Mission Road. As shown by the blue circles, approximately nine KC Scout sensors were identified within the segment. The data extraction method described in Chapter 3 revealed that only two of the KC Scout sensors (identified within the box) recorded data after 2013 and that limited sensors were removed due to roadway infrastructure projects or replaced with new equipment.

The second criteria used to identify a KC Scout sensor in a specific segment was sensor location. The preferred physical location of a single KC Scout sensor within a segment was between two interchanges or lane add/drops. The research team asserted that sensor location in the middle of a segment allows traffic to stabilize and prevents the influence of merging vehicles from on- and off-ramps. However, sensor selection priority was given to criteria one (data availability) because only the most recent KC Scout sensor data were used to update the KDOT lane closure guide. The two KC Scout sensors within the box in Figure 15 were selected because 2016 data were available; the sensors were located approximately in the middle of the segment.

Data-critical coverage gaps were identified throughout the KC Scout identification process. A data coverage gap was defined as an area with no sensors or limited or no recent available data. The first data coverage gap was identified near the center of Kansas City on I-70 near the Missouri state line, as shown in Figure 16.

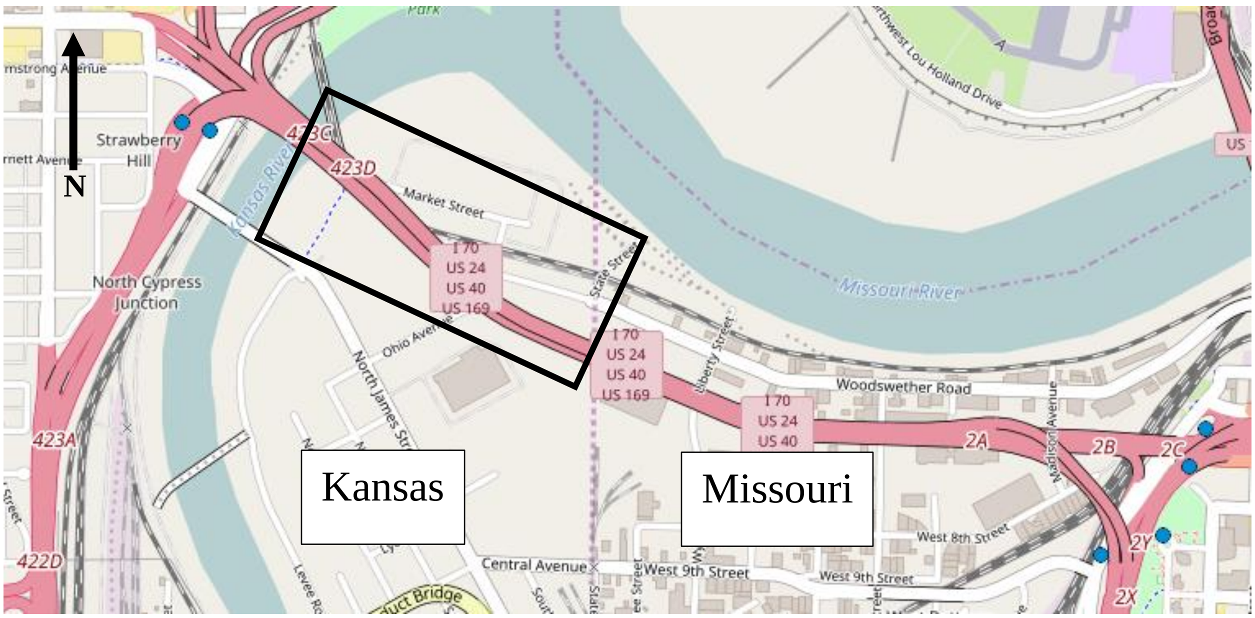


Figure 16 I-70 Location with a Gap in Data Coverage (Kansas City Scout, 2017)

The box in Figure 16 illustrates a section of I-70 that did not have nearby sensors; the KC Scout sensors to the east were located in a dense urban area where three highways converged.

Another gap in data coverage occurred at the Gateway Project, a large construction project conducted during 2016 at the interchange of I-435, I-35, and K-10 in Overland Park, Kansas (Figure 17). The largest portion of work was completed on I-435, ranging from the interchange of I-435 and US-69 to the interchange of I-435 and 95th Street. Sensors on I-435 were removed during construction and then reinstalled later, resulting in insufficient available data for I-435 in 2016 and several previous years. Because a full year's (2016) worth of data was required to update the lane closure guide, this section of roadway was not updated.

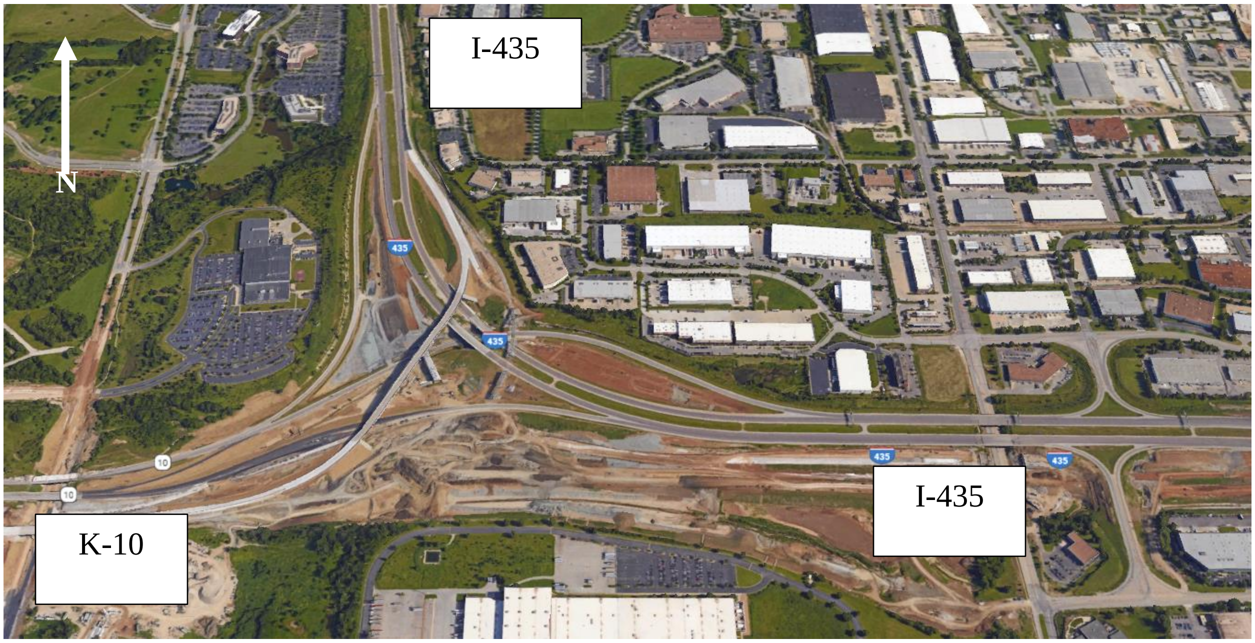


Figure 17 Google Maps Image of Gateway Project Construction (Google Maps, 2017)

Other identified areas with gaps in data coverage occurred on I-70 before the interchange of K-7 and on K-10 near the interchange of I-435. The I-70 gap occurred on the first segment of the lane closure guide. The sensor selected for the first segment stopped collecting data in 2013, thereby preventing the sensor from being used to update the lane closure guide. Therefore, the sensor located at the interchange of I-70 and K-7 was used for both the before and after segments of the roadway. The other gap in data coverage occurred because of the sensor location on the eastbound direction of K-10 at the interchange with I-435. At this interchange, eastbound K-10 splits into separate ramps for northbound and southbound I-435, and the sensors for this segment are located at the beginning of each ramp. The use of only one sensor before the split accounted for only half of the traffic information, so data from both sensors were added together to achieve an accurate traffic count in that area.

3.5 Data Extraction

Although the KDOT lane closure guide contains information for communities outside of the Kansas City metropolitan area, this research project focused on Kansas City, specifically areas in which KC Scout sensors were located. The research team used KC Scout's online data portal to request and download data from their servers. The secure data portal has a user interface that allows a user to select specific criteria for queries. The first part of the query selected KC Scout sensors to obtain data, as shown in Figure 18.

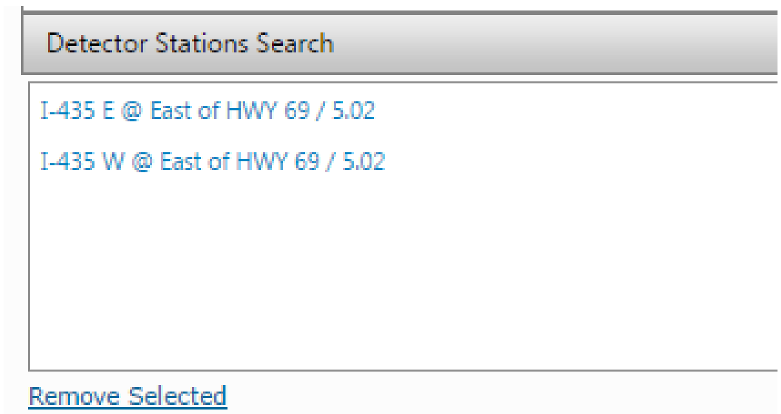


Figure 18 Example Selection of Sensors from the Data Map

Figure 18 lists two sensors, one for east and one for westbound I-435 at US-69. These two sensors appear in this list because they were selected from a Google-based map shown in Figure 12. Once the sensors were selected, the amount of requested data was determined. The user interface allows for selection of a date range such as days of week, start and end time, and the exclusion of holidays, as shown in Figure 19.

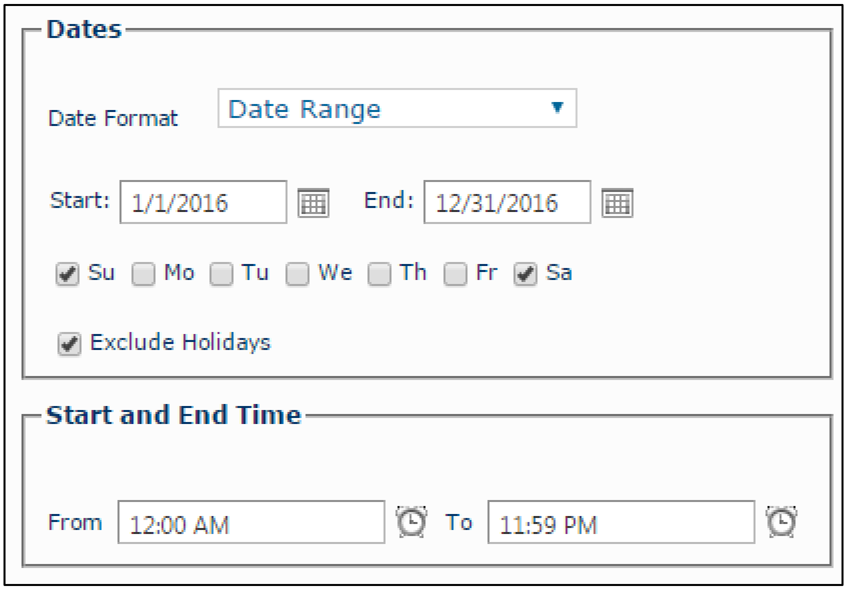


Figure 19 Data Selection User Interface

This research project used four years of traffic data (from 2013 to 2016) to allow for any possible variation in traffic from year to year, KC Scout sensor anomalies, or significant changes in roadway geometry due to new construction or temporary work zones. Data at KC Scout sensor locations were verified by comparing yearly temporal trends to determine if one-year traffic volumes for a specific hour differed widely by several hundred vehicles. After reviewing data from all sensors included in this research project, no anomalies were detected from the selected sensors. However, a significant limitation was found: some KC Scout sensors recorded less than two years of data because a significant portion of KC Scout data coverage expanded after 2013 to include growth of the Kansas City metropolitan area. Figure 20 shows an example of the KC Scout data coverage in 2013.

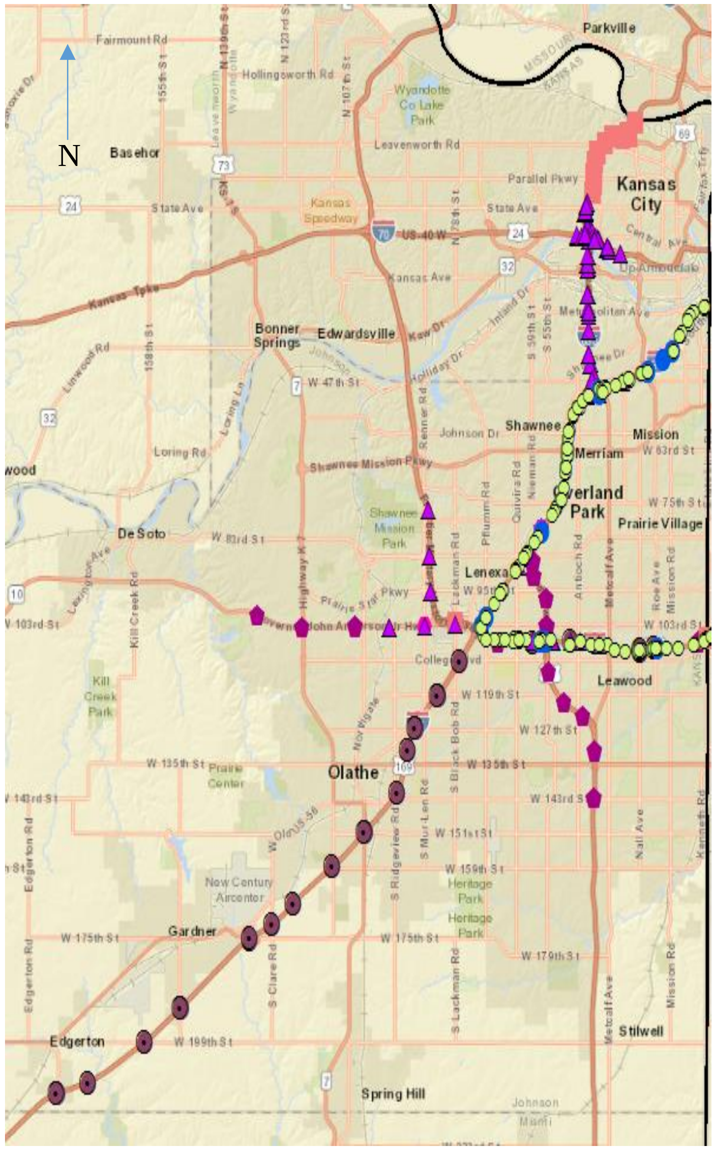


Figure 20 KC Scout Locations in 2013

After consulting with the KDOT project monitors, the research team decided to focus on 2016 data only to update the KDOT lane closure guide. Figure 21 shows the final location of all KC Scout sensors used for this project.

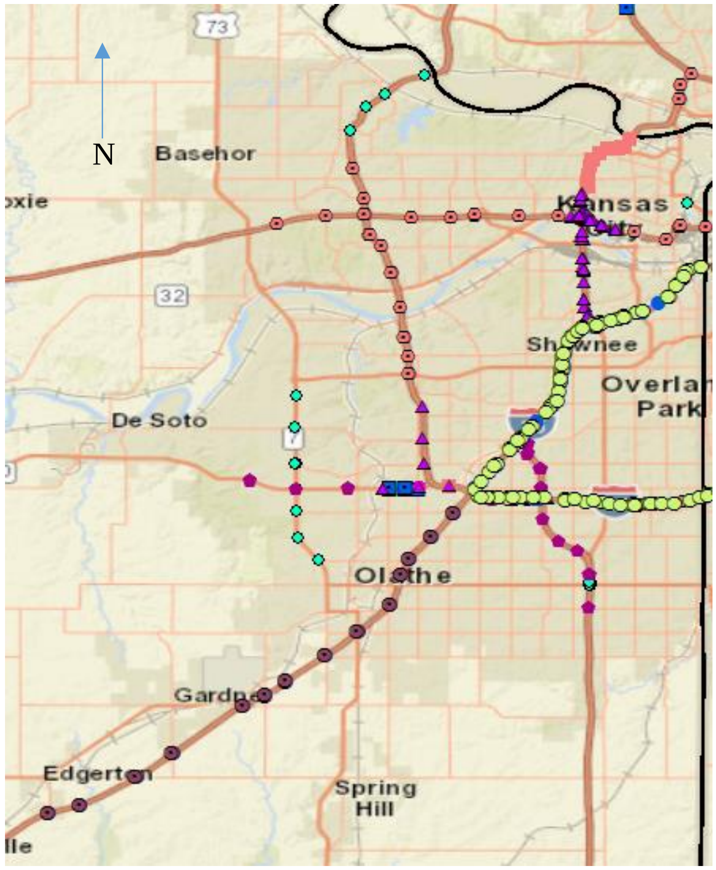


Figure 21 KC Scout Sensor Locations in 2016

As shown in

Figure 23, a total of 154 KC Scout sensors were used for this research project. For each year of data from each KC Scout sensor, two separate categories were defined: weekday (Monday–Friday) and weekend (Saturday and Sunday). Since weekday traffic exhibits the most common flow characteristics (e.g., speed, vph, crash experience, etc.), these days were used to determine the average annual weekday traffic (AAWT). Weekend traffic data were only used to determine traffic characteristics not experienced during the week. Holidays were excluded from the weekday and weekend data sets since holiday traffic characteristics typically differ significantly from weekday traffic characteristics. Data for both weekday and weekend traffic included the hours from 12:00 a.m. to 11:59 p.m. Once information for each KC Scout sensor was selected, an output screen presented options for data extraction, as shown in Figure 22.

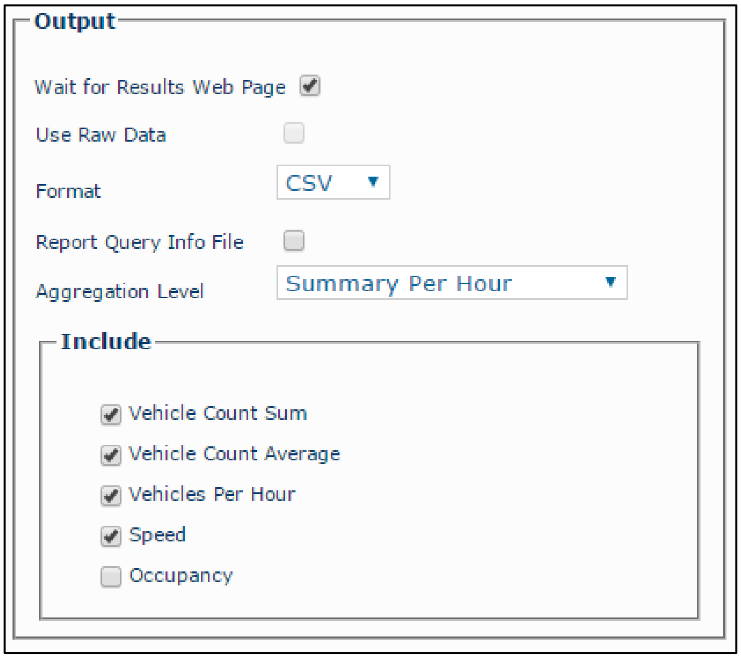


Figure 22 Data output selection

As shown in Figure 22, the output screen allows for the selection of data resolution. First, the data format was chosen, and the .csv file was found to be the most efficient format to use for data analysis in Microsoft Excel. The output screen also allowed raw data extraction, but selection of that option would result in over 20 minutes of delay as the server retrieves the data. The output screen also allows for the extraction of data such as “Vehicle Count Sum,” “Vehicle Count Average,” “Vehicles Per Hour,” “Speed,” and “Occupancy,” as shown in Figure 22. If “Use Raw Data” was selected, over 22 million data points would be extracted for each KC Scout sensor for one year. For the scope of this project, the research team, in coordination with the KDOT project monitors, elected to use aggregated data per hour, which simplified the analysis substantially while providing critical data needed to update the KDOT lane closure guide. The aggregation provided an average for each hour over the entire year for each KC Scout sensor. An example of data extraction of hourly volumes for northbound US-69 at 143rd Street is shown in Table 3.

Table 3 Four-Year Hourly Volumes for US-69 at 143rd Street

Time	2016: Jan–Dec	2015: Jan–Dec	2014: Jan –Dec	2013: Jan–Dec
12:00:00 AM	278	277	277	219
1:00:00 AM	267	264	266	199
2:00:00 AM	279	275	275	210
3:00:00 AM	339	331	332	287
4:00:00 AM	654	617	605	577
5:00:00 AM	1,687	1,627	1,563	1,567
6:00:00 AM	2,690	2,671	2,670	2,711
7:00:00 AM	2,840	2,860	2,807	2,842
8:00:00 AM	2,321	2,271	2,159	2,114
9:00:00 AM	1,905	1,797	1,688	1,648
10:00:00 AM	1,853	1,727	1,612	1,569
11:00:00 AM	1,870	1,727	1,621	1,563
12:00:00 PM	1,778	1,650	1,549	1,499
1:00:00 PM	1,731	1,607	1,516	1,460
2:00:00 PM	1,905	1,767	1,677	1,609
3:00:00 PM	2,038	1,943	1,830	1,770
4:00:00 PM	2,074	1,958	1,869	1,826
5:00:00 PM	1,863	1,748	1,663	1,612
6:00:00 PM	1,373	1,293	1,228	1,169
7:00:00 PM	959	906	865	821
8:00:00 PM	718	686	661	628
9:00:00 PM	541	524	504	481
10:00:00 PM	408	399	388	356
11:00:00 PM	321	314	311	277

As shown in Table 3, four years of hourly volume data were extracted to observe yearly trends within the data and to check for anomalies. Each hour in the table represents the yearly average weekday traffic, excluding holidays. These data were collected from both directions of travel and combined, as shown in Table 4.

Table 4 Directional Hourly Volumes with Calculated AAWT, "k" Factor, and Directional Factor

Begin MP	137.5	End MP	139.6			
Time	Northbound 2016: Jan–Dec	Southbound 2016: Jan–Dec	Both 2016 Jan–Dec	"k" Factor New "k" Factor	Directional Split North	South
12:00:00 AM	278	313	591	0.009	0.47	0.53
1:00:00 AM	267	278	545	0.0083	0.49	0.51
2:00:00 AM	279	271	550	0.0084	0.51	0.49
3:00:00 AM	339	283	622	0.0095	0.55	0.45
4:00:00 AM	654	393	1,047	0.0159	0.62	0.38
5:00:00 AM	1,687	831	2,518	0.0384	0.67	0.33
6:00:00 AM	2,690	1,345	4,035	0.0616	0.67	0.33
7:00:00 AM	2,840	1,545	4,385	0.0669	0.65	0.35
8:00:00 AM	2,321	1,405	3,726	0.0569	0.62	0.38
9:00:00 AM	1,905	1,375	3,280	0.0501	0.58	0.42
10:00:00 AM	1,853	1,537	3,390	0.0517	0.55	0.45
11:00:00 AM	1,870	1,735	3,605	0.055	0.52	0.48
12:00:00 PM	1,778	1,847	3,625	0.0553	0.49	0.51
1:00:00 PM	1,731	2,009	3,740	0.0571	0.46	0.54
2:00:00 PM	1,905	2,464	4,369	0.0667	0.44	0.56
3:00:00 PM	2,038	3,086	5,124	0.0782	0.40	0.60
4:00:00 PM	2,074	3,452	5,526	0.0844	0.38	0.62
5:00:00 PM	1,863	2,823	4,686	0.0715	0.40	0.60
6:00:00 PM	1,373	1,924	3,297	0.0503	0.42	0.58
7:00:00 PM	959	1,428	2,387	0.0364	0.40	0.60
8:00:00 PM	718	1111	1,829	0.0279	0.39	0.61
9:00:00 PM	541	821	1,362	0.0208	0.40	0.60
10:00:00 PM	408	562	970	0.0148	0.42	0.58
11:00:00 PM	321	392	713	0.0108	0.45	0.55
Total	**32,692**	**33,230**				
Total Both Directions		**65,453**				

In order to update the existing KDOT lane closure guide, two pieces of information were needed for each hour of the day at each segment: a "k" factor and a directional factor. The "k" factor is the percentage of total highway volume for one hour in both directions, as shown in Equation 5. The "k" factor was used in the calculations to determine hourly flow from the total volume of the roadway. For example, as shown in Table 4, at 7:00:00 PM the total volume was 2,387 vehicles (959 for northbound plus 1,428 for southbound). The resulting "k" factor was then calculated by dividing 2,387 by 65,453 (total volume), with a resulting value of 0.0365 (3.65%), as shown in Table 4.

The directional hour factor is the percentage of volume in one direction for one hour, as shown in Equation 6. The directional hour factor was used to determine the hourly split of traffic for a specific hour. For example, as shown in Table 4, at 7:00:00 PM the total volume for that hour was 2,387 vehicles, with 959 vehicles traveling northbound and 1,428 vehicles traveling southbound. The resulting hourly splits for northbound and southbound were 0.40 (40%) and 0.60 (60%), respectively. The results show that, during that hour, 40% of traffic travels in the northbound direction and 60% of traffic travels in the southbound direction. These results are significant to the lane closure guide because the difference in hourly volumes may change when and what type of work is allowed (i.e., whether or not a lane can be closed to traffic).

$$\text{“k” factor} = \frac{Total\ Volume\ for\ 1\ hour\ (NB+SB\ or\ EB+WB)}{AAWT} \qquad \textbf{Eq. 5}$$

$$\text{Directional hour factor} = \frac{Volume\ in\ one\ Direction\ for\ 1\ hour}{Total\ Volume\ for\ 1\ hour} \qquad \textbf{Eq. 6}$$

3.6 Lane Closure Guide Updates

Two tables within the access database were updated: DirHrFacs and SegList. The first table, DirHrFacs, contained the segment name, day of week, direction, directional hour factor, and "k" factor. No information was removed and only new information was added when updating the table. A naming convention was selected to identify each segment, and this naming convention followed the pattern of route and starting milepost. For example, a segment on I-35 starting at milepost 202.2 had an identifying marker in the DirHrFacs table of I-35MP2022, as shown in

Figure **23**.

F34VQ2	7
I35MP2022	1
I35MP2022	2
I35MP2022	3
I35MP2022	4
I35MP2022	5
I35MP2022	6

Figure 23 Labeling System used for Each Segment

The day of the week convention followed the existing lane closure guide's convention in which Sunday was labeled as 1 and Saturday was labeled as 7. A directional hour factor and "k" factor was added for each day of the week; the directional hour factor and "k" factor were identical to each other the same for each weekday, but Saturday and Sunday directional hour factors and "k" factors differed from the weekday factor to account for differences in weekend traffic characteristics. Each segment had a unique directional hour factor and "k" factor that was found previously by KDOT.

The SegList table was also updated. This table creates different segments for each route, assigning a starting and ending milepost as well as a description for the starting and ending location, and assigns traffic lanes in each direction, two-way volume, and applicable factors to the two-way volume. Information updated within this table included segments, AADT, and DirHrFacs references. When updating the segment list, the research team found several arbitrary segments within the original lane closure guide. These segments were deleted, as shown in Table 5, and segments were added due to sensor availability, as shown in Table 6.

Table 5 Sections Removed from Original Lane Closure Guide

ROUTE_NUMBER	LOCATION_DESCRIPTION	COUNTY_NUMBER	RSE_BEGIN_DESCR	RSE_END_DESCR	BEGIN_STATE_MP	END_STATE_MP
I-35	I-35 SW OF I-435 IC	46	0.3 MI N 119TH	0.35 MI N 119TH	220.489	220.56
I-35	I-35 SW OF I-435 IC	46	0.35 MI N 119TH	107TH ST	220.56	222.089
I-35	I-35 SW OF I-435 IC	46	107TH ST	107TH ST	222.089	222.11
I-35	I-35 SW OF I-435 IC	46	107TH ST	I-35/I-435/K-10/U50	222.11	222.442
I-35	I-35 S OF 95TH ST IC	46	0.6 M N I-435	95TH	222.939	223.881
I-35	I-35 N OF 75ST IC	46	NCL OP SCL MERR	6LDIV/8LDIV	227.019	227.361

I-35	I-35 N OF 75ST IC	46	6LDIV/8L DIV	67TH	227.361	228.067
I-35	I-35 E OF I-635 IC	46	I-35/I-635/U69	JO/WY CO LN NCL MISSION	230.908	231.656
I-435	I-435 N OF IC	46	.17M W I-435/K-10	87TH	10.27	10.917
I-635	I-635 S OF SHAWNEE DR	46	MERRIAM DR	JO/WY CO LN	0.237	0.379
I-635	I-635 S OF SHAWNEE DR	105	JO/WY CO LN	SHAWNEE DR	0.379	1.043
I-635	I-635 W OF K-5	105	0.5 MI N S JCT I-635/K5	N JCT I-635/K5	7.961	8.196
I-70	I-70 E OF I-635	105	JCT I-70(05)/I-635	END 2005 PROJ	418.508	419.52
I-70	I-70 E OF 18TH ST	105	END KTA	I-70/I-670	420.295	421.234
I-70	I-70 E OF 7TH ST	105	0.4 MI E I-670	I-70/U69/U169	421.582	421.605
I-70	I-70 N OF GARRETT-HOLMES IC	105	I-70/U69/U169	CENTRAL	421.605	422.296
I-70	I-70 N OF CENTRAL AVE	105	CENTRAL	5TH	422.296	422.647

US-69	US-69 S OF 135TH ST IC	46	RS 1774 151ST	135TH	137.547	139.553
US-69	US-69 S OF 135TH ST IC	46	1.6 M N RS 1774	135TH	139.553	139.565
US-69	US-69 S OF 111TH ST IC	46	119TH ST	111TH ST	142.196	143.276
US-69	US-69 S OF 103RD ST IC	46	.2 MI N I-435	103RD	144.155	144.285
US-69	US-69 S OF 95TH ST IC	46	103RD	0.2 MI N 103RD	144.286	144.446
US-69	US-69 S OF 95TH ST IC	46	0.2 MI N 103RD	0.3 MI N 103RD	144.446	144.624
US-69	US-69 S OF 95TH ST IC	46	0.3 MI N 103RD	0.8 MI N 103RD	144.624	145.045
US-69	US-69 S OF 95TH ST IC	46	0.8 MI N 103RD	95TH	145.045	145.323
US-69	US-69 N OF 95TH ST IC	46	95TH	95TH	145.323	145.362
US-69	US-69 N OF 95TH ST IC	46	95TH	0.1 MI N 95TH	145.362	145.472
US-69	US-69 N OF 95TH ST IC	46	0.1 MI N 95TH	91ST ST	145.472	145.91
US-69	US-69 N OF 95TH ST IC	46	0.3 MI S 87TH	87TH NCLOVPK	146.107	146.423
US-69	US-69 S OF I-35 IC	46	0.1 MI N 87TH	I-35/U56/U69	146.532	146.781

Table 6 Sections Added to the Lane Closure Guide

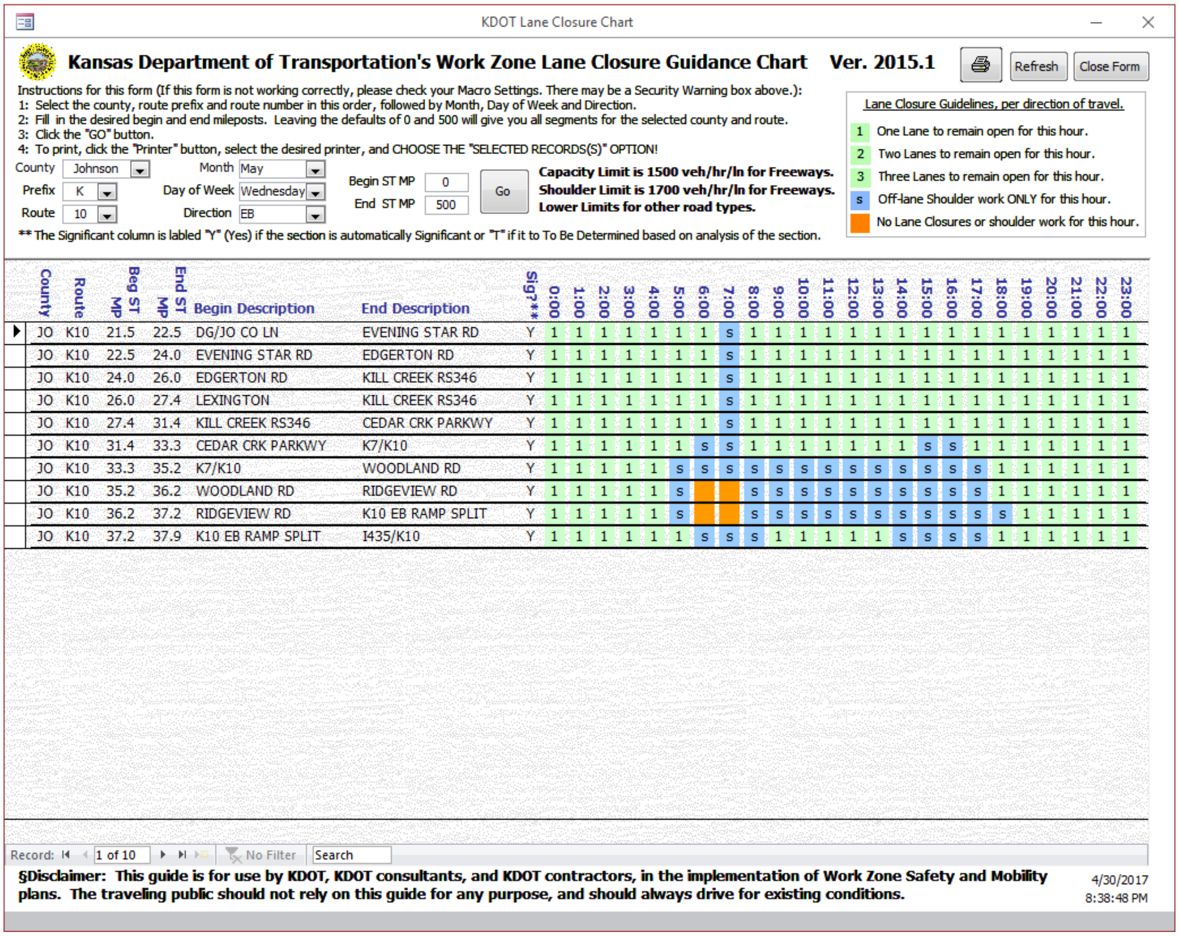
ROUTE_NUMBER	LOCATION_DESCRIPTION	COUNTY_NUMBER	RSE_BEGIN_DESCR	RSE_END_DESCR	BEGIN_STATE_MP	END_STATE_MP
I-35	I-35 N OF MIAMI COUNTY LINE	46	MIAMI CNTY LNE	SUNFLOWER RD	202.2	203
I-35	I-35 N OF SUNFLOWER RD	46	SUNFLOWER RD	HOMESTEAD LN	203	205.154

The first columns in Table 5 and Table 6 show the route to which the segment was added or deleted, labeled ROUTE_NUMBER. The LOCATION_DESCRIPTION and COUNTY_NUMBER columns describe the general location and county, respectively, of the segment. The RSE_BEGIN_DESCR and RSE_END_DESCR columns show the starting location and end location for the segment. The starting and ending locations represent a significant break within the segment, such as an interchange or a change in the number of lanes. The removed segments had arbitrary end and start locations. The final two columns, BEGIN_STATE_MP and END_STATE_MP, are the starting and ending milepost locations for the segment.

The following tables used to calculate hourly flow were not updated: day of week factor and month factor. These sections were not updated because those factors do not change section to section; they are derived from information collected by permanent ATRs. For example, a section on I-35 could have 1.03 as the day-of-the-week factor for Friday, but a roadway segment on I-35 approximately five miles away could have that same factor for Friday. Other areas of the lane closure guide that were not updated included areas outside the KC Scout network, including Wichita, Topeka, Manhattan, and Lawrence, Kansas.

3.7 Quality Control and Quality Assurance

A quality control/quality assurance (QA/QC) check was conducted to determine if the lane closure guide was returning expected values. A random updated route was selected, and then a day of the week and month with factors close to 1 were chosen, a Wednesday in May. A factor close to 1 was chosen to prevent the obscuring of results from the collected information. Then several random sections were chosen from the previously selected route to determine if the lane closure guide agreed with the data used to update it. For example, a section on K-10 between milepost 36.2 and milepost 37.2 was randomly chosen, and the lane closure guide shown in Figure 24 and Figure 25 was compared to information calculated from a table similar to Table 4, shown in Table 7.


KDOT Lane Closure Chart

Kansas Department of Transportation's Work Zone Lane Closure Guidance Chart Ver. 2015.1

Refresh | Close Form

Instructions for this form (If this form is not working correctly, please check your Macro Settings. There may be a Security Warning box above.):
1: Select the county, route prefix and route number in this order, followed by Month, Day of Week and Direction.
2: Fill in the desired begin and end mileposts. Leaving the defaults of 0 and 500 will give you all segments for the selected county and route.
3: Click the "GO" button.
4: To print, click the "Printer" button, select the desired printer, and CHOOSE THE "SELECTED RECORDS(S)" OPTION!

County: Johnson | Month: May | Begin ST MP: 0
Prefix: K | Day of Week: Wednesday | End ST MP: 500 | Go
Route: 10 | Direction: EB

Capacity Limit is 1500 veh/hr/ln for Freeways.
Shoulder Limit is 1700 veh/hr/ln for Freeways.
Lower Limits for other road types.

Lane Closure Guidelines, per direction of travel.
1 One Lane to remain open for this hour.
2 Two Lanes to remain open for this hour.
3 Three Lanes to remain open for this hour.
S Off-lane Shoulder work ONLY for this hour.
No Lane Closures or shoulder work for this hour.

** The Significant column is labled "Y" (Yes) if the section is automatically Significant or "T" if it to To Be Determined based on analysis of the section.

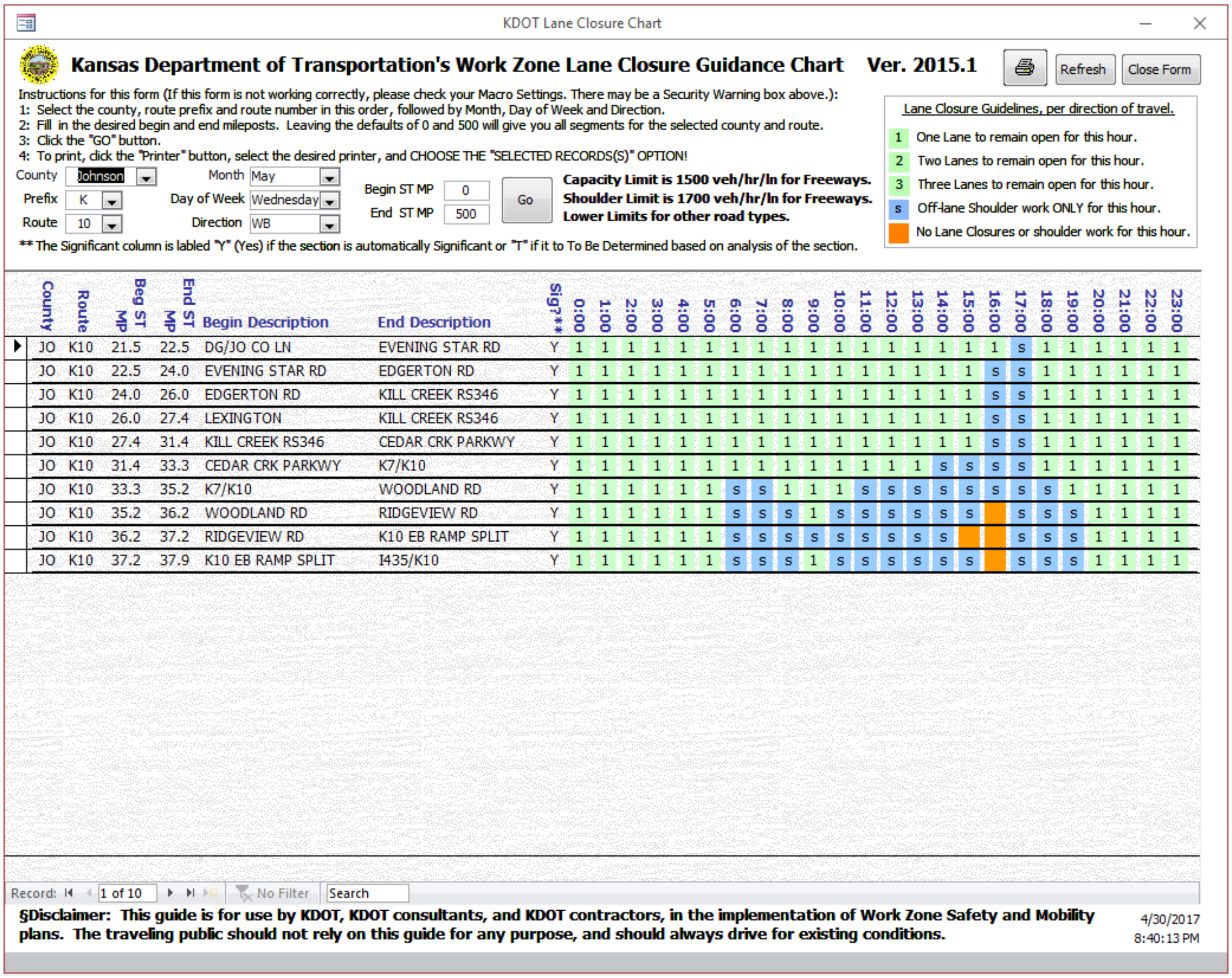
County	Route	Beg ST MP	End ST MP	Begin Description	End Description	Sig?**	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
JO	K10	21.5	22.5	DG/JO CO LN	EVENING STAR RD	Y	1	1	1	1	1	1	1	s	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	K10	22.5	24.0	EVENING STAR RD	EDGERTON RD	Y	1	1	1	1	1	1	1	s	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	K10	24.0	26.0	EDGERTON RD	KILL CREEK RS346	Y	1	1	1	1	1	1	1	s	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	K10	26.0	27.4	LEXINGTON	KILL CREEK RS346	Y	1	1	1	1	1	1	1	s	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	K10	27.4	31.4	KILL CREEK RS346	CEDAR CRK PARKWY	Y	1	1	1	1	1	1	1	s	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	K10	31.4	33.3	CEDAR CRK PARKWY	K7/K10	Y	1	1	1	1	1	1	s	s	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	1
JO	K10	33.3	35.2	K7/K10	WOODLAND RD	Y	1	1	1	1	1	s	s	s	s	s	s	s	s	s	s	s	s	s	1	1	1	1	1	1
JO	K10	35.2	36.2	WOODLAND RD	RIDGEVIEW RD	Y	1	1	1	1	1	s			s	s	s	s	s	s	s	s	s	s	1	1	1	1	1	1
JO	K10	36.2	37.2	RIDGEVIEW RD	K10 EB RAMP SPLIT	Y	1	1	1	1	1	s			s	s	s	s	s	s	s	s	s	s	s	1	1	1	1	1
JO	K10	37.2	37.9	K10 EB RAMP SPLIT	I435/K10	Y	1	1	1	1	1	1	s	s	s	1	1	1	1	1	s	s	s	s	1	1	1	1	1	1

Record: 1 of 10 | No Filter | Search

§Disclaimer: This guide is for use by KDOT, KDOT consultants, and KDOT contractors, in the implementation of Work Zone Safety and Mobility plans. The traveling public should not rely on this guide for any purpose, and should always drive for existing conditions.

4/30/2017
8:38:48 PM

Figure 24 EB Direction for K-10 on a Wednesday in May


KDOT Lane Closure Chart

Kansas Department of Transportation's Work Zone Lane Closure Guidance Chart   Ver. 2015.1

Refresh   Close Form

Instructions for this form (If this form is not working correctly, please check your Macro Settings. There may be a Security Warning box above.):
1: Select the county, route prefix and route number in this order, followed by Month, Day of Week and Direction.
2: Fill in the desired begin and end mileposts. Leaving the defaults of 0 and 500 will give you all segments for the selected county and route.
3: Click the "GO" button.
4: To print, click the "Printer" button, select the desired printer, and CHOOSE THE "SELECTED RECORDS(S)" OPTION!

County Johnson   Month May   Begin ST MP 0   Go
Prefix K   Day of Week Wednesday   End ST MP 500
Route 10   Direction WB

Capacity Limit is 1500 veh/hr/ln for Freeways.
Shoulder Limit is 1700 veh/hr/ln for Freeways.
Lower Limits for other road types.

Lane Closure Guidelines, per direction of travel.
1 One Lane to remain open for this hour.
2 Two Lanes to remain open for this hour.
3 Three Lanes to remain open for this hour.
s Off-lane Shoulder work ONLY for this hour.
No Lane Closures or shoulder work for this hour.

** The Significant column is labled "Y" (Yes) if the section is automatically Significant or "T" if it to To Be Determined based on analysis of the section.

County	Route	Beg ST MP	End ST MP	Begin Description	End Description	Sig?**	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
JO	K10	21.5	22.5	DG/JO CO LN	EVENING STAR RD	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	s	1	1	1	1	1	1
JO	K10	22.5	24.0	EVENING STAR RD	EDGERTON RD	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1
JO	K10	24.0	26.0	EDGERTON RD	KILL CREEK RS346	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1
JO	K10	26.0	27.4	LEXINGTON	KILL CREEK RS346	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1
JO	K10	27.4	31.4	KILL CREEK RS346	CEDAR CRK PARKWY	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1
JO	K10	31.4	33.3	CEDAR CRK PARKWY	K7/K10	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	s	s	s	s	1	1	1	1	1	1
JO	K10	33.3	35.2	K7/K10	WOODLAND RD	Y	1	1	1	1	1	1	s	s	1	1	1	s	s	s	s	s	s	s	s	1	1	1	1	1
JO	K10	35.2	36.2	WOODLAND RD	RIDGEVIEW RD	Y	1	1	1	1	1	1	s	s	s	1	s	s	s	s	s	s		s	s	s	1	1	1	1
JO	K10	36.2	37.2	RIDGEVIEW RD	K10 EB RAMP SPLIT	Y	1	1	1	1	1	1	s	s	s	s	s	s	s	s	s			s	s	s	1	1	1	1
JO	K10	37.2	37.9	K10 EB RAMP SPLIT	I435/K10	Y	1	1	1	1	1	1	s	s	s	1	s	s	s	s	s	s		s	s	s	1	1	1	1

Record: 1 of 10   No Filter   Search

§Disclaimer: This guide is for use by KDOT, KDOT consultants, and KDOT contractors, in the implementation of Work Zone Safety and Mobility plans. The traveling public should not rely on this guide for any purpose, and should always drive for existing conditions.

4/30/2017
8:40:13 PM

Figure 25 WB Direction for K-10 on a Wednesday in May

Table 7 Number of Required Open Lanes for K-10 between Mileposts 36.2 and 37.2

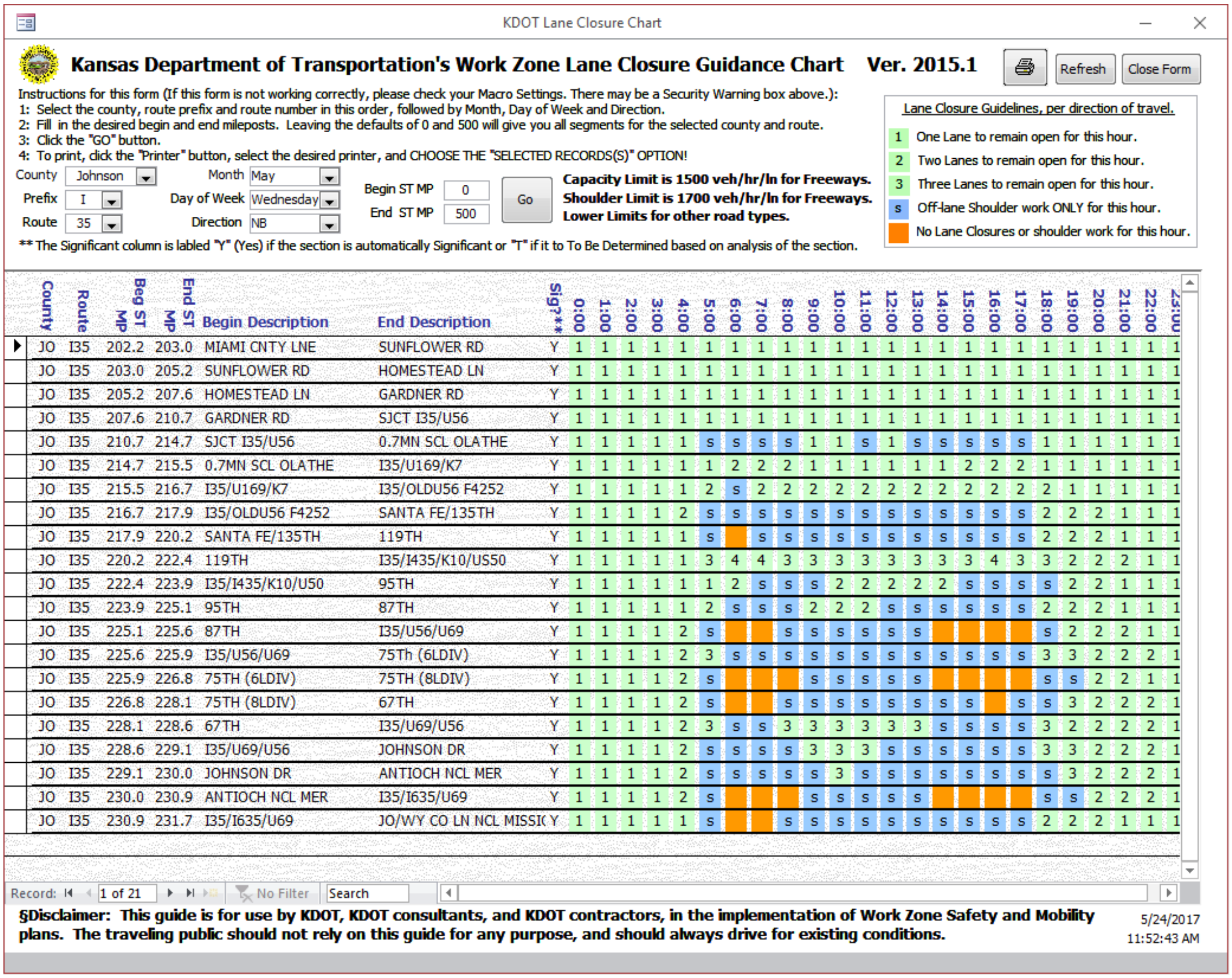
Time	Lanes Open	
	WB	EB
12:00 am	1	1
1:00 am	1	1
2:00 am	1	1
3:00 am	1	1
4:00 am	1	1
5:00 am	1	2
6:00 am	2	3
7:00 am	2	3
8:00 am	2	2
9:00 am	1	2
10:00 am	2	2
11:00 am	2	2
12:00 pm	2	2
1:00 pm	2	2
2:00 pm	2	2
3:00 pm	3	2
4:00 pm	3	2
5:00 pm	2	2
6:00 pm	2	1
7:00 pm	2	1
8:00 pm	1	1
9:00 pm	1	1
10:00 pm	1	1
11:00 pm	1	1

This chosen section of K-10 was a four-lane divided highway. The values found in Table 7 were calculated by dividing the average hourly volume by 1500 vphpl and rounding up (Eq. 3). Resulting values were the minimum number of lanes required for traffic flow assuming only 1,500 vphpl and not considering 1,700 vphpl if only shoulder work is in progress.

As shown in Figure 24, between milepost 36.2 and milepost 37.2 only shoulder work is allowed starting at 5:00 a.m., as represented by the blue box with an “s,” and starting at 6:00 a.m. no work can be done until 8:00 a.m., as represented by the orange box. After 8:00 a.m. until 7:00 p.m. only shoulder work can be done, and after 7:00 p.m. until 5:00 a.m. one lane of traffic may be closed. The lane closure guide agrees with the values calculated in Table 7. From 5:00 a.m. until 6:00 p.m. two lanes of traffic must be open in the eastbound direction, and from 6:00 a.m. until 8:00 a.m. three lanes must be open to assume a capacity of 1,500 vphpl, as calculated in Table 7, allowing no work to be done during that time. The two required open lanes calculated in Table 7 mean that only shoulder work would be allowed. Discrepancy for the last hour occurred because the hourly volume was near 1,500 vphpl and the month and day of week factors were slightly higher than 1.0, causing the hourly volume to exceed 1,500 vphpl, as shown in Figure 24.

The same process was completed for the westbound direction of K-10 between milepost 36.2 and 37.2. However, the times for no work allowed changed to 3:00–5:00 p.m. This shift represents the traffic population driving to Kansas City in the morning and driving away from Kansas City in the afternoon/evening.

Another example of the QA/QC process occurred on I-35 between milepost 230.0 and milepost 230.9. This section of I-35 experiences an AAWT of approximately 163,000 vehicles, and each direction has three lanes of available traffic. Results from the lane closure guide (Figure 26 and Figure 27) were compared to the values calculated in Table 8 using Eq. 3.



KDOT Lane Closure Chart

Kansas Department of Transportation's Work Zone Lane Closure Guidance Chart Ver. 2015.1

Refresh | Close Form

Instructions for this form (If this form is not working correctly, please check your Macro Settings. There may be a Security Warning box above.):
1: Select the county, route prefix and route number in this order, followed by Month, Day of Week and Direction.
2: Fill in the desired begin and end mileposts. Leaving the defaults of 0 and 500 will give you all segments for the selected county and route.
3: Click the "GO" button.
4: To print, click the "Printer" button, select the desired printer, and CHOOSE THE "SELECTED RECORDS(S)" OPTION!

County: Johnson | Month: May | Begin ST MP: 0
Prefix: I | Day of Week: Wednesday | End ST MP: 500
Route: 35 | Direction: NB | Go

Capacity Limit is 1500 veh/hr/ln for Freeways.
Shoulder Limit is 1700 veh/hr/ln for Freeways.
Lower Limits for other road types.

Lane Closure Guidelines, per direction of travel.
1 One Lane to remain open for this hour.
2 Two Lanes to remain open for this hour.
3 Three Lanes to remain open for this hour.
s Off-lane Shoulder work ONLY for this hour.
No Lane Closures or shoulder work for this hour.

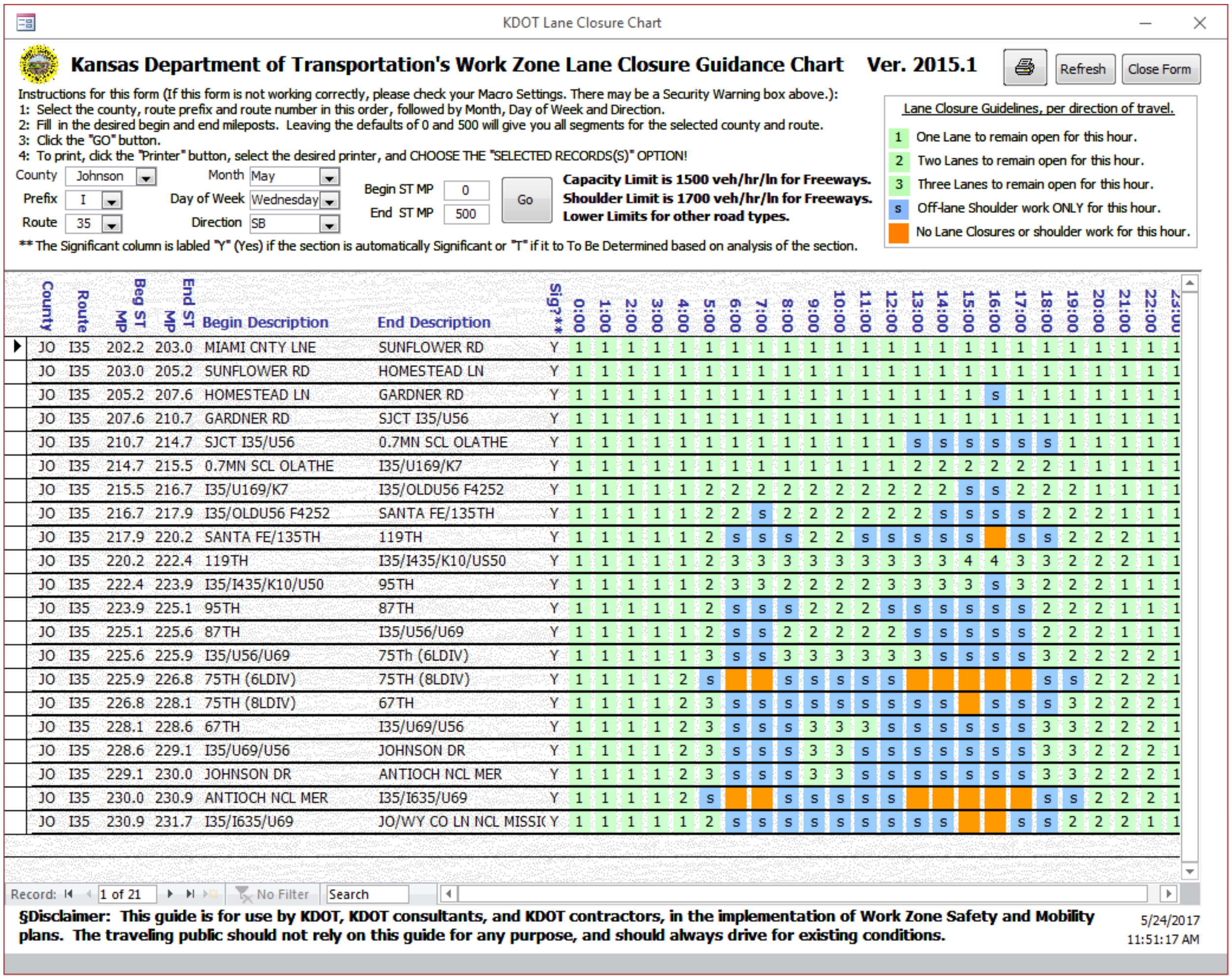
** The Significant column is labled "Y" (Yes) if the section is automatically Significant or "T" if it to To Be Determined based on analysis of the section.

County	Route	Beg ST MP	End ST MP	Begin Description	End Description	Sig?**	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
JO	I35	202.2	203.0	MIAMI CNTY LNE	SUNFLOWER RD	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	I35	203.0	205.2	SUNFLOWER RD	HOMESTEAD LN	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	I35	205.2	207.6	HOMESTEAD LN	GARDNER RD	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	I35	207.6	210.7	GARDNER RD	SJCT I35/U56	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	I35	210.7	214.7	SJCT I35/U56	0.7MN SCL OLATHE	Y	1	1	1	1	1	s	s	s	s	1	1	s	1	s	s	s	s	s	1	1	1	1	1	1
JO	I35	214.7	215.5	0.7MN SCL OLATHE	I35/U169/K7	Y	1	1	1	1	1	1	2	2	2	1	1	1	1	1	1	2	2	2	1	1	1	1	1	1
JO	I35	215.5	216.7	I35/U169/K7	I35/OLDU56 F4252	Y	1	1	1	1	1	2	s	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1
JO	I35	216.7	217.9	I35/OLDU56 F4252	SANTA FE/135TH	Y	1	1	1	1	2	s	s	s	s	s	s	s	s	s	s	s	s	s	2	2	2	1	1	1
JO	I35	217.9	220.2	SANTA FE/135TH	119TH	Y	1	1	1	1	1	s		s	s	s	s	s	s	s	s	s	s	s	2	2	2	1	1	1
JO	I35	220.2	222.4	119TH	I35/I435/K10/US50	Y	1	1	1	1	1	3	4	4	3	3	3	3	3	3	3	3	4	3	3	2	2	2	1	1
JO	I35	222.4	223.9	I35/I435/K10/U50	95TH	Y	1	1	1	1	1	1	2	s	s	s	2	2	2	2	2	s	s	s	s	2	2	1	1	1
JO	I35	223.9	225.1	95TH	87TH	Y	1	1	1	1	1	2	s	s	s	2	2	2	s	s	s	s	s	s	2	2	2	1	1	1
JO	I35	225.1	225.6	87TH	I35/U56/U69	Y	1	1	1	1	2	s			s	s	s	s	s	s					s	2	2	2	1	1
JO	I35	225.6	225.9	I35/U56/U69	75Th (6LDIV)	Y	1	1	1	1	2	3	s	s	s	s	s	s	s	s	s	s	s	s	3	3	2	2	2	1
JO	I35	225.9	226.8	75TH (6LDIV)	75TH (8LDIV)	Y	1	1	1	1	2	s				s	s	s	s	s					s	s	2	2	1	1
JO	I35	226.8	228.1	75TH (8LDIV)	67TH	Y	1	1	1	1	2	s			s	s	s	s	s	s	s	s		s	s	3	2	2	2	1
JO	I35	228.1	228.6	67TH	I35/U69/U56	Y	1	1	1	1	2	3	s	s	3	3	3	3	3	3	s	s	s	s	3	2	2	2	2	1
JO	I35	228.6	229.1	I35/U69/U56	JOHNSON DR	Y	1	1	1	1	2	s	s	s	s	3	3	3	s	s	s	s	s	s	3	3	2	2	2	1
JO	I35	229.1	230.0	JOHNSON DR	ANTIOCH NCL MER	Y	1	1	1	1	2	s	s	s	s	s	3	s	s	s	s	s	s	s	s	3	2	2	2	1
JO	I35	230.0	230.9	ANTIOCH NCL MER	I35/I635/U69	Y	1	1	1	1	2	s				s	s	s	s	s					s	s	2	2	2	1
JO	I35	230.9	231.7	I35/I635/U69	JO/WY CO LN NCL MISSI(	Y	1	1	1	1	1	s			s	s	s	s	s	s	s	s	s	s	2	2	2	1	1	1

Record: 1 of 21 | No Filter | Search

§Disclaimer: This guide is for use by KDOT, KDOT consultants, and KDOT contractors, in the implementation of Work Zone Safety and Mobility plans. The traveling public should not rely on this guide for any purpose, and should always drive for existing conditions. 5/24/2017 11:52:43 AM

Figure 26 NB Direction for I-35 on a Wednesday in May



KDOT Lane Closure Chart

Kansas Department of Transportation's Work Zone Lane Closure Guidance Chart Ver. 2015.1

Refresh | Close Form

Instructions for this form (If this form is not working correctly, please check your Macro Settings. There may be a Security Warning box above.):
1: Select the county, route prefix and route number in this order, followed by Month, Day of Week and Direction.
2: Fill in the desired begin and end mileposts. Leaving the defaults of 0 and 500 will give you all segments for the selected county and route.
3: Click the "GO" button.
4: To print, click the "Printer" button, select the desired printer, and CHOOSE THE "SELECTED RECORDS(S)" OPTION!

County: Johnson | Month: May | Begin ST MP: 0
Prefix: I | Day of Week: Wednesday | End ST MP: 500
Route: 35 | Direction: SB | Go

Capacity Limit is 1500 veh/hr/ln for Freeways.
Shoulder Limit is 1700 veh/hr/ln for Freeways.
Lower Limits for other road types.

Lane Closure Guidelines, per direction of travel.
- 1 One Lane to remain open for this hour.
- 2 Two Lanes to remain open for this hour.
- 3 Three Lanes to remain open for this hour.
- s Off-lane Shoulder work ONLY for this hour.
- No Lane Closures or shoulder work for this hour.

** The Significant column is labled "Y" (Yes) if the section is automatically Significant or "T" if it to To Be Determined based on analysis of the section.

County	Route	Beg ST MP	End ST MP	Begin Description	End Description	Sig?**	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
JO	I35	202.2	203.0	MIAMI CNTY LNE	SUNFLOWER RD	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	I35	203.0	205.2	SUNFLOWER RD	HOMESTEAD LN	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	I35	205.2	207.6	HOMESTEAD LN	GARDNER RD	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	s	1	1	1	1	1	1	1
JO	I35	207.6	210.7	GARDNER RD	SJCT I35/U56	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
JO	I35	210.7	214.7	SJCT I35/U56	0.7MN SCL OLATHE	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	s	s	s	s	s	s	1	1	1	1	1
JO	I35	214.7	215.5	0.7MN SCL OLATHE	I35/U169/K7	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1
JO	I35	215.5	216.7	I35/U169/K7	I35/OLDU56 F4252	Y	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	s	s	2	2	2	1	1	1	1
JO	I35	216.7	217.9	I35/OLDU56 F4252	SANTA FE/135TH	Y	1	1	1	1	1	2	2	s	2	2	2	2	2	2	s	s	s	s	2	2	2	1	1	1
JO	I35	217.9	220.2	SANTA FE/135TH	119TH	Y	1	1	1	1	1	2	s	s	s	2	2	s	s	s	s	s		s	s	2	2	2	1	1
JO	I35	220.2	222.4	119TH	I35/I435/K10/US50	Y	1	1	1	1	1	2	3	3	3	3	3	3	3	3	3	4	4	3	3	2	2	2	1	1
JO	I35	222.4	223.9	I35/I435/K10/U50	95TH	Y	1	1	1	1	1	2	3	3	2	2	2	2	3	3	3	3	s	3	2	2	2	1	1	1
JO	I35	223.9	225.1	95TH	87TH	Y	1	1	1	1	1	2	s	s	s	2	2	2	s	s	s	s	s	s	2	2	2	1	1	1
JO	I35	225.1	225.6	87TH	I35/U56/U69	Y	1	1	1	1	1	2	s	s	2	2	2	2	2	s	s	s	s	s	2	2	2	1	1	1
JO	I35	225.6	225.9	I35/U56/U69	75Th (6LDIV)	Y	1	1	1	1	1	3	s	s	3	3	3	3	3	3	s	s	s	s	3	2	2	2	2	1
JO	I35	225.9	226.8	75TH (6LDIV)	75TH (8LDIV)	Y	1	1	1	1	2	s			s	s	s	s	s						s	s	2	2	2	1
JO	I35	226.8	228.1	75TH (8LDIV)	67TH	Y	1	1	1	1	2	3	s	s	s	s	s	s	s	s	s		s	s	s	3	2	2	2	1
JO	I35	228.1	228.6	67TH	I35/U69/U56	Y	1	1	1	1	2	3	s	s	s	3	3	3	s	s	s	s	s	s	3	3	2	2	2	1
JO	I35	228.6	229.1	I35/U69/U56	JOHNSON DR	Y	1	1	1	1	2	3	s	s	s	3	3	s	s	s	s	s	s	s	3	3	2	2	2	1
JO	I35	229.1	230.0	JOHNSON DR	ANTIOCH NCL MER	Y	1	1	1	1	2	3	s	s	s	3	3	s	s	s	s	s	s	s	3	3	2	2	2	1
JO	I35	230.0	230.9	ANTIOCH NCL MER	I35/I635/U69	Y	1	1	1	1	2	s			s	s	s	s	s						s	s	2	2	2	1
JO	I35	230.9	231.7	I35/I635/U69	JO/WY CO LN NCL MISSI(	Y	1	1	1	1	1	2	s	s	s	s	s	s	s	s	s			s	s	2	2	2	1	1

Record: 1 of 21 | No Filter | Search

§Disclaimer: This guide is for use by KDOT, KDOT consultants, and KDOT contractors, in the implementation of Work Zone Safety and Mobility plans. The traveling public should not rely on this guide for any purpose, and should always drive for existing conditions.

5/24/2017
11:51:17 AM

Figure 27 SB Direction for I-35 on a Wednesday in May

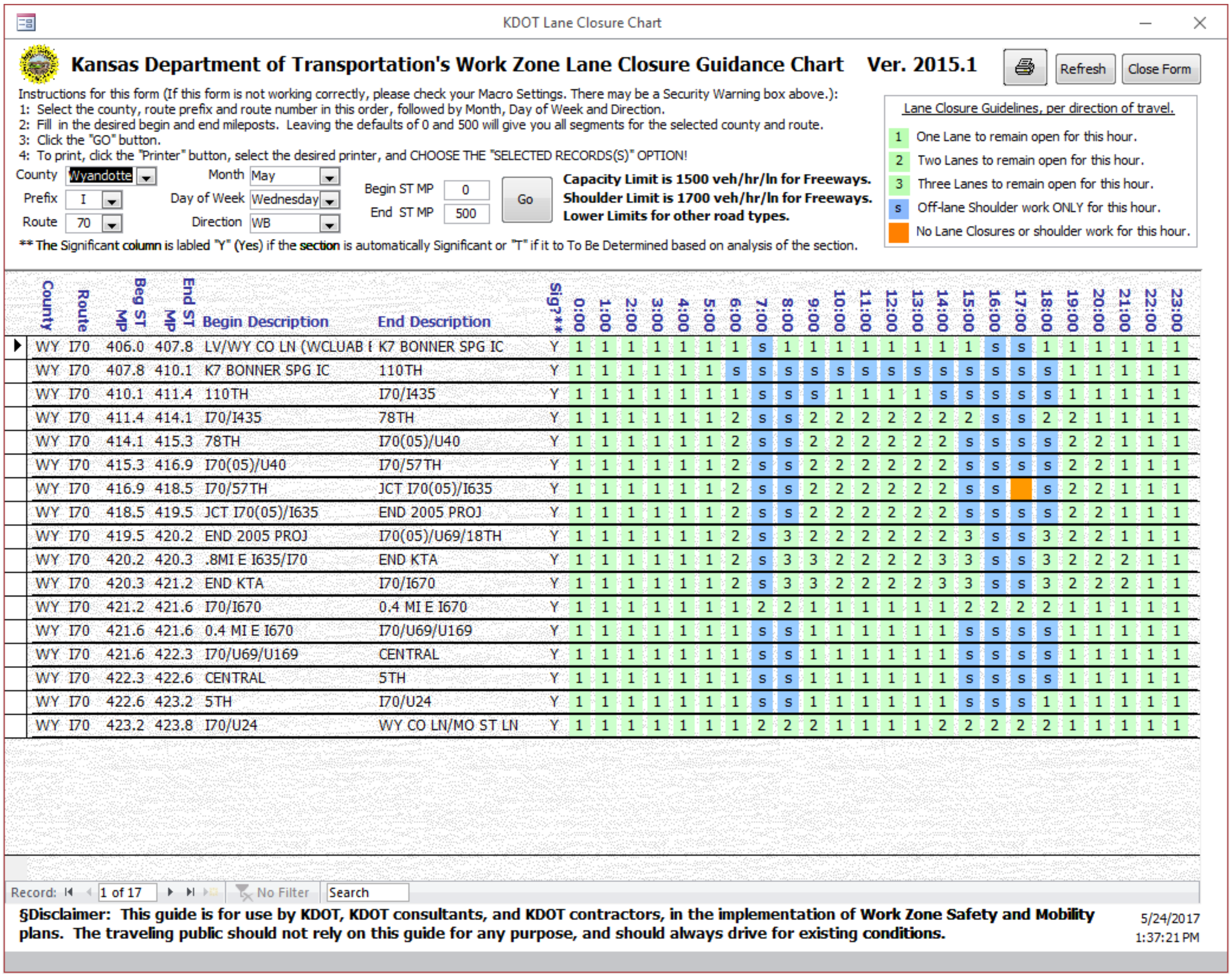
Table 8 Number of Required Open Lanes for I-35 between Mileposts 230.0 and 230.9

Time	Lanes Open	
	NB	SB
12:00:00 AM	1	1
1:00:00 AM	1	1
2:00:00 AM	1	1
3:00:00 AM	1	1
4:00:00 AM	2	2
5:00:00 AM	3	3
6:00:00 AM	4	4
7:00:00 AM	4	4
8:00:00 AM	4	3
9:00:00 AM	3	3
10:00:00 AM	3	3
11:00:00 AM	3	3
12:00:00 PM	3	3
1:00:00 PM	4	4
2:00:00 PM	4	4
3:00:00 PM	4	4
4:00:00 PM	4	4
5:00:00 PM	4	4
6:00:00 PM	3	3
7:00:00 PM	3	2
8:00:00 PM	2	2
9:00:00 PM	2	2
10:00:00 PM	2	2
11:00:00 PM	1	1

As shown in Figure 26 and Figure 27, work could be performed at one period in the morning and one period in the evening. However, the northbound direction of travel experiences a greater amount of traffic in the morning compared to the southbound direction based on the number of no-work restrictions, as represented by the orange boxes. In the evening, the southbound direction experiences more traffic than the northbound direction based on the number of no-work restrictions.

Both directions of travel from the lane closure guide were compared to Table 8 to determine their agreement with calculated values. Overall, the number of required open lanes, shoulder work only, and no work agreed with the calculated values, where three lanes open represent shoulder work only and four lanes open represent no work. However, limited discrepancies were evident. For example, the lane closure guide indicates that shoulder work can be done at 1:00 p.m. in the northbound direction, as shown in Figure 26. However, as shown in Table 8, four lanes of traffic are required, meaning that no work can be done. The discrepancy occurs because Table 8 only considers 1,500 vphpl and does not consider the 1,700 vphpl considered by the lane closure guide.

The QA/QC process also verified the separation of traffic directions; the previous lane closure guide did not consider traffic separation except for a select few corridors. For example, the previous lane closure guide showed identical lane closure recommendations for both directions on I-70 in Wyandotte County, as shown in Figure 28 and Figure 29. After the update to the lane closure guide, however, a clear separation between traffic directions was noted, as shown in Figure 30 and Figure 31.



County	Route	Beg ST MP	End ST MP	Begin Description	End Description	Sig?**	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
WY	I70	406.0	407.8	LV/WY CO LN (WCLUAB I	K7 BONNER SPG IC	Y	1	1	1	1	1	1	1	s	1	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1
WY	I70	407.8	410.1	K7 BONNER SPG IC	110TH	Y	1	1	1	1	1	1	s	s	s	s	s	s	s	s	s	s	s	s	s	1	1	1	1	1
WY	I70	410.1	411.4	110TH	I70/I435	Y	1	1	1	1	1	1	1	s	s	s	1	1	1	1	s	s	s	s	s	1	1	1	1	1
WY	I70	411.4	414.1	I70/I435	78TH	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	2	s	s	2	2	1	1	1	1
WY	I70	414.1	415.3	78TH	I70(05)/U40	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s	s	s	2	2	1	1	1
WY	I70	415.3	416.9	I70(05)/U40	I70/57TH	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s	s	s	2	2	1	1	1
WY	I70	416.9	418.5	I70/57TH	JCT I70(05)/I635	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s		s	2	2	1	1	1
WY	I70	418.5	419.5	JCT I70(05)/I635	END 2005 PROJ	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s	s	s	2	2	1	1	1
WY	I70	419.5	420.2	END 2005 PROJ	I70(05)/U69/18TH	Y	1	1	1	1	1	1	2	s	3	2	2	2	2	2	2	3	s	s	3	2	2	1	1	1
WY	I70	420.2	420.3	.8MI E I635/I70	END KTA	Y	1	1	1	1	1	1	2	s	3	3	2	2	2	2	3	3	s	s	3	2	2	2	1	1
WY	I70	420.3	421.2	END KTA	I70/I670	Y	1	1	1	1	1	1	2	s	3	3	2	2	2	2	3	3	s	s	3	2	2	2	1	1
WY	I70	421.2	421.6	I70/I670	0.4 MI E I670	Y	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	2	2	2	2	1	1	1	1	1
WY	I70	421.6	421.6	0.4 MI E I670	I70/U69/U169	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	s	1	1	1	1	1
WY	I70	421.6	422.3	I70/U69/U169	CENTRAL	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	s	1	1	1	1	1
WY	I70	422.3	422.6	CENTRAL	5TH	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	s	1	1	1	1	1
WY	I70	422.6	423.2	5TH	I70/U24	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	1	1	1	1	1	1
WY	I70	423.2	423.8	I70/U24	WY CO LN/MO ST LN	Y	1	1	1	1	1	1	1	2	2	2	1	1	1	1	2	2	2	2	2	1	1	1	1	1

Figure 28 Lane Closure Guide for Westbound I-70 Pre-Update

KDOT Lane Closure Chart

Kansas Department of Transportation's Work Zone Lane Closure Guidance Chart Ver. 2015.1

Refresh | Close Form

Instructions for this form (If this form is not working correctly, please check your Macro Settings. There may be a Security Warning box above.):
1: Select the county, route prefix and route number in this order, followed by Month, Day of Week and Direction.
2: Fill in the desired begin and end mileposts. Leaving the defaults of 0 and 500 will give you all segments for the selected county and route.
3: Click the "GO" button.
4: To print, click the "Printer" button, select the desired printer, and CHOOSE THE "SELECTED RECORDS(S)" OPTION!

Lane Closure Guidelines, per direction of travel.
- 1 One Lane to remain open for this hour.
- 2 Two Lanes to remain open for this hour.
- 3 Three Lanes to remain open for this hour.
- s Off-lane Shoulder work ONLY for this hour.
- No Lane Closures or shoulder work for this hour.

County: Wyandotte | Month: May | Begin ST MP: 0
Prefix: I | Day of Week: Wednesday | End ST MP: 500
Route: 70 | Direction: EB | Go

Capacity Limit is 1500 veh/hr/ln for Freeways.
Shoulder Limit is 1700 veh/hr/ln for Freeways.
Lower Limits for other road types.

** The Significant column is labled "Y" (Yes) if the section is automatically Significant or "T" if it to To Be Determined based on analysis of the section.

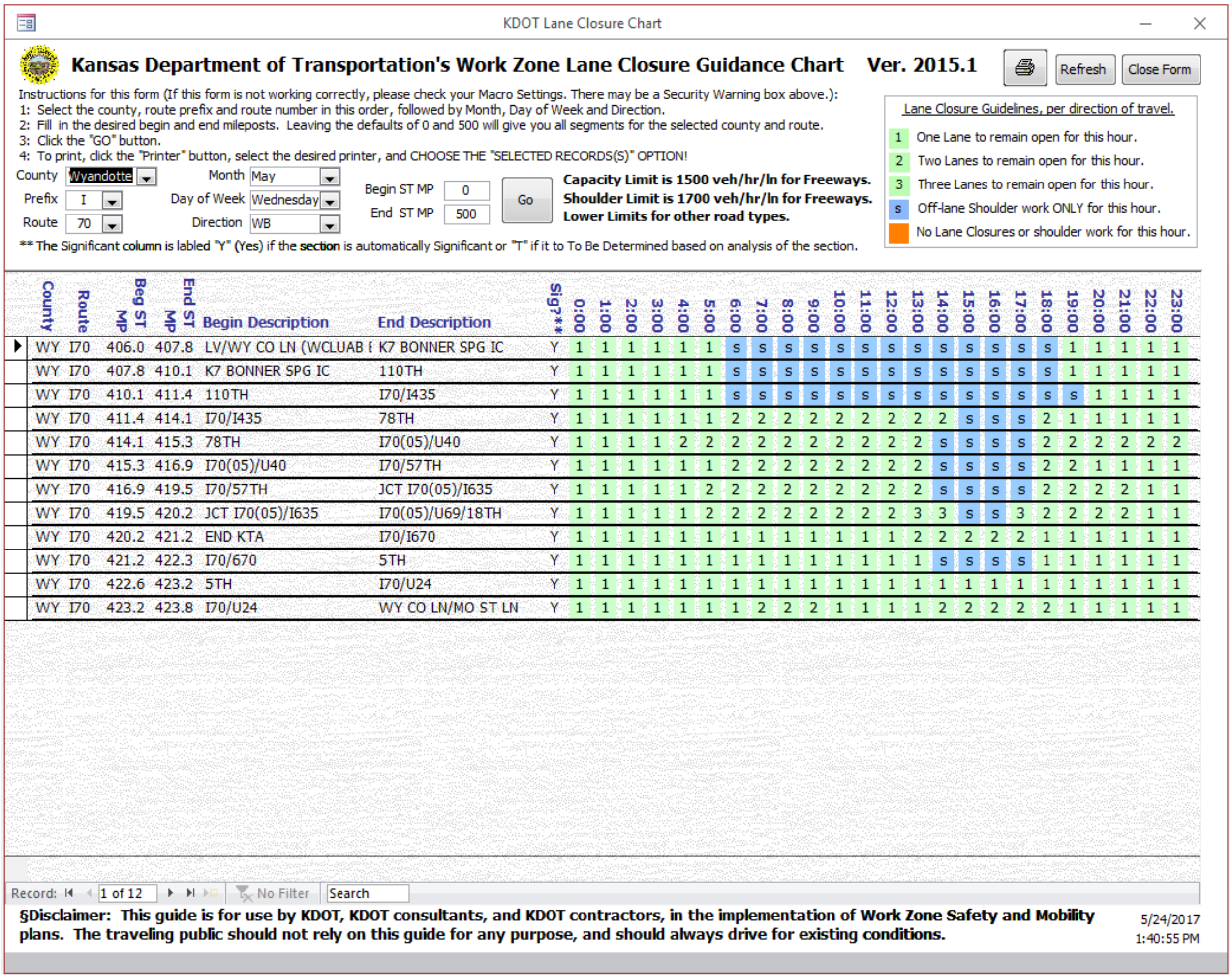
County	Route	Beg ST MP	End ST MP	Begin Description	End Description	Sig?**	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
WY	I70	406.0	407.8	LV/WY CO LN (WCLUAB I	K7 BONNER SPG IC	Y	1	1	1	1	1	1	1	s	1	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1
WY	I70	407.8	410.1	K7 BONNER SPG IC	110TH	Y	1	1	1	1	1	1	s	s	s	s	s	s	s	s	s	s	s	s	s	1	1	1	1	1
WY	I70	410.1	411.4	110TH	I70/I435	Y	1	1	1	1	1	1	1	s	s	s	1	1	1	1	s	s	s	s	s	1	1	1	1	1
WY	I70	411.4	414.1	I70/I435	78TH	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	2	s	s	2	2	1	1	1	1
WY	I70	414.1	415.3	78TH	I70(05)/U40	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s	s	s	2	2	1	1	1
WY	I70	415.3	416.9	I70(05)/U40	I70/57TH	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s	s	s	2	2	1	1	1
WY	I70	416.9	418.5	I70/57TH	JCT I70(05)/I635	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s		s	2	2	1	1	1
WY	I70	418.5	419.5	JCT I70(05)/I635	END 2005 PROJ	Y	1	1	1	1	1	1	2	s	s	2	2	2	2	2	2	s	s	s	s	2	2	1	1	1
WY	I70	419.5	420.2	END 2005 PROJ	I70(05)/U69/18TH	Y	1	1	1	1	1	1	2	s	3	2	2	2	2	2	2	3	s	s	3	2	2	1	1	1
WY	I70	420.2	420.3	.8MI E I635/I70	END KTA	Y	1	1	1	1	1	1	2	s	3	3	2	2	2	2	3	3	s	s	3	2	2	2	1	1
WY	I70	420.3	421.2	END KTA	I70/I670	Y	1	1	1	1	1	1	2	s	3	3	2	2	2	2	3	3	s	s	3	2	2	2	1	1
WY	I70	421.2	421.6	I70/I670	0.4 MI E I670	Y	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	2	2	2	2	1	1	1	1	1
WY	I70	421.6	421.6	0.4 MI E I670	I70/U69/U169	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	s	1	1	1	1	1
WY	I70	421.6	422.3	I70/U69/U169	CENTRAL	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	s	1	1	1	1	1
WY	I70	422.3	422.6	CENTRAL	5TH	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	s	1	1	1	1	1
WY	I70	422.6	423.2	5TH	I70/U24	Y	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	s	s	s	1	1	1	1	1	1
WY	I70	423.2	423.8	I70/U24	WY CO LN/MO ST LN	Y	1	1	1	1	1	1	1	2	2	2	1	1	1	1	2	2	2	2	2	1	1	1	1	1

Record: 14 of 17 | No Filter | Search

§Disclaimer: This guide is for use by KDOT, KDOT consultants, and KDOT contractors, in the implementation of Work Zone Safety and Mobility plans. The traveling public should not rely on this guide for any purpose, and should always drive for existing conditions.

5/24/2017
1:35:34 PM

Figure 29 Lane Closure Guide for Eastbound I-70 Pre-Update



KDOT Lane Closure Chart

Kansas Department of Transportation's Work Zone Lane Closure Guidance Chart Ver. 2015.1

Refresh | Close Form

Instructions for this form (If this form is not working correctly, please check your Macro Settings. There may be a Security Warning box above.):
1: Select the county, route prefix and route number in this order, followed by Month, Day of Week and Direction.
2: Fill in the desired begin and end mileposts. Leaving the defaults of 0 and 500 will give you all segments for the selected county and route.
3: Click the "GO" button.
4: To print, click the "Printer" button, select the desired printer, and CHOOSE THE "SELECTED RECORDS(S)" OPTION!

County: Wyandotte | Month: May | Begin ST MP: 0
Prefix: I | Day of Week: Wednesday | End ST MP: 500
Route: 70 | Direction: WB | Go

Capacity Limit is 1500 veh/hr/ln for Freeways.
Shoulder Limit is 1700 veh/hr/ln for Freeways.
Lower Limits for other road types.

Lane Closure Guidelines, per direction of travel.
- 1 One Lane to remain open for this hour.
- 2 Two Lanes to remain open for this hour.
- 3 Three Lanes to remain open for this hour.
- s Off-lane Shoulder work ONLY for this hour.
- No Lane Closures or shoulder work for this hour.

** The Significant column is labled "Y" (Yes) if the section is automatically Significant or "T" if it to To Be Determined based on analysis of the section.

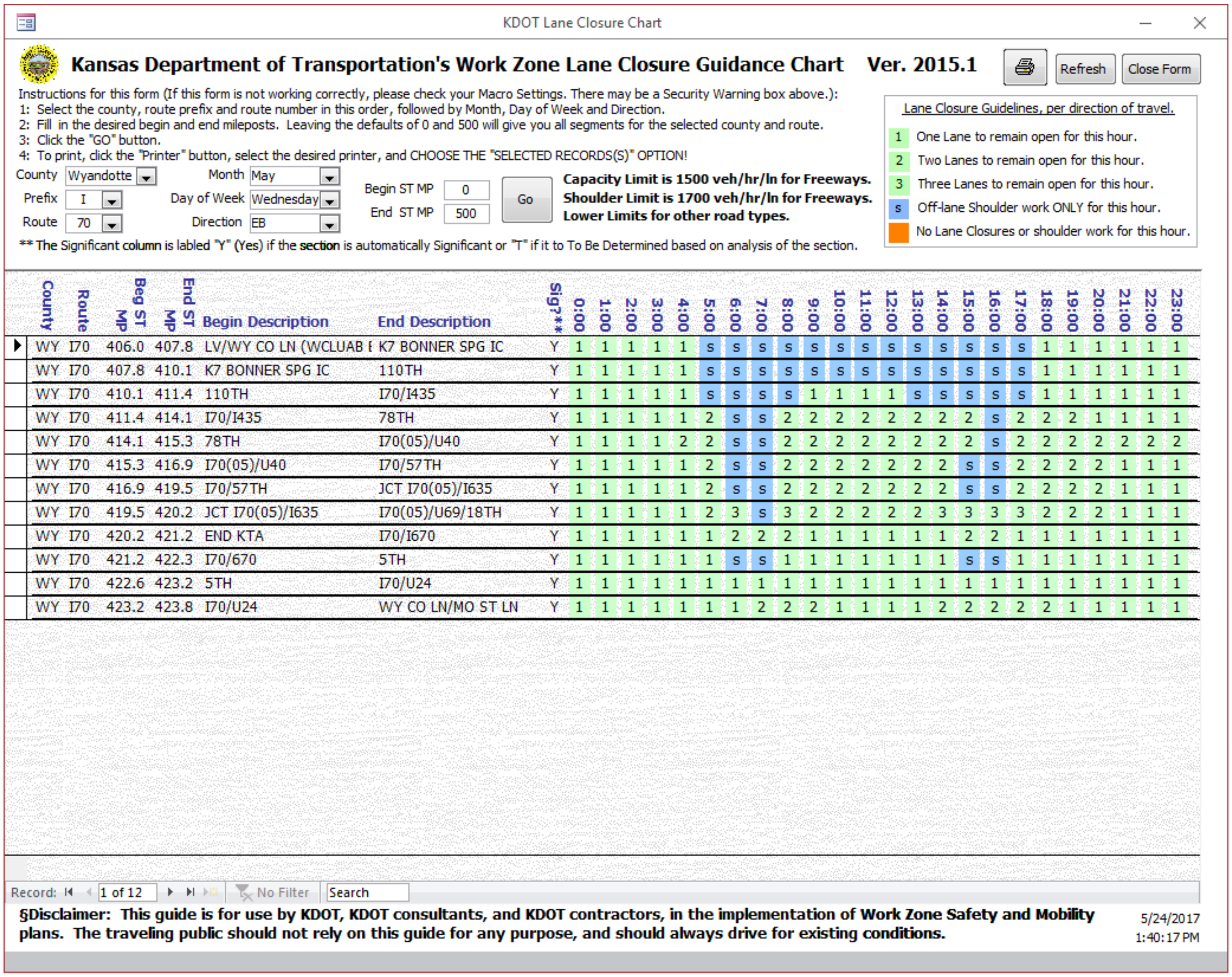
County	Route	Beg ST MP	End ST MP	Begin Description	End Description	Sig?**	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
WY	I70	406.0	407.8	LV/WY CO LN (WCLUAB I	K7 BONNER SPG IC	Y	1	1	1	1	1	1	s	s	s	s	s	s	s	s	s	s	s	s	s	1	1	1	1	1
WY	I70	407.8	410.1	K7 BONNER SPG IC	110TH	Y	1	1	1	1	1	1	s	s	s	s	s	s	s	s	s	s	s	s	s	1	1	1	1	1
WY	I70	410.1	411.4	110TH	I70/I435	Y	1	1	1	1	1	1	s	s	s	s	s	s	s	s	s	s	s	s	s	s	1	1	1	1
WY	I70	411.4	414.1	I70/I435	78TH	Y	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	s	s	s	2	1	1	1	1	1
WY	I70	414.1	415.3	78TH	I70(05)/U40	Y	1	1	1	1	2	2	2	2	2	2	2	2	2	2	s	s	s	s	2	2	2	2	2	2
WY	I70	415.3	416.9	I70(05)/U40	I70/57TH	Y	1	1	1	1	1	1	2	2	2	2	2	2	2	2	s	s	s	s	2	2	1	1	1	1
WY	I70	416.9	419.5	I70/57TH	JCT I70(05)/I635	Y	1	1	1	1	1	2	2	2	2	2	2	2	2	2	s	s	s	s	2	2	2	2	1	1
WY	I70	419.5	420.2	JCT I70(05)/I635	I70(05)/U69/18TH	Y	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	s	s	3	2	2	2	2	1	1
WY	I70	420.2	421.2	END KTA	I70/I670	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	1	1	1	1	1	1
WY	I70	421.2	422.3	I70/670	5TH	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	s	s	s	s	1	1	1	1	1	1
WY	I70	422.6	423.2	5TH	I70/U24	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
WY	I70	423.2	423.8	I70/U24	WY CO LN/MO ST LN	Y	1	1	1	1	1	1	1	2	2	2	1	1	1	1	2	2	2	2	2	1	1	1	1	1

Record: 1 of 12 | No Filter | Search

§Disclaimer: This guide is for use by KDOT, KDOT consultants, and KDOT contractors, in the implementation of Work Zone Safety and Mobility plans. The traveling public should not rely on this guide for any purpose, and should always drive for existing conditions.

5/24/2017
1:40:55 PM

Figure 30 Lane Closure Guide for Westbound I-70 Post-Update



KDOT Lane Closure Chart

Kansas Department of Transportation's Work Zone Lane Closure Guidance Chart Ver. 2015.1

Refresh | Close Form

Instructions for this form (If this form is not working correctly, please check your Macro Settings. There may be a Security Warning box above.):
1: Select the county, route prefix and route number in this order, followed by Month, Day of Week and Direction.
2: Fill in the desired begin and end mileposts. Leaving the defaults of 0 and 500 will give you all segments for the selected county and route.
3: Click the "GO" button.
4: To print, click the "Printer" button, select the desired printer, and CHOOSE THE "SELECTED RECORDS(S)" OPTION!

County: Wyandotte | Month: May | Begin ST MP: 0
Prefix: I | Day of Week: Wednesday | End ST MP: 500
Route: 70 | Direction: EB | Go

Capacity Limit is 1500 veh/hr/ln for Freeways.
Shoulder Limit is 1700 veh/hr/ln for Freeways.
Lower Limits for other road types.

Lane Closure Guidelines, per direction of travel.
1 One Lane to remain open for this hour.
2 Two Lanes to remain open for this hour.
3 Three Lanes to remain open for this hour.
s Off-lane Shoulder work ONLY for this hour.
No Lane Closures or shoulder work for this hour.

** The Significant column is labled "Y" (Yes) if the section is automatically Significant or "T" if it to To Be Determined based on analysis of the section.

County	Route	Beg ST MP	End ST MP	Begin Description	End Description	Sig?**	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
WY	I70	406.0	407.8	LV/WY CO LN (WCLUAB I	K7 BONNER SPG IC	Y	1	1	1	1	1	s	s	s	s	s	s	s	s	s	s	s	s	s	1	1	1	1	1	1
WY	I70	407.8	410.1	K7 BONNER SPG IC	110TH	Y	1	1	1	1	1	s	s	s	s	s	s	s	s	s	s	s	s	s	1	1	1	1	1	1
WY	I70	410.1	411.4	110TH	I70/I435	Y	1	1	1	1	1	s	s	s	s	1	1	1	1	s	s	s	s	s	1	1	1	1	1	1
WY	I70	411.4	414.1	I70/I435	78TH	Y	1	1	1	1	1	2	s	s	2	2	2	2	2	2	2	2	s	2	2	2	1	1	1	1
WY	I70	414.1	415.3	78TH	I70(05)/U40	Y	1	1	1	1	2	2	s	s	2	2	2	2	2	2	2	2	s	2	2	2	2	2	2	2
WY	I70	415.3	416.9	I70(05)/U40	I70/57TH	Y	1	1	1	1	1	2	s	s	2	2	2	2	2	2	2	s	s	2	2	2	2	1	1	1
WY	I70	416.9	419.5	I70/57TH	JCT I70(05)/I635	Y	1	1	1	1	1	2	s	s	2	2	2	2	2	2	2	s	s	2	2	2	2	1	1	1
WY	I70	419.5	420.2	JCT I70(05)/I635	I70(05)/U69/18TH	Y	1	1	1	1	1	2	3	s	3	2	2	2	2	2	3	3	3	3	2	2	2	1	1	1
WY	I70	420.2	421.2	END KTA	I70/I670	Y	1	1	1	1	1	1	2	2	2	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1
WY	I70	421.2	422.3	I70/670	5TH	Y	1	1	1	1	1	1	s	s	1	1	1	1	1	1	1	s	s	1	1	1	1	1	1	1
WY	I70	422.6	423.2	5TH	I70/U24	Y	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
WY	I70	423.2	423.8	I70/U24	WY CO LN/MO ST LN	Y	1	1	1	1	1	1	1	2	2	2	1	1	1	1	2	2	2	2	2	1	1	1	1	1

Record: 1 of 12 | No Filter | Search

§Disclaimer: This guide is for use by KDOT, KDOT consultants, and KDOT contractors, in the implementation of Work Zone Safety and Mobility plans. The traveling public should not rely on this guide for any purpose, and should always drive for existing conditions.

5/24/2017
1:40:17 PM

Figure 31 Lane Closure Guide for Eastbound I-70 Post-Update

Based on the QA/QC process, the new lane closure guide covers a majority of Kansas City metropolitan roads that existed in the previous version of the KDOT lane closure guide. Figure 30 shows the coverage of the new lane closure guide in the Kansas City area based on data from KC Scout sensors from the year 2016.

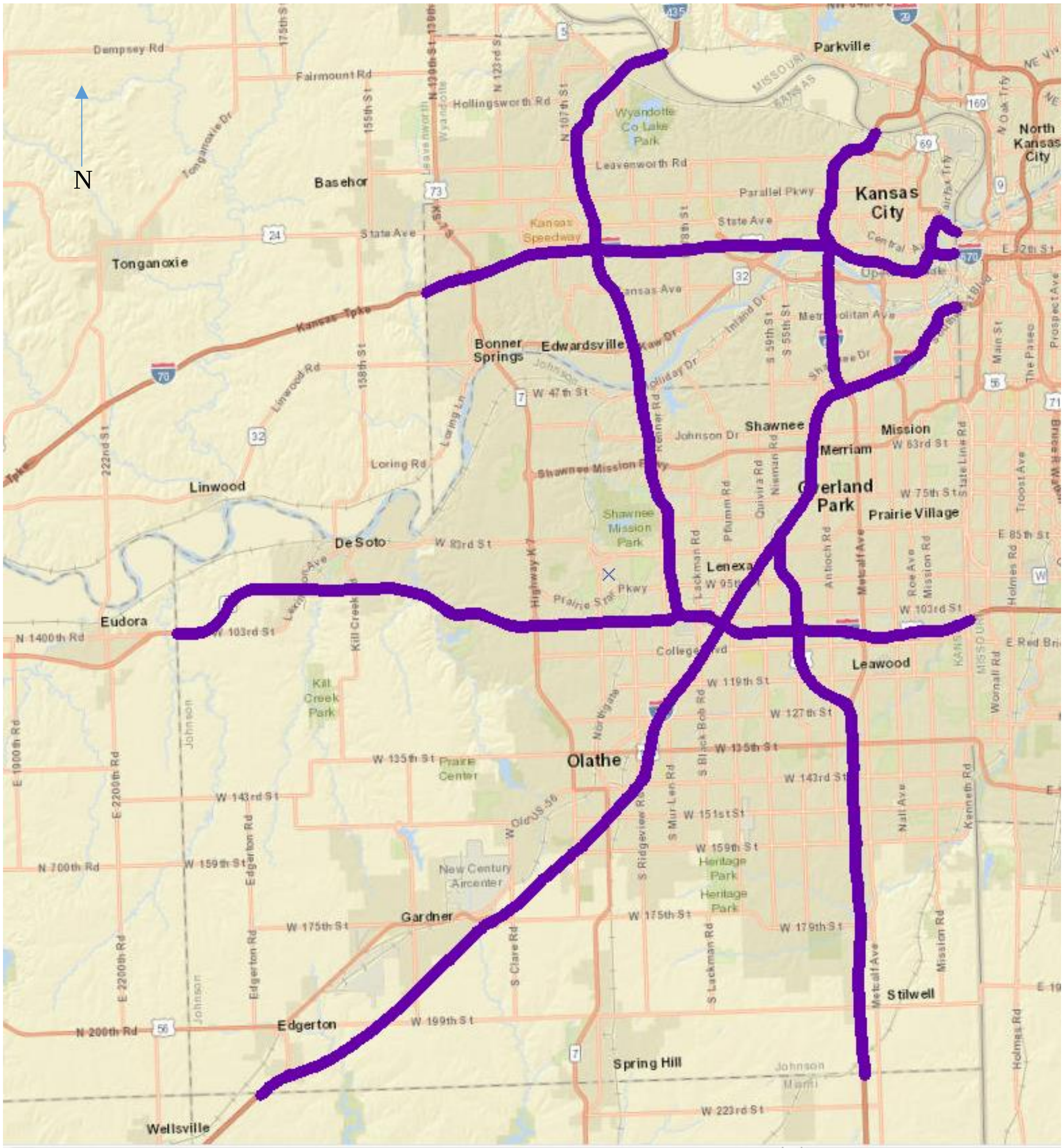


Figure 30 Lane Closure Guide Coverage Area

Chapter 4 - Data Verification

To verify the data collected by the KC Scout sensors used to update the KDOT lane closure guide were accurate, the sensor data were compared with pneumatic road tube data. The pneumatic road tubes, held in place by asphalt tape, were installed in the eastbound lane of K-10 shortly before the exit ramp at the interchange of Woodland Drive. K-10 is a 4-lane median divided highway with a posted speed limit of 70 mph. This section of roadway has an average annual weekday traffic (AAWT) count of approximately 59,322 vehicles with the eastbound direction of travel experiencing approximately 50% of the trips. The road tubes were installed below the KC Scout Wavetronix sensor located in the clear zone of the roadway on a pole with a camera using the configuration as shown in Figure 31. The road tube configuration consisted of four tubes stretching across the road alternating between short and long. The short tubes terminated at the centerline or the roadway. This configuration was chosen because it separated vehicle counts and speeds based on which lane the vehicle was travelling in. However, due to an error in the short tubes installation the short tubes, which monitored the right lane, were not used and the study relied on the tubes that stretched across both lanes of traffic. The configuration used (two road tubes across both lanes) does not allow the separation of traffic into two lanes as shown in Figure 32 and data collected identified both lanes as one lane. Data from the road tubes were collected using a Jamar Apollyon counter located on the side of the roadway.

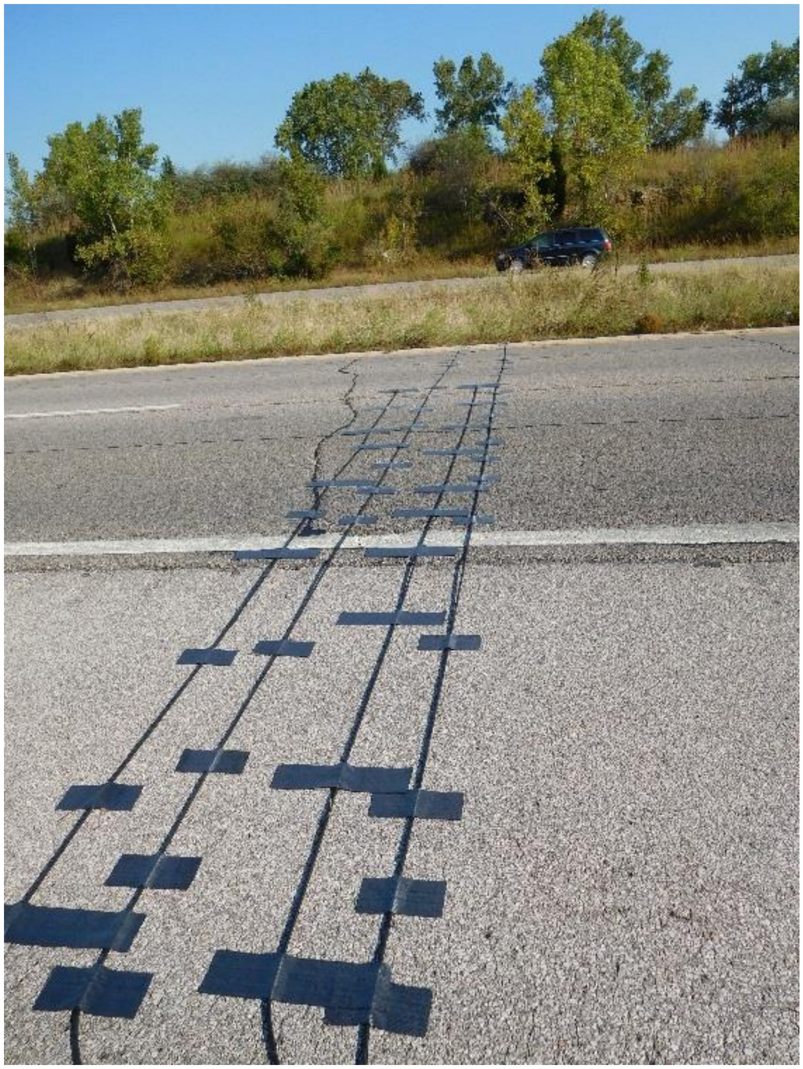


Figure 31 Road Tube Configuration of Alternating Short and Long

Figure 32 Road Tube Configuration Below Data Collection Tower

The road tubes collected data for multiple days, however, a single day of data were used for the verification (Monday) from 12:00 AM to 10:00 PM. The road tubes counted approximately 26,227 vehicles during the time period. An average speed of with 74 mph was observed and an 85^{th} percentile speed of 83 mph was also observed as shown in Table 9.

Table 9 Data Collected from Road Tubes

K-10 at Woodland Interchange	
Vehicle Count	26,227
Average Speed	74 mph
85th Percentile Speed	83 mph

To accurately compare counts and speed between the pneumatic road tubes that observed individual vehicle speed and counts, 5 mph intervals were created to compare to the 5 mph aggregated bins the Wavetronix collected. Figure 33 shows the vehicle counts for 5-mph intervals between 36 mph and 95 mph and the cumulative percentage of vehicle speeds. The largest speed group was found to be between 76 and 80 mph (7,222veh) followed by the speed group between 81 and 85 mph (6,183veh). The cumulative percentage represents the total number of cars counted below the speed. For example, 50 percent of vehicles traveled at or below 74 mph and 85 percent of vehicles traveled at or below 83 mph.

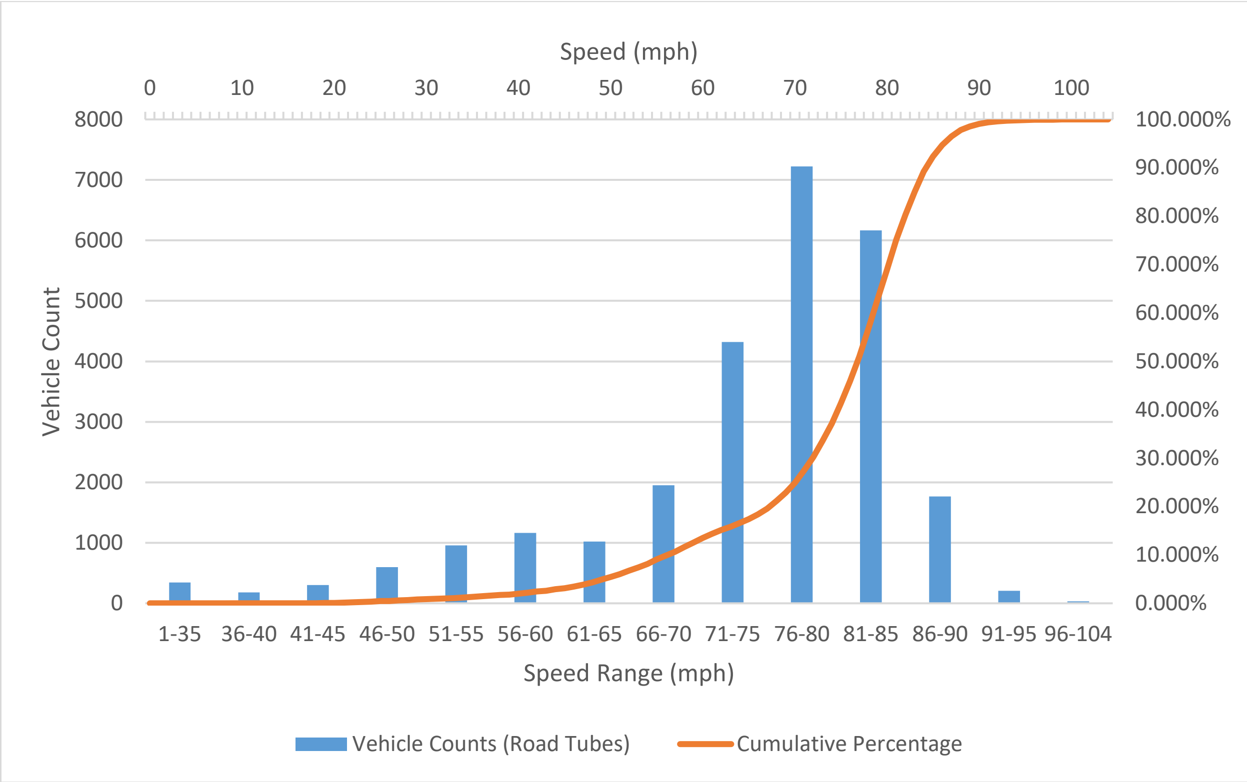


Figure 33 Vehicle Counts for 5-mph Intervals and Cumulative Percentage of Vehicle Speeds

4.1 Sensor Comparison

To determine the accuracy of the KC Scout Wavetronix data collection, two categories were compare to the road tubes which included, 1) traffic counts using 15 minute intervals, and; 2) average speeds using 5 mph intervals. The traffic counts for each 15 minute intervals were compared using a standard t-test. Before a t-test could be used, an f-test was performed to determine if the distribution variances were equal. The f-test found the variance in each sample was not the same. Therefore, a t-test assuming unequal variances was used.

To perform a t-test, a null hypothesis and an alternative hypothesis were developed and tested. The null hypothesis for this analysis was the mean differences were equal to zero, or there were not a statistically significant differences between the means of each distribution. The alternative hypothesis was that the mean differences was not equal to zero, or there was a statistically significant difference between the two distribution means. The t-test used 88 observations for each category: road tubes and KC Scout. The results of the t-test generated a p-value of 0.2166 (two-tail test). The p-value was greater than the tested alpha (0.05, or 95% confidence interval) as shown in Table 10. A p-value greater than 0.05 indicated a rejection of the alternative hypothesis in favor of the null hypothesis. The results indicated the differences in the means were not significantly different.

Table 10 t-Test Conducted on the 15-Minute Vehicle Counts from Road Tubes and KC Scout

	Road Tubes	*KC Scout*
Mean	298.03	338.97
Variance	39064.65	56774.13
Observations	88	88
Hypothesized Mean Difference	0	
df	168	
t Stat	-1.2403	
P(T<=t) one-tail	0.1083	
t Critical one-tail	1.6540	
P(T<=t) two-tail	0.2166	
t Critical two-tail	1.9742	

In addition to conducting the t-test, vehicle counts were plotted showing 3-hour interval counts for both the road tubes and KC Scout Wavetronix sensor as shown in Figure 34. Additionally, a percentage difference was found for each 3-hour interval as was determined and shown in Figure 34. The percentage difference was calculated by determining the difference between KC Scout and Road Tubes and then dividing by the average between the two.

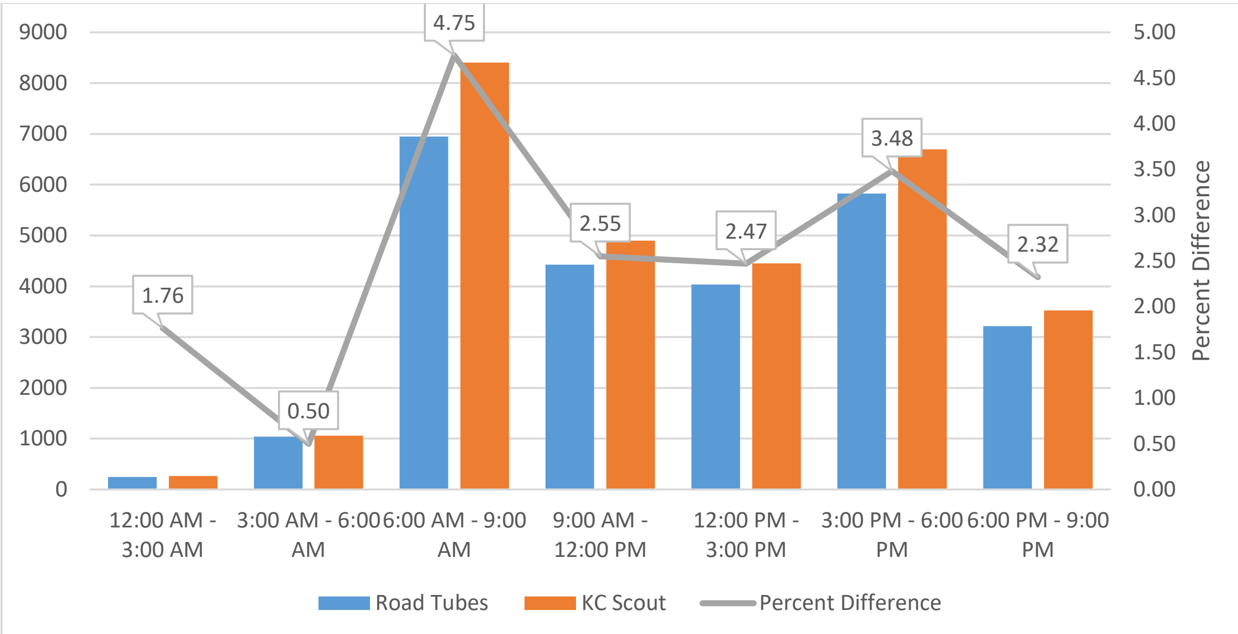


Figure 34 Bar Graph with Vehicle Counts for 3-Hour Intervals and the Percent Difference Between the Two Counters

As shown in Figure 34, the KC Scout Wavetronix sensor consistently counted more vehicles than the road tubes. It was also found that as the number of vehicles counted increased, the percent difference increased apart from between the hours of 12:00 AM and 3:00 PM

The other category compared between the KC Scout Wavetonix sensor and the road tubes was vehicle average speed. Five-minute intervals were chosen to reduce the amount of possible error from the Wavetronix device. Currently, KC Scout collects an average speed every 30 seconds along the highway. However, if no vehicle was present and there was nothing to detect during that 30-second interval, the average speed from the previous interval carried through to the next interval.

The comparison between average speeds collected were performed using a standard t-test using the same methodology as was used to compare vehicle volumes. Additionally, an f-test was used to determine if variances were equal. The results showed the variances between the two data sources were unequal, therefore, a t-test assuming unequal variances was used.

This t-test also used a null hypothesis of the mean difference between the two distributions were equal to zero and an alternative hypothesis that the distribution mean differences were not equal to zero. The results from the t-test showed a p-value below 0.001 (two-tail test) as shown in Table 11. The p-value was lower than the 95% confidence level indicating a rejection of the null hypothesis and accepting the alternative hypothesis. The t-test showed there was a statistically significant difference between the average speeds collected from the KC Scout Wavetronix and road tubes. An additional t-test was conducted correcting the error associated with average speeds being assigned when no vehicle was counted and the p-value was smaller than the p-value shown in Table 11.

Table 11 t-Test Conducted on the 5-Minute Average Speeds (MPH) from Road Tubes and KC Scout

	KC Scout	*Road Tubes*
Mean	69.48	76.19
Variance	45.38	57.11
Observations	264	264
Hypothesized Mean Difference	0	
df	519	
t Stat	-10.772	
P(T<=t) one-tail	7.36E-25	
t Critical one-tail	1.648	
P(T<=t) two-tail	1.47E-24	
t Critical two-tail	1.965	

4.2 Additional Analysis

In addition to verifying the accuracy of the KC Scout sensors, an analysis was performed to determine if a general equation for lane occupancy could be determined. Two separate general equations are used to determine this. The first equation comes from the Federal Highway Administration’s (FHWA) Traffic Control Systems Handbook (FHWA, 2017) as shown by Equation 7.

$$\theta = \frac{100}{TL}\sum_{i=1}^{N}(t_i - D)$$ **Eq. 7**

Where:

θ = Raw occupancy, in percent,
T = Specified time period, in seconds,
L = Ratio of the effective length of the vehicle plus the loop to the vehicle length,
ti = Measured detector pulse presence, in seconds,
N = Number of vehicles detected in the time period, and
D = Detector drop out time – detector pickup time.

The second equation comes from the 4th Edition of Traffic Engineering (Roess, Prassas, & McShane, 2011) as shown by Equation 8.

$$D = \frac{5{,}280 * O}{L_v + L_d}$$ **Eq. 8**

Where:

D = Density, veh/mi/ln,
O = Occupancy, in percent,
L_v = Average length of vehicle, in feet, and
L_d = Length of detector, in feet.

To determine lane occupancy using either equation, specific information was required from both the Wavetronix device and road tubes that were not provided in data outputs such as: length of detector and measured detector pulse presence. A regression analysis was performed in order to find an equation for occupancy without specific detector information. Data used in the analysis originates from five data collection sensors using one week of data in 5-minute intervals. To accomplish this task, eight categories from the sensor data output were used: number of lanes, vehicles per hour, occupancy, speed, and four classifications of vehicles. Using Equation 9, the number of lanes, vehicles per hour, and speed were used to determine density (Roess, Prassas, & McShane, 2011).

$$D = \frac{5280 * vehicles\ per\ hour}{Speed * 3600 * Number\ of\ Lanes} \quad \textbf{Eq. 9}$$

Using backwards elimination, the relationship between occupancy, density, and four classifications of vehicles was determined as shown in Equation 10 with parameter estimates shown in Table 12.

$$O = \beta_0 + \beta_1 * D + \beta_2 * VC1 + \beta_3 * VC2 + \beta_4 * VC3 + \beta_5 * VC4 \quad \textbf{Eq. 10}$$

Where:

O = Occupancy, in percent,
D = Density, veh/mi/ln,
VC1 = Number of motorcycles during interval,
VC2 = Number of passenger cars during interval,
VC3 = Number of recreational vehicles and buses during interval, and
VC4 = Number of tractor-trailers during interval.

Table 12 Parameter Estimates from Regression Equation

Variable	Label	DF	Parameter Estimate	Standard Error	t Value
Intercept	β_0	1	-0.58798	0.01008	-58.32
Density	β_1	1	0.35881	0.00219	164.06
VC1	β_2	1	-0.03098	0.00090325	-34.29
VC2	β_3	1	0.00063075	0.00019463	3.24
VC3	β_4	1	-0.0415	0.00094714	-43.82
VC4	β_5	1	0.06906	0.00138	50.16

The regression analysis was performed at the 95% confidence interval which resulted in a critical t-value of 1.960. As shown in Table 12, the t-value for each of the parameters were greater than the critical t-value resulting in all parameters being kept because each parameter was statistically significant. The regression analysis used 10,080 observations and the equation shown in equation 10 resulted in an R-Square value of 0.971. This indicated that 97.1% of the variance in lane occupancy could be explained by density, and the four vehicle classifications. Based on the R-Square value, the regression equation shows a strong correlation between Occupancy and the five parameters used.

Chapter 5 - Conclusions

Minimizing traffic congestion and delays in densely populated areas is crucial to the functionality of a city. One way to reduce congestion and traffic delays is to implement appropriate scheduling of work zones. Work zones that occur during peak traffic times could reduce highway capacity and cause unnecessary bottlenecking and delays. KDOT created the lane closure guide to minimize the impact of work zones on traffic.

The lane closure guide offers a set of guidelines for contractors and KDOT employees to use to determine when to conduct work that involves traffic lane closures. The lane closure guide uses 1,500 vphpl as the lane capacity during work zone activities. Information collected from a review of relevant literature and a summary of practice surveys found that capacities through work zones varies between 1,200 vphpl and 1,800 vphpl. The range accounts for various locations, fluctuating truck traffic, and terrain type. The value used by the lane closure was within this range.

Once information about capacity was found, the lane closure guide was updated with the most current information available from KC Scout, a network of sensors and cameras that collect traffic data on major freeways in the Kansas City area. The information collected by the sensors is stored in Lee’s Summit, Missouri at the KC Scout headquarters. The data were extracted using the KC Scout user interface. The extracted data included traffic volumes for each hour in both directions for each segment of the lane closure guide.

This study updated two major tables in the lane closure guide: directional hour factors and segment list. Factors in the directional hour factors table were applied to the AAWT to determine an hourly volume in each direction. The segment list table contained each segment and the values associated with the segment, such as the number of lanes and AAWT. The segment list also linked each segment with appropriate directional hour factors, day of week factors, and month factors.

Compared to the previous lane closure guide, the updated lane closure guide provides increased accuracy of current and future traffic patterns. In some instances, the new AAWT was similar to the previous AAWT, indicating that area had not grown significantly since the last update. However, some sections of I-35 had an increase of approximately 20,000 vehicles per day, a change that was most apparent on time restrictions for only shoulder work or forced lane closures. The updated lane closure guide also separates traffic directions, allowing work that requires a lane closure in one direction in the morning and the other direction in the evening, as shown in Figure 30 and Figure 31.

The lane closure guide was not updated for roads outside the KC Scout network, including areas in Wichita, Topeka, Manhattan, and Lawrence, Kansas. In addition, the day of week factor and the month factor were not updated because these factors did not change for some segments on each roadway. Finally, locations with gaps in data coverage also were not updated. One gap in data coverage occurred on I-70 between the interchange of Washington Blvd. and I-70 and the Kansas/Missouri state line. Another gap of data occurred on I-435 at the Gateway Project.

During the sensor verification two separate categories were compared for accuracy: vehicle counts and speed. A t-test comparison found the mean differences between vehicles counts were not significantly different. However, a t-test comparison of the mean differences between average vehicle speeds found the data was statistically different.

In addition to verifying the sensor data a regression analysis was completed to determine if occupancy was based off of roadway density and the four classifications of vehicles used by

KC Scout. The equation shown in the previous section found all variables were statistically significant and could account for over 97% of the variation in occupancy. However, the general equation may not work on all sensors with the KC Scout network because of differences in calibration and other variables that were not available.

5.1 Contributions to Highway Safety and Operations

The research completed in this research project will contribute to highway safety and operations in several ways. One contribution is to KDOT design engineering and contractors working on interstates and highways as well as within work zones in the Kansas City, KS metropolitan area. The updated lane closure guide separates the travel direction and provides a more accurate picture of the expected traffic flows during the week and when appropriate capacity is needed during possible construction times. Another contribution to the state-of-the-practice is using traffic management center to develop lane closure guidance instead of multiple data sources, outdate data, or engineering judgement. Currently, a few states are using traffic management center data to assist in reducing the impact of work zones rather than travel time for the travelling public. It is expected that once KDOT fully implements the revised lane closure guide, lives will be saved, time will be saved, and reduction in headway and increase speeds will help operations on Kansas City highways during construction.

5.2 Study Limitations

During the completion of this project several limitations were determined. One limitation occurred during the KC Scout data extraction phase of the project. Several locations within the Kansas City, Kansas metropolitan area did not have traffic data because of lack of sensors. However, the Gateway Project was recently completed and data collection sensors were installed in the area and have started to collect data. Another limitation of this research project occurred during the road tube data collection. User error and unknown circumstances led to only 22 hours of useable data. The user error occurred because of a misunderstanding from the JAMAR user manual and could have been prevented by speaking to a representative familiar with the counter. Additionally, downloading data from the counter periodically during the duration of data collection may have prevented the unknown cause error. The final limitation occurs with the regression equation found in Chapter 4. One sensor from each interstate and highway in the Kansas City, Kansas metropolitan area was selected to reduce potential bias from using just one sensor. However, the estimates found using the regression equation may not be applicable to all sensors within the network because each sensor is configured individually and all sensors may not be configured identically.

Chapter 6 - References

Al-Kaisy, A., & Hall, F. (2003). Guidelines for Estimating Capacity at Freeway Reconstruction Zones. *Journal of Transportation Engineering*, 572-577.

Benekohal, R., Kaja-Mohideen, A.-Z., & Chitturi, M. (n.d.). *Evaluation of Construction Work Zone Operational Issues: Capacity, Queue, and Delay*.

Bham, G., & Khazraee, H. (2011). *Missouri Work Zone Capacity: Results of Field Data Analysis.* Jefferson City, MO: Missouri Department of Transportation.

Dissanayake, S., & Ortiz, L. (2015). *Highway Work Zone Capacity Estimation Using Field Data from Kansas.* Topeka, KS: Kansas Department of Transportation.

Du, B., & Chien, S. (2014). Feasibility of shoulder use for highway work zone optimization. *Journal of Traffic and Transportation Engineering*, 235-246.

Edara, P., Kianfar, J., & Sun, C. (2012, June). Analytical Methods for Deriving Work Zone Capacities from Field Data. *American Society of Civil Engineers*, 809-818.

Federal Highway Administation. (2017, February). *Traffic Control Systems Handbook: Chapter 3. Control Concepts - Urban and Suburban Streets.* Retrieved from https://ops.fhwa.dot.gov/publications/fhwahop06006/chapter_3p1.htm

Federal Highway Administration. (2012). *Manual on Uniform Traffic Control Devices.* Washington, DC: U.S. Department of Transportation.

Fei, L., Zhu, H., & Han, X. (2016). Analysis of traffic congestion induced by the work zone. *Physica A*, 497-505.

Google Maps. (2017). *Google Maps*. Retrieved from Google: https://www.google.com/maps/@38.9916831,-94.6969082,149a,35y,1.69h,54.91t/data=!3m1!1e3

Guerrini, F. (2014, October 14). *Traffic Congestion Costs Americans $124 Billion A Year, Report Says*. Retrieved from Forbes: https://www.forbes.com/sites/federicoguerrini/2014/10/14/traffic-congestion-costs-americans-124-billion-a-year-report-says/#437dd426c107

Heaslip, K. P. (2007). *Modelling Driver Behavior in Work Zones: An Evaluation of Traffic Flow Impacts in Freeway Work Zones with Full Lane Closures.* Amherst, MA: University of Massachusetts Amherst.

IowaDOT. (2014). *Lane Closure Planning.* Retrieved from Iowa Department of Transportation: https://secure.iowadot.gov/lcptool/Index.aspx

Kansas City Scout. (2017). *Edit Detector Station Report*. Retrieved from Kansas City Scout: http://www.kcscout.net/KcDataPortal/Home/QueryEdit.aspx?id=3051

Kansas Department of Transportation. (2007). *Automated Traffic Recorders in Urban Areas.*

Kwon, E., & Park, C. (2016). *Development of a Guidline for Work Zone Diversion Rate and Capacity Redution.* St. Paul, Minnesota: Minnesota Department of Transportation.

Marsh Products. (2000, November 10). Retrieved from http://www.marshproducts.com/pdf/Inductive%20Loop%20Write%20up.pdf

Maze, T., Schrock, S., & Kamyab, A. (2000). Capacity of Freeway Work Zone Lane Closures. *Mid-Contenent Transportation Symposium*, (pp. 178-183).

Notbohm, T., Drakopoulos, A., & Dehman, A. (2006). *Freeway Work Zone Lane Capacity.*

Roess, R. P., Prassas, E. S., & McShane, W. R. (2011). *Traffic Engineering Fourth Edition.* Upper Saddle River, NJ: Pearson.

Sarasua, W., Davis, W., Chowdhury, M., & Ogle, J. (2005). *Development of a Methodology to Estimate the Interstate Highway Capacity for Short-Term Work Zone Lane Closures.*

Smyth, A. (2015, June 30). *Traffic Monitoring in the National Roads Authority - the why and how*. Retrieved from Engineers Journal: http://www.engineersjournal.ie/2015/06/30/traffic-monitoring-nra/

South Carolina Department of Transportation. (2017, January 10). *Hourly Restrictions for Lane Closures on Interstate Routes.* Retrieved from http://www.scdot.org/doing/technicalPDFs/publicationsManuals/trafficEngineering/InterstateHourRestrictions.pdf

Tennessee Department of Transportation. (2017, February). *Work Zone Safety and Mobility Manual*. Retrieved from TDOT: http://www.tn.gov/tdot/article/roadway-design-work-zone-safety-and-mobility-manual