

Kansas Demonstration Project:
The Use of Smart Work Zone Technology
During Construction of the
I-35/Homestead Lane Interchange in
Johnson County Kansas



Final Report
December 2014



U.S. Department of Transportation
Federal Highway Administration

FOREWORD

The purpose of the Highways for LIFE (HfL) pilot program is to accelerate the use of innovations that improve highway safety and quality while reducing congestion caused by construction. **LIFE** is an acronym for **L**onger-lasting highway infrastructure using **I**nnovations to accomplish the **F**ast construction of **E**fficient and safe highways and bridges.

Specifically, HfL focuses on speeding up the widespread adoption of proven innovations in the highway community. “Innovations” is an inclusive term used to encompass technologies, materials, tools, equipment, procedures, specifications, methodologies, processes, and practices used to finance, design, or construct highways. HfL is based on the recognition that innovations are available that, if widely and rapidly implemented, would result in significant benefits to road users and highway agencies.

Although innovations themselves are important, HfL is as much about changing the highway community’s culture from one that considers innovation something that only adds to the workload, delays projects, raises costs, or increases risk to one that sees it as an opportunity to provide better highway transportation service. HfL is also an effort to change the way highway community decision makers and participants perceive their jobs and the service they provide.

The HfL pilot program, described in Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) Section 1502, includes funding for demonstration construction projects. By providing incentives for projects, HfL promotes improvements in safety, construction-related congestion, and quality that can be achieved through the use of performance goals and innovations. This report documents one such HfL demonstration project.

Additional information on the HfL program is available at www.fhwa.dot.gov/hfl.

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The U.S. Government assumes no liability for its contents or use thereof. This report does not constitute a standard, specification, or regulation.

The U.S. Government does not endorse products or manufacturers. Trade and manufacturers’ names appear in this report only because they are considered essential to the object of the document.

1. Report No.	2. Government Accession No	3. Recipient's Catalog No	
3. Title and Subtitle Kansas Demonstration Project: Improvements to the Homestead Lane/I-35 Interchange in Johnson County		5. Report Date December 2014	6. Performing Organization Code
7. Authors Jay Bledsoe, Deepak Raghunathan, and Jerry Ullman		8. Performing Organization Report No.	
9. Performing Organization Name and Address Applied Research Associates, Inc. 100 Trade Centre Drive, Suite 200 Champaign, IL 61820		10. Work Unit No. (TRAIS) C6B	11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Infrastructure Federal Highway Administration 1200 New Jersey Avenue SE Washington, DC 20590		13. Type of Report and Period Covered Final Report	14. Sponsoring Agency Code
15. Supplementary Notes Contracting Officer's Representative: Julie Zirlin Contracting Officer's Task Manager: Ewa Flom			
16. Abstract The project described in this report was located at the intersection of I-35 and Homestead Lane in Johnson County, Kansas. Prior to construction, Homestead Lane was a two-lane highway passing over I-35 just outside Olathe, Kansas. There was no access to I-35 at this location. At the time of construction, I-35 was a four-lane interstate route carrying more than 25,000 vehicles per day. While the interchange design (diverging diamond) at this location is itself new to Kansas, the Highways for LIFE innovation involves the use of a real-time traffic system intended to provide direct information to the traveling public. It consists of a series of portable trailer-mounted message boards that display information from traffic detection trailers spaced along the route. The messages are intended to provide the public with information concerning travel time, delay, congestion, or other events within the work zone far enough in advance of their decision points to allow alternate route selection. The trailer-mounted sensors collect vehicle speed, classification, volume, and lane occupancy data for up to 10 lanes of traffic in each direction. These data are supplied to software via the internet and analyzed, resulting in a completely automated system to provide appropriate messages to the public through the variable message boards. There was only one crash reported during the construction period. However, the crash was reported as a "medical emergency" and was not considered related to the construction activities. The Smart Work Zone technology employed on this project did not eliminate any of the costs associated with traditional construction. All costs, excluding the construction costs, associated with the innovation were considered. An economic analysis showed that the implementation of the Smart Work Zone technology resulted in an additional cost of approximately \$1,650,000. The majority of this cost was associated with the lease/purchase of the portable message system, the associated software and upgrades to existing software, and data analysis.			
17. Key Words Highways for LIFE,		18. Distribution Statement No restriction. This document is available to the public through the Highways for LIFE website: www.fhwa.dot.gov/hfl/	
Security Classif. (of this report) Unclassified	19. Security Classif. (of this page) Unclassified	20. No. of Pages 57	21. Price

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
(none)	mil	25.4	micrometers	µm
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yards	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	Newtons	N
lbf/in ² (psi)	poundforce per square inch	6.89	kiloPascals	kPa
k/in ² (ksi)	kips per square inch	6.89	megaPascals	MPa
DENSITY				
lb/ft ³ (pcf)	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m ³
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
µm	micrometers	0.039	mil	(none)
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela per square meter	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	Newtons	0.225	poundforce	lbf
kPa	kiloPascals	0.145	poundforce per square inch	lbf/in ² (psi)
MPa	megaPascals	0.145	kips per square inch	k/in ² (ksi)

TABLE OF CONTENTS

INTRODUCTION.....	1
HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS	1
Project Solicitation, Evaluation, and Selection	1
HfL Project Performance Goals	2
REPORT SCOPE AND ORGANIZATION	3
PROJECT OVERVIEW AND LESSONS LEARNED	5
PROJECT OVERVIEW	5
DATA COLLECTION	5
ECONOMIC ANALYSIS	6
LESSONS LEARNED.....	6
PROJECT DETAILS	7
BACKGROUND.....	7
PROJECT DESCRIPTION.....	8
DATA ACQUISITION AND ANALYSIS	19
SAFETY	19
CONSTRUCTION CONGESTION AND TRAVEL TIME STUDY	20
Lane Closures and Detours	20
Traffic Study.....	21
QUALITY	26
USER SATISFACTION	27
ECONOMIC ANALYSIS	29
CONSTRUCTION COSTS	29
USER COSTS.....	29
Traffic Patterns and Queuing.....	30
Delay Costs	31
SAFETY COSTS.....	32
COST SUMMARY	32
TECHNOLOGY TRANSFER.....	33
APPENDIX: USER SATISFACTION SURVEY	35
ACKNOWLEDGMENTS	47
REFERENCES.....	49

LIST OF FIGURES

Figure 1. Map. Project location.....	7
Figure 2. Photo. First portable changeable message sign location. (courtesy: KDOT).....	12
Figure 3. Photo. Homestead Lane Bridge over I-35 being demolished during an overnight closure. (courtesy: KDOT).....	13
Figure 4. Map. Placement of data collection and message boards along the project (courtesy: KDOT).....	13
Figure 5. Photo. CCTV trailer.....	14
Figure 6. Photo. Noncontact sensor used to collect traffic data.....	14
Figure 7. Screenshot. Project information incorporated into regional application.....	15
Figure 8. Map. View of interchange design (courtesy: KDOT).	17
Figure 9. Map. I-35 detour route (courtesy: KDOT).	21
Figure 10. Map. WIM site (circled in red) #E7PK42 (source: KDOT website).....	30
Figure 11. Graph. Traffic distribution trends at the project location.	31
Figure 12. Illustration. KDOT’s webinar invitation.	33
Figure 13. Chart. Frequency of travel.....	35
Figure 14. Chart. Construction efforts on highway	36
Figure 15. Chart. Satisfaction with Construction Efforts	37
Figure 16. Chart. Knowledge of Smart Work Zone.....	38
Figure 17. Chart. Ratings of the Usefulness of Various Smart Work Zone Attributes	39
Figure 18. Chart. Support for KDOT’s Smart Work Zone features	40
Figure 19. Chart. Overall experience driving through I-35	41
Figure 20. Chart. Overall satisfaction with the Smart Work Zone on I-35	42
Figure 21. Chart. Primary sources of information about this construction zone	43
Figure 22. Chart. Age Categories	44
Figure 23. Chart. Gender of Respondents.....	45

LIST OF TABLES

Table 1. Bid results.	16
Table 2. Major project milestones.	16
Table 3. Preconstruction crash statistics, 2008-2012.	19
Table 4. Construction closure schedule.	20
Table 5. Location of Wavetronics sensors.	23
Table 6. Comparison of traffic counts before and during construction.	24
Table 7. Travel times and average speeds, northbound.	25
Table 8. Travel times and average speeds, southbound.	26
Table 9. Capital construction cost comparison.	29
Table 10. Traffic inputs for queue check.	31
Table 11. Frequency of travel.	35
Table 12. Construction efforts on highway.	36
Table 13. Satisfaction with Various Construction Efforts.	37
Table 14. Knowledge of Smart Work Zone.	38
Table 15. Ratings of the Usefulness of Various Smart Work Zone Attributes.	39
Table 16. Support for KDOT’s Smart Work Zone features.	40
Table 17. Overall experience driving through I-35.	41
Table 18. Overall satisfaction with the Smart Work Zone on I-35.	42
Table 19. Primary sources of information about this construction zone.	43
Table 20. Age Categories.	44
Table 21. Gender of Respondents.	45

ABBREVIATIONS AND SYMBOLS

CCTV	closed-circuit television
dB(A)	A-weighted decibel
FHWA	Federal Highway Administration
HfL	Highways for LIFE
IRI	International Roughness Index
ITS	intelligent transportation system
LED	light-emitting diode
LTPP	Long Term Pavement Performance
KDOT	Kansas Department of Transportation
MARC	Mid-America Regional Council
OBSI	onboard sound intensity
OSHA	Occupational Safety and Health Administration
PDO	property damage only
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users

INTRODUCTION

HIGHWAYS FOR LIFE DEMONSTRATION PROJECTS

The Highways for LIFE (HfL) pilot program, the Federal Highway Administration (FHWA) initiative to accelerate innovation in the highway community, provides incentive funding for demonstration construction projects. Through these projects, the HfL program promotes and documents improvements in safety, construction-related congestion, and quality that can be achieved by setting performance goals and adopting innovations.

The HfL program—described in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)—may provide incentives to a maximum of 15 demonstration projects a year. The funding amount may total up to 20 percent of the project cost, but not more than \$5 million. Also, the Federal share for an HfL project may be up to 100 percent, thus waiving the typical State-match portion. At the State's request, a combination of funding and waived match may be applied to a project.

To be considered for HfL funding, a project must involve constructing, reconstructing, or rehabilitating a route or connection on an eligible Federal-aid highway. It must use innovative technologies, manufacturing processes, financing, or contracting methods that improve safety, reduce construction congestion, and enhance quality and user satisfaction. To provide a target for each of these areas, HfL has established demonstration project performance goals.

The performance goals emphasize the needs of highway users and reinforce the importance of addressing safety, congestion, user satisfaction, and quality in every project. The goals define the desired result while encouraging innovative solutions, raising the bar in highway transportation service and safety. User-based performance goals also serve as a new business model for how agencies can manage the highway project delivery process.

HfL project promotion involves showing the highway community and the public how demonstration projects are designed and built and how they perform. Broadly promoting successes encourages more widespread application of performance goals and innovations in the future.

Project Solicitation, Evaluation, and Selection

FHWA has issued open solicitations for HfL project applications annually since fiscal year 2006. State highway agencies submit applications through FHWA Divisions. The HfL team reviews each application for completeness and clarity, and contacts applicants to discuss technical issues and obtain commitments on project issues. Documentation of these questions and comments is sent to applicants, who responded in writing.

The project selection panel consists of representatives of the FHWA offices of Infrastructure, Safety, and Operations; the Resource Center Construction and Project Management team; the Division offices; and the HfL team. After evaluating and rating the applications and

supplemental information, panel members convene to reach a consensus on the projects to recommend for approval. The panel gives priority to projects that accomplish the following:

- Address the HfL performance goals for safety, construction congestion, quality, and user satisfaction.
- Use innovative technologies, manufacturing processes, financing, contracting practices, and performance measures that demonstrate substantial improvements in safety, congestion, quality, and cost-effectiveness. An innovation must be one the applicant State has never or rarely used, even if it is standard practice in other States.
- Include innovations that will change administration of the State's highway program to more quickly build long-lasting, high-quality, cost-effective projects that improve safety and reduce congestion.
- Will be ready for construction within 1 year of approval of the project application. For the HfL program, FHWA considers a project ready for construction when the FHWA Division authorizes it.
- Demonstrate the willingness of the applicant department of transportation to participate in technology transfer and information dissemination activities associated with the project.

HfL Project Performance Goals

The HfL performance goals focus on the expressed needs and wants of highway users. They are set at a level that represents the best of what the highway community can do, not just the average of what has been done. States are encouraged to use all applicable goals on a project:

- **Safety**
 - Work zone safety during construction—Work zone crash rate equal to or less than the preconstruction rate at the project location.
 - Worker safety during construction—Incident rate for worker injuries of less than 4.0, based on incidents reported via Occupational Safety and Health Administration (OSHA) Form 300.
 - Facility safety after construction—Twenty percent reduction in fatalities and injuries in 3-year average crash rates, using preconstruction rates as the baseline.
- **Construction Congestion**
 - Faster construction—Fifty percent reduction in the time highway users are impacted, compared to traditional methods.
 - Trip time during construction—Less than 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling.
 - Queue length during construction—A moving queue length of less than 0.5 miles in a rural area or less than 1.5 miles in an urban area (in both cases, at a travel speed 20 percent less than the posted speed).
- **Quality**
 - Smoothness—International Roughness Index (IRI) measurement of less than 48 inches per mile.

- Noise—Tire-pavement noise measurement of less than 96.0 A-weighted decibels (dB(A)), using the onboard sound intensity (OBSI) test method.
- **User Satisfaction**
 - User satisfaction—An assessment of how satisfied users are with the new facility compared to its previous condition and with the approach used to minimize disruption during construction. The goal is a rating of 4 or more points on a 7-point Likert scale.

REPORT SCOPE AND ORGANIZATION

This report documents the Kansas Department of Transportation's (KDOT) HfL demonstration project, which involved the use of a work zone intelligent transportation system (ITS) during the construction of a diverging diamond interchange at the intersection of I-35 and Homestead Lane in Johnson County. The report presents project details relevant to the HfL program, including safety, construction congestion, and user satisfaction. HfL performance metrics and economic analysis lessons learned are also discussed, along with innovative methods of public involvement and technology transfer.

PROJECT OVERVIEW AND LESSONS LEARNED

PROJECT OVERVIEW

The project was located at the intersection of I-35 and Homestead Lane in Johnson County. Prior to construction, Homestead Lane was a two-lane highway passing over I-35 just outside Olathe. There was no access to I-35 at this location. At the time of construction, I-35 was a four-lane interstate route (two lanes in each direction) carrying more than 25,000 vehicles per day.

While the interchange design (diverging diamond) at this location is itself new to Kansas, the HfL innovation involves the use of a real-time traffic system intended to provide direct information to the traveling public. It consists of a series of portable trailer-mounted message boards that display information from traffic detection trailers spaced along the route. The messages are intended to provide the public with information concerning travel time, delay, congestion, or other events within the work zone far enough in advance of their decision points to allow alternate route selection.

The trailer-mounted sensors collect vehicle speed, classification, volume, and lane occupancy data for up to 10 lanes of traffic in each direction. The data are supplied to software via the internet and analyzed, resulting in a completely automated system to provide appropriate messages to the public through the variable message boards.

DATA COLLECTION

Safety, construction congestion, and user satisfaction data were collected before and during construction to demonstrate that innovations can be deployed while simultaneously meeting the HfL performance goals in these areas.

The safety goals for the project included both worker safety and motorist measures.

The worker safety goal was an incident rate of 4.0 or less based on the OSHA 300 form. There were no worker injuries reported during the construction of this project, obviously achieving the worker safety goal.

The motorist goal during construction was a crash rate equal to or less than the preconstruction crash rate. There was only one crash reported during the construction period. However, the crash was reported as a “medical emergency” and was not considered related to the construction activities. Given this consideration, the absence of any crashes within the work zone results in a crash rate less than the 3-year average crash rate reported for this location.

No user satisfaction survey was conducted prior to construction. However, a survey was conducted after construction was completed. The results of this survey are presented in the appendix.

ECONOMIC ANALYSIS

The Smart Work Zone technology employed on this project did not eliminate any of the costs associated with traditional construction. All costs associated with the innovation were considered above the cost of construction. An economic analysis showed that the implementation of the Smart Work Zone technology resulted in an additional cost of approximately \$1,650,000. The majority of this cost was associated with the lease/purchase of the portable message system, the associated software and upgrades to existing software, and data analysis. The equipment and software remain with the agency for use on future projects, and Kansas is expecting the useful life of the equipment to be approximately 5 years.

LESSONS LEARNED

The experience gained on this project was extremely valuable to the KDOT. The use of this new technology provided several insights in the areas traffic management that will be useful in future implementations.

Some issues were identified that should be considered for future use of this technology:

- The side fire radar was difficult to keep aligned during construction, which resulted in significant loss of data. There is a need to check the configuration of the devices and perform more frequent data checks during construction.
- The display signs used white light-emitting diodes (LEDs) that proved difficult to read during daylight hours.
- Although the vendor liked the process of not dealing with the DOT directly for the bidding and contracting process, communications with the vendor proved more difficult during the operations phase.

In addition:

- KDOT feels that there is a need to have systems engineering process and documentation at an early stage for projects of similar nature.
- KDOT recommends the use of a systems testing clause in the contract language for future Smart Work Zone projects.
- KDOT recommends the use of detailed sheet showing how Smart Work Zone systems fit into the standard drawing for typical signing.
- KDOT also feels that there is a scope for the use of Smart Work Zone systems in the work area to mitigate downstream traffic impacts.

Feedback from the public via the user survey indicated that there was a high level of satisfaction with the product and its operation.

The overall success of this project—as measured in reduced congestion, reduced crash incidents, and user satisfaction—will encourage the future use of this technology.

PROJECT DETAILS

BACKGROUND

The I-35 and Homestead Lane Interchange Project, Kansas Department of Transportation (KDOT) Project Number 35-46 KA 1109-02, was located in Johnson County, Kansas, a few miles southwest of Olathe (see figure 1). The urban areas closest to the project location were Edgerton to the northwest and Gardner to the northeast. The existing structure on Homestead provided no access to the interstate and was constructed in 1959. The area has seen a significant increase in traffic due to the development of land just north of the project location, prompting the need to expand the capacity of roadway and provide interstate access.

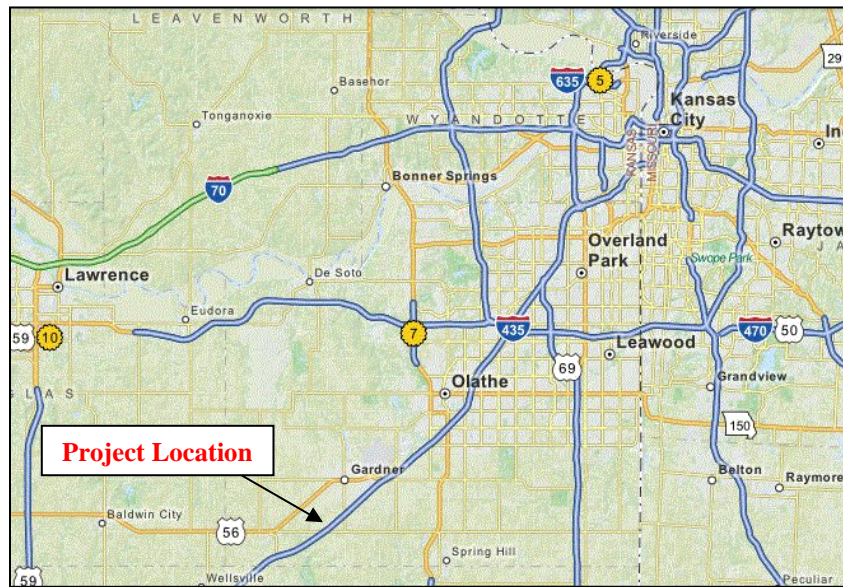


Figure 1. Map. Project location.

The project was 1.48 miles long and involved construction of a new grade separated diverging diamond interchange, roadway improvements along Homestead Lane, and intersection improvements at 199th Street. In addition, the project also included demolition of the existing Homestead Lane Bridge, eradication of the existing Homestead Lane from I-35 north to 199th Street, and reconstruction of Homestead Lane from I-35 north to 199th Street as a 4-lane roadway. This project was tied to KDOT Project 46 KA-1109-03 which involved reconstruction of Homestead Lane between 199th Street and 191st Street, and KDOT project 46 KA-1529-01 which involved reconstruction of 191st Street between Waverly Road and Four Corners Road. This I-35 and Homestead Lane Interchange Project was identified as a significant project according to the significant project criteria as defined in the Kansas Work Zone Safety and Mobility Processes and Procedures ⁽¹⁾.

During the project, the existing plain shoulders were replaced with reinforced shoulders for future use as driving lanes, and I-35 was reduced to one lane in each direction with concrete safety barriers 24 hours/day. Partnering with KDOT on this project were the counties of Johnson

and Miami, the cities of Edgerton and Gardner, Mid-America Regional Council (MARC), and the FHWA.

Per 2011 traffic estimates, the traffic volume at I-35 in the vicinity of the interchange was approximately 25,900 vehicles per day, of which 19.8 percent were heavy vehicles. The volumes are forecasted to be between 70,000 vehicles per day south of the interchange and 91,925 vehicles per day north of the interchange by the year 2040.

PROJECT DESCRIPTION

Smart Work Zone Systems

Although Smart Work Zone systems have been around for more than 13 years, they have become more robust and scalable, and they have found elaborate use over the last 5 years or so. They are portable and automated systems with temporary components that obtain and analyze traffic flow data in real time, providing frequently updated information to motorists. Smart Work Zone systems are used to address challenges such as increased exposure, increased probability of crashes, increased congestion, and increased customer frustration, and they can be leased, purchased, or acquired through contractors. ITS technology is used to provide:

- Effective work zone management and operations.
- Improved work zone safety, mobility, and customer satisfaction.
- Improved lane capacity.
- Estimation of traffic delays.
- Reduced travel times and queue lengths.
- Queue detection and warning.
- Better incident detection and management.
- Improved speed management and enforcement.
- Improved performance monitoring.
- Assessing work hours.
- Improved traffic monitoring and management (e.g., dynamic lane merge systems).
- Tracking of contract incentives and disincentives.
- Improved communications and relationships with the traveling public and stakeholders.

The ITS tools can be used both in and around the work zones. The ITS components include:

- Sensors (e.g., Bluetooth, radar) to collect data on traffic conditions.
- Communications equipment to transfer the data.
- Software to process/analyze the data and data storage.
- Electronic equipment to disseminate information to end users and implement traffic control/management decisions (e.g., web, variable message signs).

These tools typically are used in conjunction with sound planning, traffic control, coordination, communication, and impacts estimation.

Work Zone Challenges and Use of ITS

The primary challenges encountered on work zones and their ITS-related responses include:

- **Increased congestion:** The increased congestion in the work zone occurs due to lane closures, lane shifts, and merge conditions. These conditions result in increased end-of-queue crashes, increased delay, road user dissatisfaction, increased difficulty in emergency vehicle access and responses, and reduced efficiency because of delayed contractor vehicle access. To reduce the congestion-related problems in work zones, the following ITS technologies are employed:
 - Speed detection and warning systems.
 - Traveler information systems, especially active diversion scenario where motorists are provided alternate route information.
 - Data on best times to work and for deliveries, such as travel time data that can be used to adjust lane closure hours and to help contractors plan for delivery schedules.
- **Speed management concerns:** Speeding vehicles pose a serious threat to the safety of the motorists and workers. Thus, it is important to have effective speed management measures in work zones. Some of the work zone speed-related challenges include setting of speed limits, improving compliance with speed limits, reduced availability of law enforcement, and availability of limited areas to pull over speeders. These challenges can be addressed with the use of speed monitoring systems, variable speed limit systems, and automated speed enforcement systems.
- **Increased crash frequency:** The crash-related challenges in work zones include the following:
 - Promptness of incident detection and response.
 - Increased congestion.
 - Increased secondary crashes.
 - Enhanced intrusions.
 - Reduced work vehicle access/egress.

These challenges are addressed using cameras and queue detection systems, intrusion alarms, and entry/exit warning signs.

- **Performance monitoring concerns:** The performance monitoring challenges in work zones are because of the following:
 - Lack of adequate work zone performance data/resources on safety, mobility, and work zone processes. This includes the absence of real time data.
 - Limited personnel to gather data.
 - Difficulty in assessing impacts and estimating work zone performance.
 - Limited information available on work windows.
 - Ineffectiveness of work zone strategies.

The performance-related challenges can be addressed through archiving performance data, determining best work times, and documenting the effects of different work zone strategies.

Although work zone ITS provides a solution to the aforementioned challenges, it needs to be used in conjunction with other work zone strategies such as project coordination and scheduling, contracting, accelerated construction technologies, transportation management and planning, and public information and outreach campaigns.

ITS systems have matured in recent times, and the availability of more permanent and reliable ITS, increased documentation, and a better understanding of the same is helping agencies put these systems to better use.

Motivation for Innovation

The intent of this project was to build an interchange to provide access to I-35, to accommodate the significant increase in traffic due to a new intermodal facility and increased development in the region. The northeast segment of I-35 was congested during peak hours, and there were projects planned for construction near I-35 and I-435 in Kansas City, just 15 miles to the northeast of the location. Potential congestion and potential impacts from nearby projects warranted traffic mitigation measures. In addition, KDOT noted that any breakdown in the Smart Work Zone systems would not severely hinder the traffic operations or affect the contractor's schedule, and the agency anticipated no severe traffic congestion during the construction. All these factors, along with the project timeframe and the proximity of the location to KDOT headquarters, made this project a good candidate for deploying innovative technologies.

To meet the HfL goals, KDOT wanted to do the following:

- Reduce the number of vehicles traveling through the work zone by notifying drivers of congestion at a time and location when drivers familiar with the area can choose alternate routes.
- Enhance traffic flows through work zones with fewer instances of braking and slowing of vehicles by giving advanced information to drivers by means of a public website.
- Use traffic data to identify the time of day the traffic volumes are low, thereby allowing for contractors to spend more time at the work site.

KDOT also planned to use a portion of the HfL grants to upgrade their ITS software for use in future projects.

Smart Work Zone Specifications

In addition to its own permanent ITS and maintenance equipment specifications, KDOT used Smart Work Zone specification language on system specifications and vendor qualifications from other States. The specifications were then reviewed by KDOT contracting, KDOT legal

staff, the local FHWA division office, and a contractor hired by KDOT to check for the presence of any proprietary language.

KDOT's Smart Work Zone System Overview

KDOT's goals on this project included using Smart Work Zone systems to provide real-time traffic information to motorists upstream of key decision points to help increase safety and mobility. KDOT's key requirements for the Smart Work Zone systems used on this project were:

- Portability – Easy to carry, install, and use on multiple projects.
- Real-time capabilities – To provide real-time information to road users.
- Automated system – To provide a fully automated system with minimum manual intervention, such as overriding message signs during incidents.
- Single source proven system – For having a reliable system that has been proven to be effective in previous implementations.
- Public website – To provide users with advanced notifications of traffic flow patterns.

KDOT's Smart Work Zone system applications on this project included the following:

- Queue warnings.
- Automated variable speed limits.
- Travel times.
- Alternate routes (as appropriate).

Some of the traffic related benefits KDOT achieved through the use of Smart Work Zone Systems were the following:

- KDOT was able to provide real time information to the traveling public.
- The speed limits could be changed real time to ease traffic congestion problems, encourage traffic speed compliance, and reduced rear end crashes.
- Promotion of the public website by the KDOT helped the travelling public to make informed decisions on their travel and choose alternate routes if necessary.

Traffic Control and Field Operations

The work zone was shorter compared to the interchange, with the northbound and southbound message boards being around 15 miles apart. The distance between the first message board and the last variable speed limit sign was around 9 miles. The detour around the project location was around 13 miles.

A detailed Temporary Traffic Control Plan was prepared for this project. Per the plan, traffic control operations were required to be conducted for construction of the intersection of 199th Street and Homestead Lane, as well as improvements adjacent to I-35. During construction, the Homestead Lane from 207th Street to 199th Street was to be closed and local access was to be provided on an as needed basis; however no through traffic was to be accommodated. The intersection of 199th Street and Homestead Lane was to be closed during the reconstruction of

the intersection. A detour plan was created to direct traffic traveling both northbound and southbound on Homestead Lane to utilize Waverly Road to the east, and traffic traveling eastbound and westbound on 199th Street to use 191st street to the north. The construction of the interchange ramps, acceleration and deceleration lanes required two phases of work adjacent to the existing through lanes on I-35 to be carried out. While the first phase would involve placement of concrete safety barrier on the shoulders of both northbound and southbound I-35 during work beyond the existing shoulder, Phase 2 would require a lane to be dropped on I-35 in each direction so as to construct acceleration and deceleration lanes. Lanes on I-35 would be dropped using advanced signing as detailed on KDOT Standard Detail TE744, and Type F-3 concrete safety barrier was installed to protect the work zone. A layout plan was also created and included in the project drawings detailing the work zone requirements ⁽¹⁾.

A total of 18 message boards, 12 on the mainline and 6 on the sides, were deployed on this project. Figure 2 is an aerial photo showing the location of the first portable changeable message sign on the project.



Figure 2. Photo. First portable changeable message sign location. (courtesy: KDOT)

The demolition of the Homestead lane bridge over I-35 in Johnson County was also carried out. The demolition required significant coordination with numerous organizations including local municipalities, police, fire, and other emergency response agencies. A dirt bed was placed onto the existing I-35 pavement underneath the bridge on both northbound and southbound I-35 to protect it, and then demolition work was carried out. The bridge deck was then removed by utilizing heavy equipment, and the bridge columns were removed using the blasting process (see figure 3).



Figure 3. Photo. Homestead Lane Bridge over I-35 being demolished during an overnight closure. (courtesy: KDOT)

KDOT used more than 50 noncontact sensors, cameras, and variable message signs placed along side the roadway to collect and transfer data to a central processor via the internet (see figure 4). After analysis, the software sends the appropriate message to a series of variable message boards strategically along the highway, to relay information to the public.



Figure 4. Map. Placement of data collection and message boards along the project (courtesy: KDOT).

Figures 5 and 6 show the closed-circuit television (CCTV) trailer and noncontact sensor that were used to collect the traffic data on this project.



Figure 5. Photo. CCTV trailer.



Figure 6. Photo. Noncontact sensor used to collect traffic data.

Public Outreach

In addition to the portable message signs placed along the roadway, traffic data and video feeds were supplied to the Kansas City traffic management center, KCSCOUT (<http://www.kcscout.net/>) to aid in the early detection of incidents, queue lengths, and traffic flow. The media and the traveling public were updated about the traffic flow patterns, lane closures, news releases, and other project-related information through the following resources:

- Public website (<http://public.jamlogic.com/Trafax/287/3>).
- Greater Kansas City Metro Area website (www.ksdot.org/kcmetro/default.asp).
- KDOT 511 traveler information. Road users could call 511 on any phone (landline or cellular) from anywhere in Kansas to learn more about traffic impacts on this project.
- KDOT 511 website (<http://511.ksdot.org>).
- I-35 Southwest Johnson County Interchange website (<http://i35swjohnsoncointerchange.ksdot.org/>).
- Kansas City Metro Area's Twitter account, @KansasCityKDOT.

Users of KCSCOUT were directed to the Jamlogic map, where camera feeds and content of the message boards could be viewed before deciding on a travel route. Figure 7 shows a graphic representation of the collected data along with a real-time camera feed from the project location.

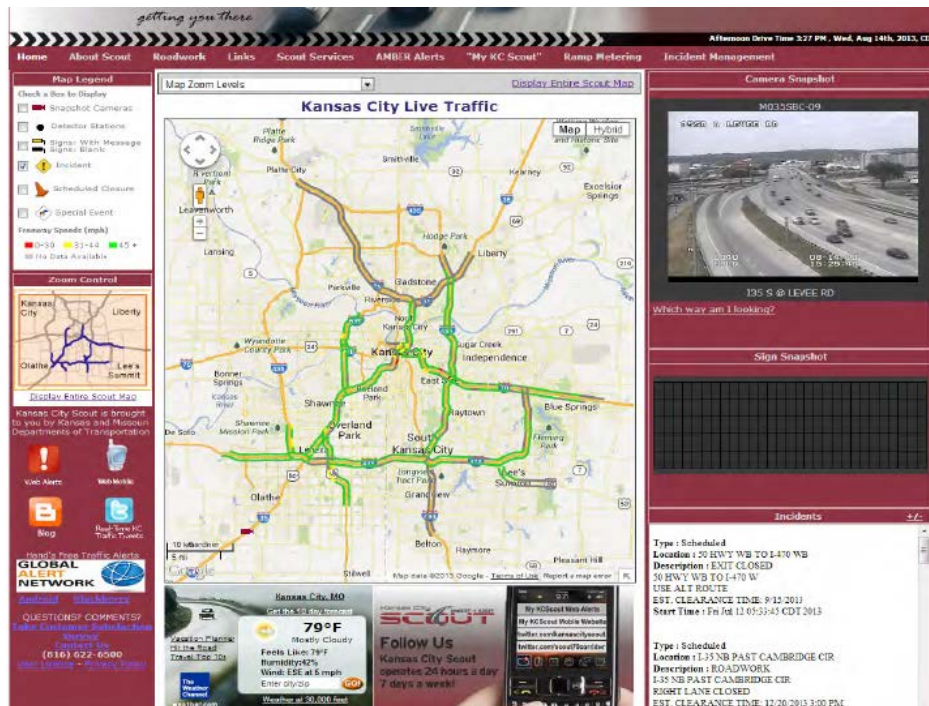


Figure 7. Screenshot. Project information incorporated into regional application.

Because this was the first diverging diamond interchange constructed in Kansas, the DOT placed great importance on educating the public before the project was initiated and throughout the construction phase. A public hearing was held in late 2011 to provide information regarding the diverging diamond interchange concept and to discuss the timeframe for the construction. Maps

and plan sheets were made available for review, and a project-related presentation was conducted using a virtual drive-through video. However, the use of Smart Work Zone technology had not been considered or approved at the time of the hearing, so no discussion of this concept was included.

Bidding Information

KDOT received five bids for the 1-35 Smart Work Zone project; the winning bid was \$1,046,540.00 by Clarkson Construction Company. Table 1 presents the bid results for the project. Ver-Mac was the contractor-selected vendor approved by the KDOT for Smart Work Zone System implementation.

Table 1. Bid results.

Bidder	Bid Amount	% of Low Bid
Engineer's Estimate		
Clarkson Construction Company	\$1,046,540.00	100%
Apac Kansas Inc-KS City Div, Reno Branch	\$1,121,040.00	107%
Miles Excavating Inc.	\$1,139,980.00	109%
T J Lambrecht Const Inc. & Subsidiary	\$1,145,783.84	109%
Radmacher Brothers Excavating CO Inc .& Affiliated Companies	\$1,196,940.00	114%

Project Schedule

KDOT's preliminary field work on this project included preliminary traffic data, the public website, and system requirements. Table 2 presents the major project milestones and the timelines.

Table 2. Major project milestones.

Project Activity	Date(s)
Open house to review project goals and preliminary choices	October 29, 2009
Development of ranking criteria for the interchange choices that met project goals	Fall 2009 - Winter 2009
Public open house to present the preferred interchange location at Homestead Lane	April 29, 2010
Environmental and design surveys	Spring 2010 - Summer 2010
Selection of diverging diamond interchange option	Fall 2010
Completion of final design	Fall 2011
Project letting	Spring 2012
Notice to proceed	Spring 2012
Commencement of construction	Spring 2012

Construction of the new diverging diamond interchange (see figure 8) involved dramatic changes to the existing facility. Lanes on I-35 were widened, ramps were constructed to access to the crossroad, and a new bridge was built to expand the capacity of Homestead Lane. The new

configuration is expected to expand access, reduce travel time through the interchange and provide fewer conflict points, and result in fewer severe crashes than with a conventional interchange.

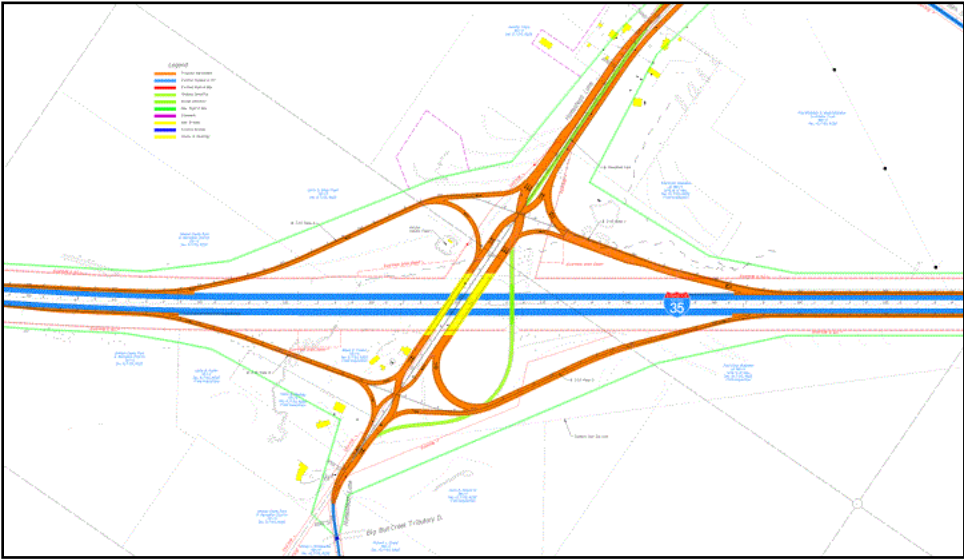


Figure 8. Map. View of interchange design (courtesy: KDOT).

DATA ACQUISITION AND ANALYSIS

Data collection and analysis on the Homestead Lane/I-35 interchange project consisted of acquiring and comparing data before, during, and after construction to measure progress toward HfL goals. All data were collected through the existing sensors along the highway and those installed as part of the innovation. The sensors allowed 24-hour per day collection throughout the analysis period without the need for physical site visits.

It was expected that the results would provide a guide as to the expected future performance of the innovations in future applications.

SAFETY

Safety goals for HfL projects are based on worker safety during construction and traveler safety during and after project completion. The worker safety goal is set at a 4.0 or less based on the OSHA 300 form available from the contractor. The public goal is a crash rate equal to or less than the preconstruction crash rate.

Table 3 presents the crash history at the project location for 2010 through 2012. Crash data for 2013 were not available for inclusion in this report. The 5-year crash rate for the project location was calculated to be .564 (per 1 million vehicle miles traveled), a rate approximately 17 percent below the statewide average of .676.

Table 3. Preconstruction crash statistics, 2008-2012.

Route	Location Reference	Length	Year	Crash Occurrences			
				Total	Fatal	Injury	PDO
I-35	Sunflower Road to Gardner Road	4.712	2008	29	0	8	21
			2009	17	1	5	11
			2010	35	0	4	31
			2011	30	0	4	26
			2012	15	0	3	12
			Total	126	1	24	101

PDO = property damage only

Only one crash was reported during the construction period. However, the crash was classified as a “medical emergency” and was not considered related to the construction activities. Given this consideration, the HfL goal of a construction crash rate less than the preconstruction rate was achieved.

Similarly, no worker injuries were reported on this project. The performance goal of achieving an incident rate for worker injuries of less than 4.0 (based on OSHA Form 300) was thus met.

In most cases, it could be assumed that the crash rate would increase during the time of construction. In this case, several factors may contribute to the lower work zone rate. First, most of the construction took place without disruption to the I-35 traffic. Homestead Lane was

completely closed for much of the construction time, eliminating the possibility of crashes within the project limits.

Given these factors, it seems safe to assume that the impact of the project on safety was negligible.

CONSTRUCTION CONGESTION AND TRAVEL TIME STUDY

The goal established by the HfL program is a reduction in construction time of at least 50 percent. A second goal is to reduce the impacts of construction on traffic. In this case, a reduction in construction time was not considered, as the innovation really had no impact on construction activities. The use of Smart Work Zone technology was included only to minimize congestion and trip time through the project.

Smart Work Zone technology allowed the real-time manipulation of traffic through variable speed limits and advance warnings to the public of possible delays to facilitate movement. Conventional traffic control probably would have consisted of static message signing and 24-hour per day reduced speed limits through the work area.

Lane Closures and Detours

Construction included weekend overnight lane, roadway, and ramp closures. Table 4 shows the closure schedule.

Table 4. Construction closure schedule.

Date/Time	Closed Route
Monday, March 18, 2013	<ul style="list-style-type: none"> • I-35 closed K-33 to 175th Street
Thursday, March 28, 2013	<ul style="list-style-type: none"> • I-35 closed 175th Street to K-33
Saturday, April 6, 2013	<ul style="list-style-type: none"> • I-35 closed K-33 to 175th Street
Thursday, April 11, 2013	<ul style="list-style-type: none"> • I-35 closed 175th Street to K-33
7:00 p.m. Friday, July 26, 2013, to 5:00 p.m. Saturday, July 27, 2013	<ul style="list-style-type: none"> • Northbound and southbound I-35 right lanes at Homestead Lane
8:00 p.m. Friday, July 26, 2013, to 9:00 a.m. Saturday, July 27, 2013	<ul style="list-style-type: none"> • Southbound I-35 left lane at 175th Street • Northbound I-35 left lane at K-33 • K-33 to northbound I-35 ramp • Sunflower Road to northbound I-35 ramp • 175th Street to southbound I-35 ramp • Gardner Road to southbound I-35 ramp
9:00 p.m. Friday, July 26, 2013, to 8:00 a.m. Saturday, July 27, 2013	<ul style="list-style-type: none"> • All lanes of northbound I-35 from 175th Street to K-33 • All lanes of southbound I-35 from K-33 to 175th Street

During this period, advance message boards were used to alert traffic to the closures. A marked detour, around 16.7 miles long, was provided (see figure 9).

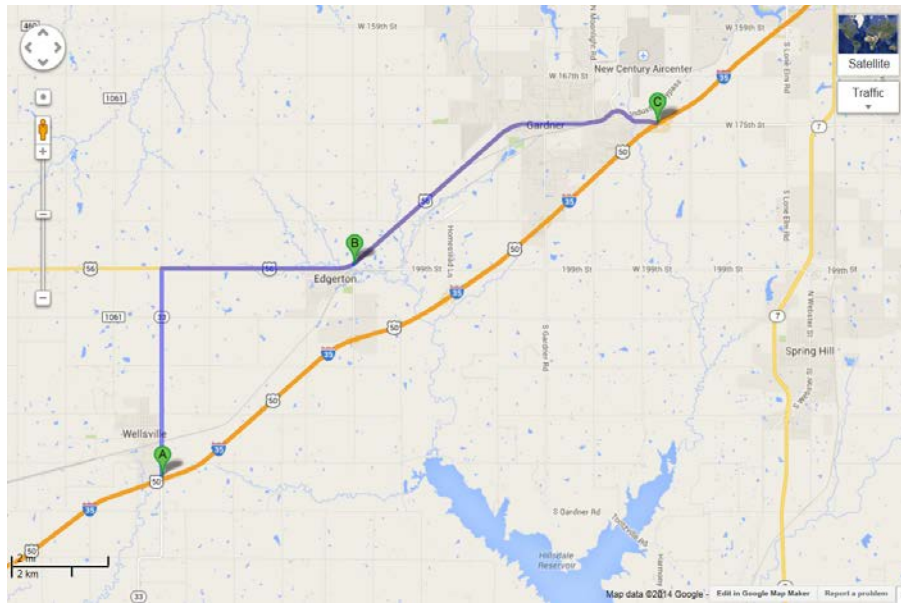


Figure 9. Map. I-35 detour route (courtesy: KDOT).

The southbound detour involved exiting southbound I-35 traffic at U.S. 56, heading westbound on U.S. 56 to southbound K-33, and taking K-33 back to southbound I-35. The northbound detour involved exiting I-35 traffic at K-33, heading northbound on K-33 to eastbound U.S. 56, and then back to northbound I-35.

Traffic Study

A review of 2011 traffic data indicated that I-35 in the vicinity of the interchange carried approximately 25,900 vehicles per day, with 19.8 percent of those classified as heavy vehicles. By the year 2040, these volumes were forecasted to be between 70,000 vehicles per day south of the interchange and 91,925 vehicles per day north of the interchange.

The traffic control plan developed for I-35 consisted of single-lane closures northbound and southbound, along with a short full road closure with traffic diverted around the bridge structure via the on and off ramps to Homestead Lane. An analysis using the FHWA QuickZone tool suggested that queues could develop in the southbound direction in the p.m. peak period during the week. The magnitude of maximum anticipated queues ranged from 0.02 miles on Monday to 1.92 miles on Friday. These queue lengths corresponded to maximum anticipated delays between 0.26 and 27.34 minutes. A second analysis using the Freeval tool yielded similar results.

Because of the potential delays anticipated from the project, KDOT applied and was approved for HfL funding to install and operate a work zone ITS along I-35 and nearby routes. The system consisted of:

- A series of 21 Wavetronics sensors positioned periodically along I-35, beginning approximately 7 miles upstream of the interchange on both approaches.
- 18 portable changeable message signs installed periodically along I-35, south 199th

Street, and Homestead Lane.

- 7 variable speed limit signs on I-35
- 6 CCTV cameras at selected Wavetronic sensor locations to facilitate real-time monitoring of traffic conditions.

The Wavetronics sensors continuously recorded current speeds, sensor occupancy, and traffic counts (volumes) and periodically uploaded them to the central processing unit for analyses.

Preconfigured messages on the portable changeable message signs, as well as the speed displayed on the variable speed limit signs, were activated based on the analyzed Wavetronics data. The messages would indicate current travel times to various downstream exits or some type of delay message (when queues were present) that would encourage diversion to an alternate route.

Travel times were estimated by taking the measured speed at the sensor and extrapolating it upstream and downstream from that sensor location for a given distance to estimate an average travel time over that distance. Linking the various sensor “segments” together provided an estimate of the current travel time through the project.

The ITS was installed in mid-April 2013 in anticipation of the project. After some initial glitches, the system was operational on about May 1, 2013. Some issues with the system occurred during June and July, but the system was functioning essentially full time starting in August 2013. The system continued collecting data until late 2013.

To assess the impacts of the project on I-35 travelers, the data from the work zone ITS were extracted from the system website and analyzed. Volume counts and computed travel times were analyzed to determine whether there was significant diversion from I-35 during the project and the amount of additional travel time that occurred while the project was being performed.

Data Reduction and Analysis

Archived project emails were obtained to determine actual dates and times when I-35 lanes were closed for the project. A series of mid-day single lane closures occurred throughout June and July 2013 to set the concrete barrier in position for the long-term closure. Review of speeds and travel times on I-35 during these dates suggested that such mid-day closures had no measurable effect, consistent with initial impact estimates. Beginning on August 5, 2013, one lane of I-35 in each direction was closed. This left one lane open in each direction through approximately 8,500 feet (1.6 miles) across the Homestead Lane interchange. The project remained in that condition until September 28, 2013. A series of mid-day lane closures were then used to remove the barrier and complete the project.

Table 5 summarizes the locations of the Wavetronics sensors along I-35. Volumes at sensors 1 and 21 were analyzed to assess any regional diversions that may have occurred during the project, while data from sensors 6 and 17 were evaluated to determine if more localized changes in traffic volumes occurred, presumably as a direct result of the message board messages suggesting the use of an alternate route during periods of significant queuing and delay. While it

is true that sensors closer to the actual interchange, such as sensors 10 and 11 (see highlighted rows) were available, there were possible calibration problems with some or all of those closer sensors due to construction activities, which gave the researchers pause in using those data.

Table 5. Location of Wavetronics sensors.

Sensor	Location	Distance to Interchange, miles
1 NB	South of exit 198 off ramp (Poplar Street, K-33)	7.4
2 NB	North of exit 198 on ramp (Poplar Street, K-33)	6.8
3 NB	1.5 miles before exit 202	3.9
4 NB	1.0 mile before exit 202	3.4
5 NB	South of exit 202 off ramp (Sunflower Road)	2.4
6 NB	North of exit 202 on ramp	1.9
7 NB	0.5 mile north of exit 202 on ramp	1.4
8 NB	West of Bull Creek Bridge	0.9
9 NB	0.5 mile south of Homestead Bridge	0.5
	Just south of Homestead Bridge	0.0
	Just north of Homestead Bridge	0.1
12 SB	0.5 mile north of Homestead Bridge	0.6
13 SB	Just north of west 199 th Street Bridge	1.1
14 SB	Halfway between exit 207 southbound on ramp and west 199 th Street Bridge	1.7
15 SB	South of exit 207 southbound on ramp	2.3
16 SB	Just before exit 207 southbound off ramp	2.9
17 SB	0.8 mile north of Exit 207	3.7
18 SB	1.2 mile south of exit 210	4.1
19 SB	0.8 mile south of exit 210 southbound on ramp	4.5
20 SB	Just south of exit 210 on ramp	5.3
21 SB	At exit 210 southbound off ramp	6.0

NB = northbound; SB = southbound

Results

The month of May 2013 was selected as the “before” condition against which any changes in volumes at the sensor stations during the project (August and September) would be compared. Regional traffic counts performed during May, August, and September illustrated that overall travel demands during those months were approximately the same.⁽²⁾ This implies that any differences between May 2013 and the project time period measured with the work zone ITS are likely attributable to the effects of the project.

Table 6 provides a comparison of 24-hour, morning peak (6:00 to 9:00 a.m.) and afternoon peak (4:00 to 7:00 p.m.) counts for weekdays in May and the project timeframe at each sensor station of interest. Sensor 21 SB is located upstream of a major interchange with U.S. 56, and so much of the higher traffic volumes at that location are destined for that route. Holidays (Memorial Day and Labor Day) were excluded from the analysis.

Table 6. Comparison of traffic counts before and during construction.

Sensor	May 2013	August-September 2013	Change (%)
2 NB:			
24-hour	10,772	10,250	-522 (-4.8%)
a.m. peak	2,064	2,125	+61 (+3.0%)
p.m. peak	2,063	1,982	-81(-3.9%)
6 NB:			
24-hour	12,013	11,576	-437 (-3.6%)
a.m. peak	2,871	2,894	+23 (+0.8%)
p.m. peak	2,213	2,121	-92 (-4.2%)
15 SB:			
24-hour	11,118	10,024	-94 (-0.8%)
a.m. peak	2,631	2,651	+20 (+0.7%)
p.m. peak	2,036	1,724	-312 (-15.3%)
21 SB:			
24-hour	23,489	22,728	-761 (-3.2%)
a.m. peak	6,437	6,555	+118 (+1.8%)
p.m. peak	4,397	4,233	-64 (-1.5%)

Overall, the data suggest that a small amount of diversion may have taken place as a result of the project. Sensors farthest away from the interchange (sensors 2 and 21) counted slightly less traffic in August and September than occurred in May. A slight increase in counts was observed in both directions for the morning peak period, while counts were down in both directions during the afternoon peak. The amount of the reduction in the southbound direction at sensor 15 is somewhat suspect. Several periods of unusual counts were evident in the August-September time period. It is not known whether project activities in the vicinity of the sensor adversely affected the sensor, whether the sensor itself was periodically malfunctioning, or whether the counts were indeed accurate and indicative of a true drop in demand.

In general, the project and associated traffic control had negligible effects on average travel times in either direction of travel. As shown in tables 7 and 8, average morning peak period travel times were actually slightly less during the project than they were previously. In the afternoon peak period, average travel times were slightly lower northbound and slightly higher southbound. Similar trends were evident during the midday time period and at night.

The project also had only a small effect on travel time reliability. Measures of reliability examined included the 95th and 99th percentile travel times, the maximum travel time, and the 95th percentile buffer index. The buffer index is simply a dimensionless parameter relating the average and 95th percentile travel times for a given time period as follows:

$$\frac{95^{\text{th}} - \text{Average}}{\text{Average}}$$

The buffer index reflects the additional travel time that drivers must allow due to the uncertainty of the travel times that occur day-to-day during that time period. Low buffer indices imply highly reliable travel times exist for that route.

Table 7. Travel times and average speeds, northbound.

Travel Times	May 2013	Aug-Sep 2013	Change
a.m. peak:			
Average	9.49 min (61 mph)	9.36 min (62 mph)	-0.13 min (+1 mph)
95 th Percentile	9.49 min (61 mph)	9.68 min (60 mph)	+0.19 min (-1 mph)
Buffer Index	0.000	0.034	+0.034
99 th Percentile	9.52 min (61 mph)	10.13 min (57 mph)	+0.61 min (-4 mph)
Maximum	9.90 min (59 mph)	11.17 min (52 mph)	+1.27 min (-7 mph)
Midday:			
Average	9.49 min (61 mph)	9.46 min (62 mph)	-0.03 min (+1 mph)
95 th Percentile	9.51 min (61 mph)	9.79 min (60 mph)	+0.28 min (-1 mph)
Buffer Index	0.000	0.035	+0.035
99 th Percentile	9.56 min (61 mph)	10.83 min (54 mph)	+1.27 min (-7 mph)
Maximum	9.75 min (60 mph)	24.12 min (24 mph)	+14.37 (-36 mph)
p.m. peak:			
Average	9.49 min (61 mph)	9.34 min (62 mph)	-0.15 min (+1 mph)
95 th Percentile	9.51 min (61 mph)	9.62 min (60 mph)	+0.11 min (-1 mph)
Buffer Index	0.000	0.030	+0.030
99 th Percentile	9.55 min (61 mph)	9.77 min (60 mph)	+0.22 min (-1 mph)
Maximum	9.58 min (61 mph)	9.97 min (60 mph)	+0.39 min (-1 mph)
Night:			
Average	9.53 min (61 mph)	9.43 min (61 mph)	-0.10 min (0 mph)
95 th Percentile	9.60 min (61 mph)	9.73 min (60 mph)	+0.13 min (-1 mph)
Buffer Index	0.008	0.033	+0.025
99 th Percentile	9.73 min (60 mph)	9.86 min (59 mph)	+0.13 min (-1 mph)
Maximum	11.51 min (51 mph)	10.10 min (58 mph)	-1.41 min (+7 mph)

Table 8. Travel times and average speeds, southbound.

Travel Times	May 2013	Aug-Sep 2013	Change
a.m. peak:			
Average	5.22 min (64 mph)	5.14 min (65 mph)	-0.08 min (+1 mph)
95 th Percentile	5.23 min (64 mph)	5.30 min (63 mph)	+0.07 min (-1 mph)
Buffer Index	0.003	0.030	+0.027
99 th Percentile	5.34 min (63 mph)	5.39 min (62 mph)	+0.05 min (-1 mph)
Maximum	5.49 min (61 mph)	5.76 min (58 mph)	+0.27 (-3 mph)
Midday:			
Average	5.21 min (64 mph)	5.28 min (64 mph)	+0.07 min (0 mph)
95 th Percentile	5.23 min (64 mph)	5.40 min (62 mph)	+0.17 min (-2 mph)
Buffer Index	0.003	0.022	+0.019
99 th Percentile	5.31 min (63 mph)	9.32 min (36 mph)	+4.01 min (-27 mph)
Maximum	5.39 min (62 mph)	19.65 min (17 mph)	+14.26 min (-45 mph)
p.m. peak:			
Average	5.21 min (64 mph)	5.29 min (64 mph)	+0.08 min (0 mph)
95 th Percentile	5.24 min (64 mph)	5.38 min (62 mph)	+0.14 min (-2 mph)
Buffer Index	0.006	0.016	+0.010
99 th Percentile	5.30 min (63 mph)	11.33 min (30 mph)	+6.03 min (-33 mph)
Maximum	5.35 min (63 mph)	22.59 min (15 mph)	+17.24 min (-48 mph)
Night:			
Average	5.23 min (64 mph)	5.20 min (64 mph)	-0.03 min (0 mph)
95 th Percentile	5.28 min (64 mph)	5.39 min (62 mph)	+0.11 min (-2 mph)
Buffer Index	0.009	0.037	+0.028
99 th Percentile	5.37 min (63 mph)	5.48 min (61 mph)	+0.11 min (-2 mph)
Maximum	5.98 min (56 mph)	6.28 min (54 mph)	+0.30 min (-2 mph)

The maximum travel times increased substantially during the project only during the midday time period northbound and in the midday and p.m. peak periods southbound. Compared to the maximum delays measured prior to construction, the maximum travel times measured were 14 to 17 minutes higher. However, it also evident that such increases occurred very infrequently and only for fairly short periods of time, as the 95th and 99th percentile travel times as well the buffer indices displayed only marginal increases. In other words, the increases seen in the maximum travel times during those time periods occurred less than 1 percent of the time while the project was in place.

With regards to the total road user cost impacts resulting from this project, all of the average travel times were slightly less during construction than before. Similarly, the average changes in travel times in the peak periods essentially offset each other, as do the changes in midday and nighttime average travel times. Consequently, based on the data collected, one can conclude that the project had minimal road user impacts that were related to mobility.

QUALITY

As this innovation consisted of only Smart Work Zone technology, no testing was conducted for noise and smoothness.

USER SATISFACTION

KDOT contracted ETC Institute to survey Kansas residents traveling on I-35 between K-33 (exit for Wellsville) and U.S. 56 (exit for Gardner). The phone survey, which was conducted in October 2013, involved 400 residents who traveled the I-35 corridor during the construction period. KDOT's objective was to determine perceptions of the construction zone on this section of I-35, the first Smart Work Zone employed in the State. The following were the major findings from the survey:

- An overwhelming number of those surveyed were supportive of the Smart Work Zone technology.
- Eighty-one percent rated their experience either “better” or “much better” than their experience in other, conventional work zones.
- Seventy-five percent were satisfied with how safe they felt driving through the construction work zone.
- Seventy-one percent were satisfied with the quality of signage that was available.
- Sixty-nine percent were satisfied with KDOT's overall efforts to minimize disruptions to traffic flow in the work zone.
- Sixty-seven percent were satisfied with the traffic flow through the construction zone.
- Seventy-five percent felt the enhanced signage in the Smart Work Zone was useful.
- Seventy-one percent felt the variable speed limit signs were useful.
- Seventy percent felt the Smart Work Zone website was useful.
- Seventy percent felt the speed sensors were useful.
- Only nine percent of the residents surveyed had heard the term “Smart Work Zone” prior to this survey.
- The two Smart Work Zone attributes that residents observed most often (or were most aware of) were the variable speed limit signs (92 percent) and the portable message signs (90 percent).
- Seventy percent reported that the message boards in the work zone were the primary source from which they received information about the construction zone.

The HfL program emphasizes two main items with respect to user satisfaction: the overall satisfaction with the facility/technology and the approach used to minimize traffic disruption. For this project, on a 7-point Likert scale, 93 percent of survey respondents gave a 4 or greater rating for their overall satisfaction with the Smart Work Zone, and 93.4 percent gave a 4 or greater rating for traffic flow through the work zone.

User satisfaction charts and tables are presented in the appendix.

ECONOMIC ANALYSIS

A major component of the HFL program is to quantify the monetary value of the selected innovation when compared to the most likely traditional method in use by the agency. Several items are included in this analysis—base construction/design costs, user cost associated with delays and detours, and the safety value of reduced crashes associated with reduced construction time or other innovative safety features. In this case, most of the data were supplied by the innovation itself; all traffic data used in the analysis were collected through the noncontact sensors associated with the Smart Work Zone.

CONSTRUCTION COSTS

Construction costs for the interchange were not considered as part of the HfL project. In this case, capital costs include only the costs to the agency of the equipment required for the Smart Work Zone, the cost of the JamLogic software used in the analysis, and an upgrade to the State’s existing ITS software. All of the items that were originally assumed for the project were still employed in addition to the Smart Work Zone costs. Therefore, there is no real baseline for comparison. All costs associated with this technology are in addition to the normal traffic control items. Table 9 lists the initial costs.

Table 9. Capital construction cost comparison.

Item	Smart Work Zone
Variable speed limit signs	\$52,000
Variable message trailer	\$279,000
Trailer-mounted cameras	\$132,000
Trailer-mounted traffic sensors	\$283,500
Software/consulting	\$315,026
ITS software upgrade	\$588,474
Mobilization	-
	\$1,650,000

The cost of implementing the Smart Work Zone technology is more than \$1.6 million greater than that of the conventional solution. However, \$746,500 of this total is in hardware that KDOT now owns and can reuse on future projects. It is estimated that the equipment will be used and depreciated over the next 5 years at a usage rate of 75 percent.

USER COSTS

Three categories of user costs are normally used in an economic/life cycle cost analysis: vehicle operating costs, delay costs, and safety-related costs. Given the analysis presented previously concerning the traffic study, there is considered to be no delay or vehicle operating costs (or savings) associated with the project. No construction-related work zone incidents were reported during this project, and thus, no safety-related costs or savings resulted from the use of the Smart

Work Zone technology. The possible reasons for these conclusions are many. First, most of the construction took place off of the I-35 corridor, with the cross route closed to traffic. Mainline travel was impacted only for limited times necessary to tie in ramp connections and construct limited widening operations. Also, much of the work was performed at night, again limiting the exposure of the traffic to delay. It is also possible that the Smart Work Zone technology aided in the elimination of congestion by informing the public of congestion, reduced speeds, or incidents far enough in advance to allow them to take alternate routes. This is impossible to quantify, given the lack of volume data on possible alternate routes.

The actual cost of the innovation on this specific project would be based on a percentage of the initial cost, based on the depreciated 5-year life of the equipment and software.

Traffic Patterns and Queuing

Since the hourly traffic distribution patterns were unavailable for the project site, a nearby WIM site (see figure 10) located in Franklin County on I-35, NE of K-33, NE of Wellsville Exit, was evaluated to better understand the traffic trends of the project location. The hourly traffic distribution trends for the project site and the WIM site, both located on interstate I-35, were assumed to be comparable because of their proximity and similar traffic volumes.



Figure 10. Map. WIM site (circled in red) #E7PK42 (source: KDOT website)

The traffic parameters and their corresponding values, presented in table 10, were used to analyze queuing patterns at the project location.

Table 10. Traffic inputs for queue check.

Traffic parameter	Value	Source
Hourly traffic distribution	Averages obtained from ATR from WIM Station #E7PK42	Kansas DOT Website. http://www.ksdot.org/Assets/wwwksdotorg/bureaus/burTransPlan/maps/VehicleClass/2011_Dist4.pdf
Normal lane capacity	2,250 vehicles per hour	Highway Capacity Manual 2011
Work zone lane capacity	1,450 vehicles per hour	Highway Capacity Manual 2011

The data from table 10 were used to determine the vehicle demand across the project location. The traffic trends are presented in figure 11. As can be observed, the hourly traffic at most times of the day was significantly lower than the work zone capacity. Also, it can be noted that the peak hour traffic volume is less than 10% of the normal lane capacity. Overall, it can be safely assumed that there was no queuing/delays around the project work zone during the construction period.

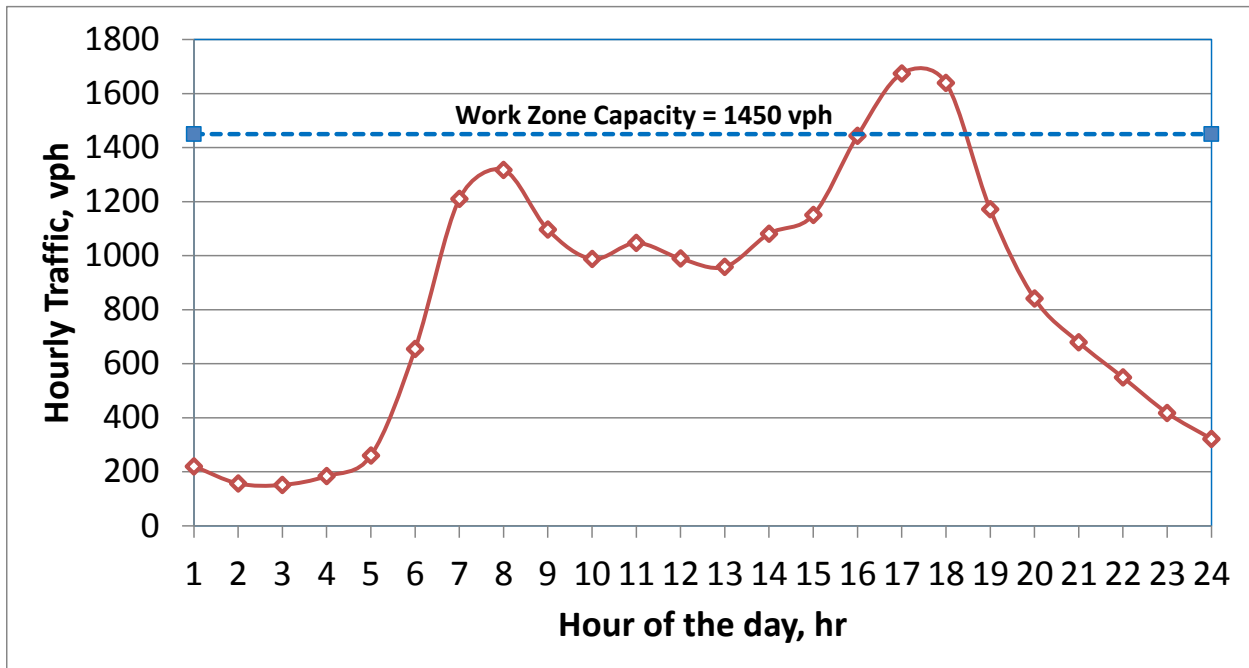


Figure 11. Graph. Traffic distribution trends at the project location.

Delay Costs

The as-built case involved the use of Smart Work Zone technologies that would alert users about the traffic patterns across I-35 and Homestead Lane, thereby allowing them to make informed decisions regarding their travel routes. In contrast, the baseline case would have involved the use of KDOT’s existing ITS. It can thus be assumed that any construction-related user delays would have been same for both traditional and as-built scenarios. However, the absence of

queuing/delays across the project location indicate that there were minimal or no user delay costs on this project. Although there was a detour in place during the overnight full closures, one lane in each direction was maintained for most of the construction period. Furthermore, the detour diversion traffic percentage was very low, so as not to result in any vehicle operating costs.

The use of Smart Work Zones did not result in any user cost savings; however, the intangible benefits include:

- Allowing road users to make informed travel-related decisions during the construction period.
- Improving work zone safety, mobility, and customer satisfaction.

The future use of Smart Work Zones across project locations with higher traffic volumes is expected to result in user cost savings.

SAFETY COSTS

There were no construction-related work zone incidents during this project. Given the limited time the construction actually affected traffic on I-35, it is safe to assume that there was no net impact to the public with regard to safety. Thus, no safety-related costs or savings resulted from the use of the Smart Work Zone technology.

COST SUMMARY

Capital costs for the Smart Work Zone technology totaled about \$1.64 million. All of this cost was in addition to the costs expected in a traditional work zone operation. However, about \$750,000 of this cost was for the lease/purchase of the portable message system, the associated software and upgrades to existing software, and data analysis. KDOT plans to use the equipment and software, the life expectancy of which is approximately 5 years, for future projects.

TECHNOLOGY TRANSFER

To promote the innovative Smart Work Zone technology, KDOT and FHWA organized a webinar for the I-35 Smart Work Zone project. The webinar provided an overview of the Smart Work Zone system used on the project, including technical presentations, a virtual drive-through of the Smart Work Zone, and demonstration of the JamLogic software. Figure 12 presents a copy of KDOT's webinar invitation.



The graphic is a blue-themed invitation for a webinar. On the left, it says 'You are invited to a project webinar NEW DATE! August 15, 2013 12:00pm - 3:00pm CST'. Below this, it lists 'Webinar Includes: • Technical Presentations • Virtual "drive-through" of the Smart Work Zone • Demonstration of JamLogic® Software'. In the center, there are four small images showing construction equipment and signs, with arrows pointing from the text area towards them. On the right, it says 'KDOT I-35 Smart Work Zone'. At the bottom, there are logos for the Kansas Department of Transportation, the U.S. Department of Transportation Federal Highway Administration, and 'HIGHWAYS FOR LIFE Accelerating Innovation for the American Driving Experience.'

You are invited to a project
webinar
NEW DATE!
August 15, 2013
12:00pm - 3:00pm CST

Webinar Includes:

- Technical Presentations
- Virtual "drive-through" of the Smart Work Zone
- Demonstration of JamLogic® Software

This free webinar will provide an overview of the Kansas Department of Transportation's first major work zone ITS project, a Smart Work Zone on I-35 near Kansas City, Kansas. The Smart Work Zone system includes portable changeable message boards, portable cameras, portable traffic sensors, and portable variable speed limit signs to communicate construction traffic information to drivers on I-35. The system will be active at the time of the webinar. Presentations will cover a national overview on Smart Work Zone technology, details on the I-35 project, and a demonstration of the JamLogic® Software.

To register, visit <http://t2ctt.adobeconnect.com/i35webinar/event/registration.html>

Kansas Department of Transportation
U.S. Department of Transportation
Federal Highway Administration
HIGHWAYS FOR LIFE
Accelerating Innovation for the American Driving Experience.

Figure 12. Illustration. KDOT's webinar invitation.

APPENDIX: USER SATISFACTION SURVEY

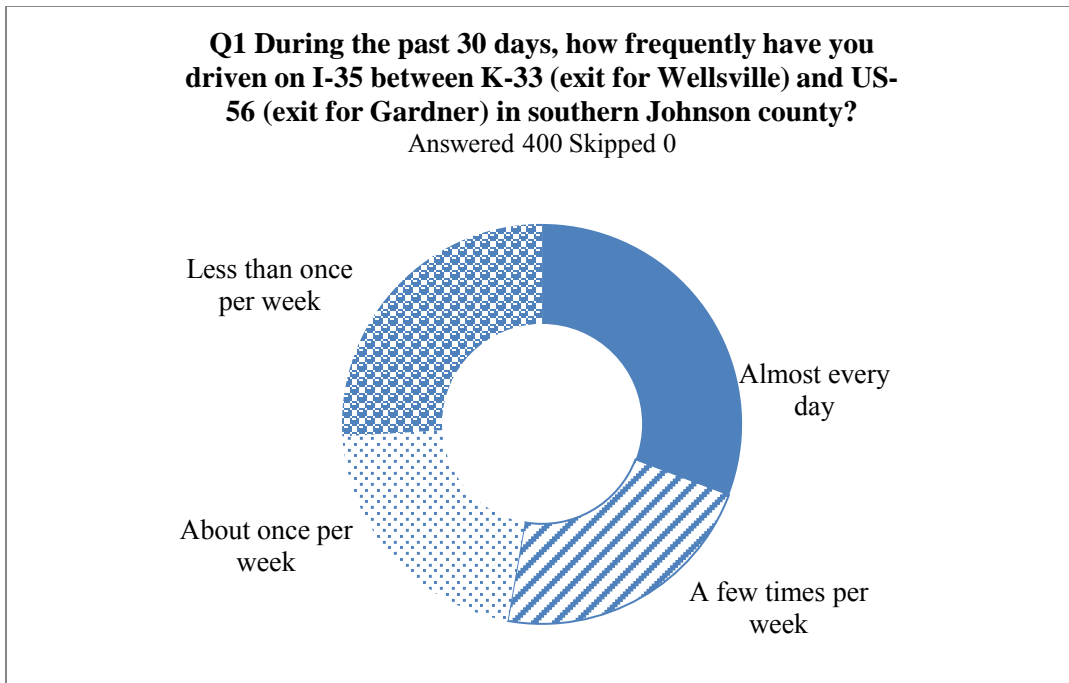


Figure 13. Chart. Frequency of travel

Table 11. Frequency of travel

Answer Choices	Responses	
	Number	Percent
Almost every day	123	30.75%
A few times per week	88	22.00%
About once per week	85	21.25%
Less than once per week	104	26.00%
Total	400	100%

Q2 Have you noticed the construction efforts that are currently taking place on this section of highway?

Answered 400 Skipped 0



Figure 14. Chart. Construction efforts on highway

Table 12. Construction efforts on highway

Answer Choices	Responses	
	Number	Percent
Yes	400	100.00%
Total	400	100%

Q3. Satisfaction with Various Construction Efforts on I-35 Between K-33 and US-56 in Southern JOCO

by percentage of residents who rated the item on a 7-point scale, where a rating of 7 meant "very satisfied" and a rating of 1 meant "very dissatisfied" (exc

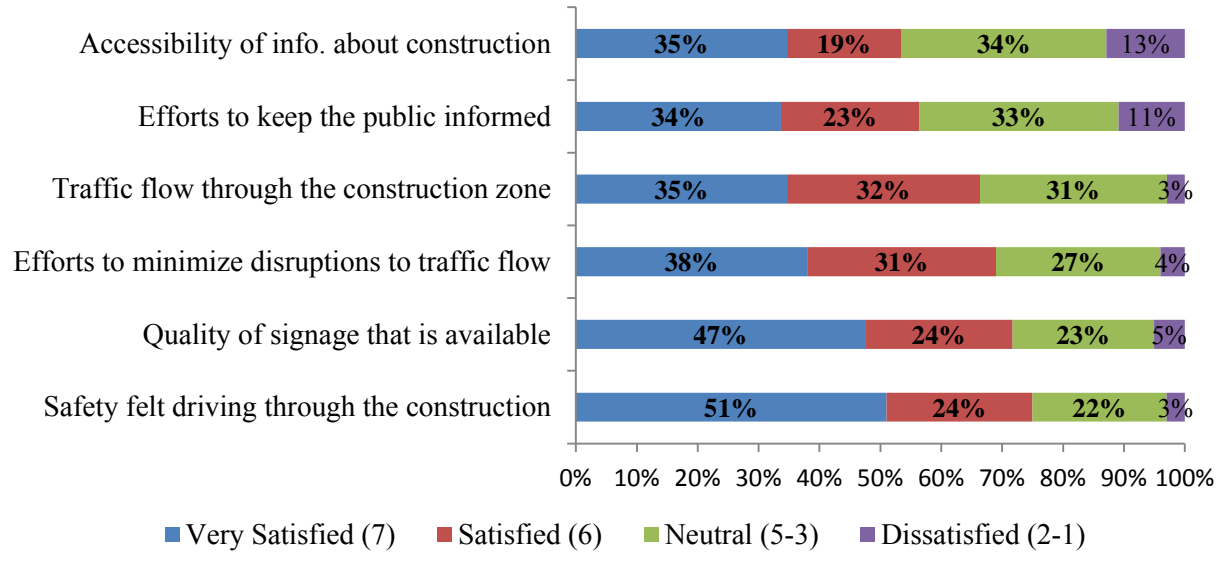


Figure 15. Chart. Satisfaction with Construction Efforts

Table 13. Satisfaction with Various Construction Efforts

	Very Satisfied (7)	Satisfied (6)	Neutral (5-3)	Dissatisfied (2-1)
Safety felt driving through the construction	51%	24%	22%	3%
Quality of signage that is available	47%	24%	23%	5%
Efforts to minimize disruptions to traffic flow	38%	31%	27%	4%
Traffic flow through the construction zone	35%	32%	31%	3%
Efforts to keep the public informed	34%	23%	33%	11%
Accessibility of info. about construction	35%	19%	34%	13%

Q4 For your information, the construction zone on this section of I-35 is the first of its kind in Kansas, and it has been called a “Smart Work Zone” by KDOT. Prior to this call, had you heard the term “Smart Work Zone” used to describe this or any other cons

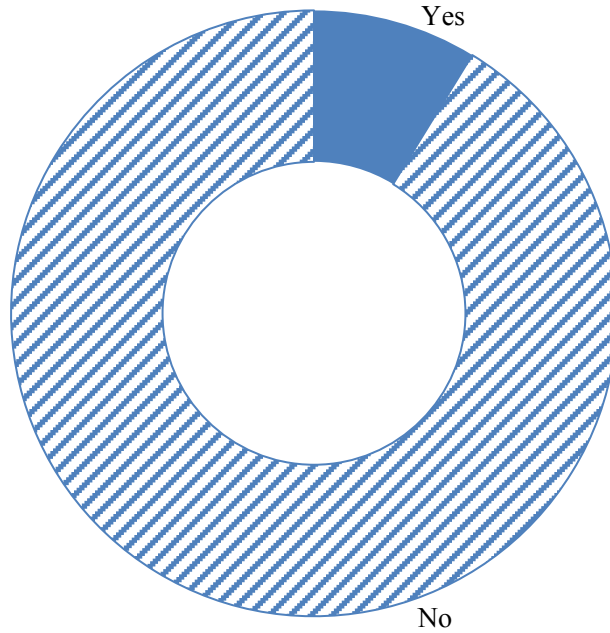


Figure 16. Chart. Knowledge of Smart Work Zone

Table 14. Knowledge of Smart Work Zone

Answer Choices	Responses	
	Number	Percent
Yes	35	8.75%
No	365	91.25%
Total	400	100%

Q5. Ratings of the Usefulness of Various Smart Work Zone Attributes

by percentage of residents who rated the item on a 7-point scale, where a rating of 7 meant "very useful" and a rating of 1 meant "not useful at all" (excluding don't knows)

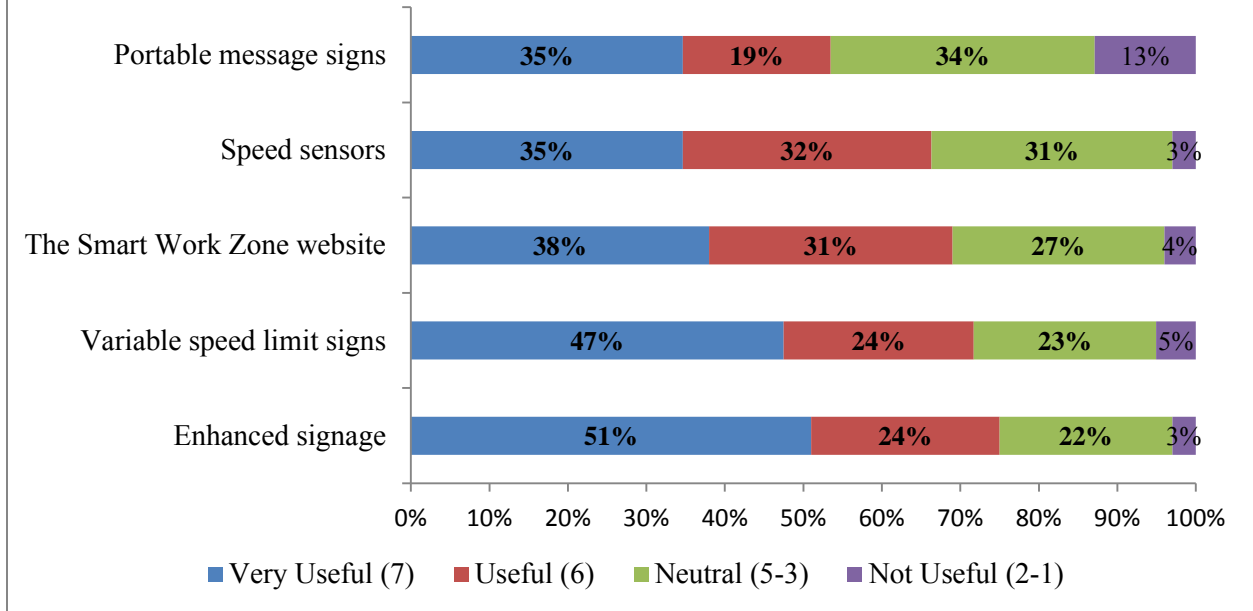


Figure 17. Chart. Ratings of the Usefulness of Various Smart Work Zone Attributes

Table 15. Ratings of the Usefulness of Various Smart Work Zone Attributes

	Very Useful (7)	Useful (6)	Neutral (5-3)	Not Useful (2-1)
Enhanced signage	51%	24%	22%	3%
Variable speed limit signs	47%	24%	23%	5%
The Smart Work Zone website	38%	31%	27%	4%
Speed sensors	35%	32%	31%	3%
Portable message signs	35%	19%	34%	13%

Q6 How supportive would you be of having KDOT add SMART WORK ZONE features, such as the ones I just described, to other highway construction projects in Kansas?

Answered 400 Skipped 0

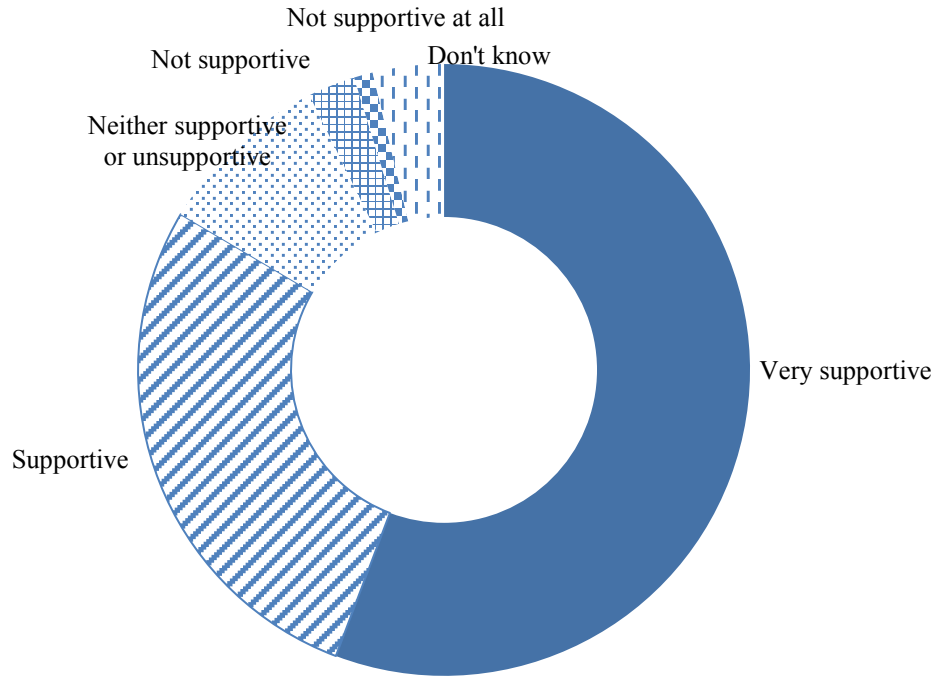


Figure 18. Chart. Support for KDOT’s Smart Work Zone features

Table 16. Support for KDOT’s Smart Work Zone features

Answer Choices	Responses	
	Number	Percent
Very supportive	223	55.75%
Supportive	111	27.75%
Neither supportive or unsupportive	37	9.25%
Not supportive	10	2.50%
Not supportive at all	4	1.00%
Don't know	15	3.75%
Total	400	100%

Q7 Compared to other highway construction zones you have experienced, how would you rate your overall experience driving through this section of I-35? Would you say it was:

Answered 400 Skipped 0

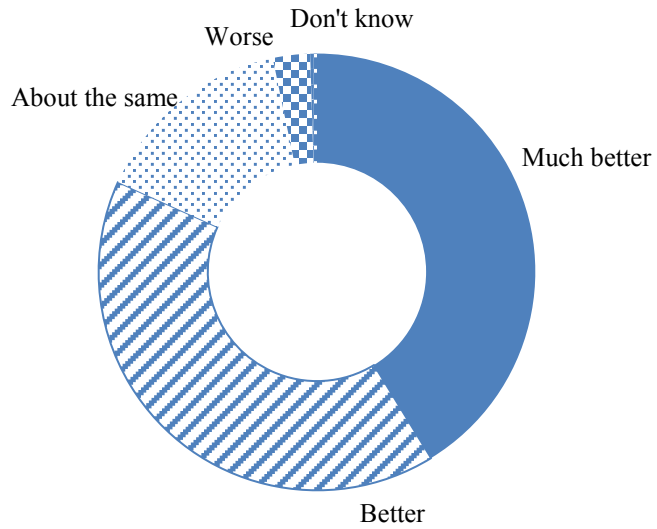


Figure 19. Chart. Overall experience driving through I-35

Table 17. Overall experience driving through I-35

Answer Choices	Responses	
	Number	Percent
Much better	165	41.25%
Better	162	40.50%
About the same	60	15.00%
Worse	11	2.75%
Don't know	2	0.50%
Total	400	100%

Q8 Using a 7-point scale, where 7 means very satisfied and 1 means very dissatisfied, how would you rates your overall satisfaction with the SMART WORK ZONE on this Section of I-35?

Answered 400 Skipped 0

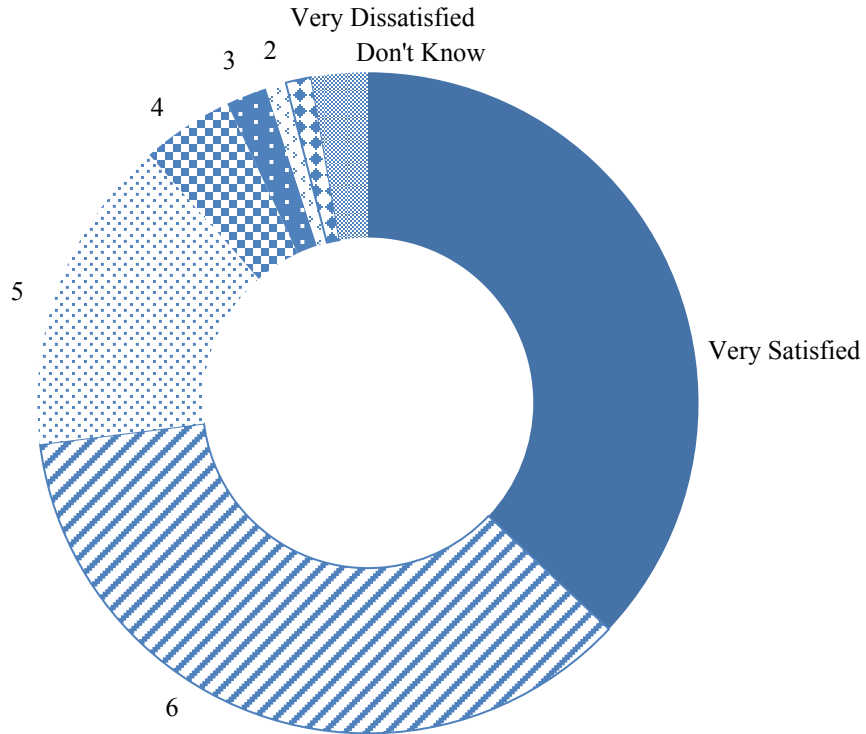


Figure 20. Chart. Overall satisfaction with the Smart Work Zone on I-35

Table 18. Overall satisfaction with the Smart Work Zone on I-35

Answer Choices	Responses	
	Number	Percent
Very Satisfied	148	37.00%
6	144	36.00%
5	62	15.50%
4	18	4.50%
3	8	2.00%
2	4	1.00%
Very Dissatisfied	5	1.25%
Don't Know	11	2.75%
Total	400	100%

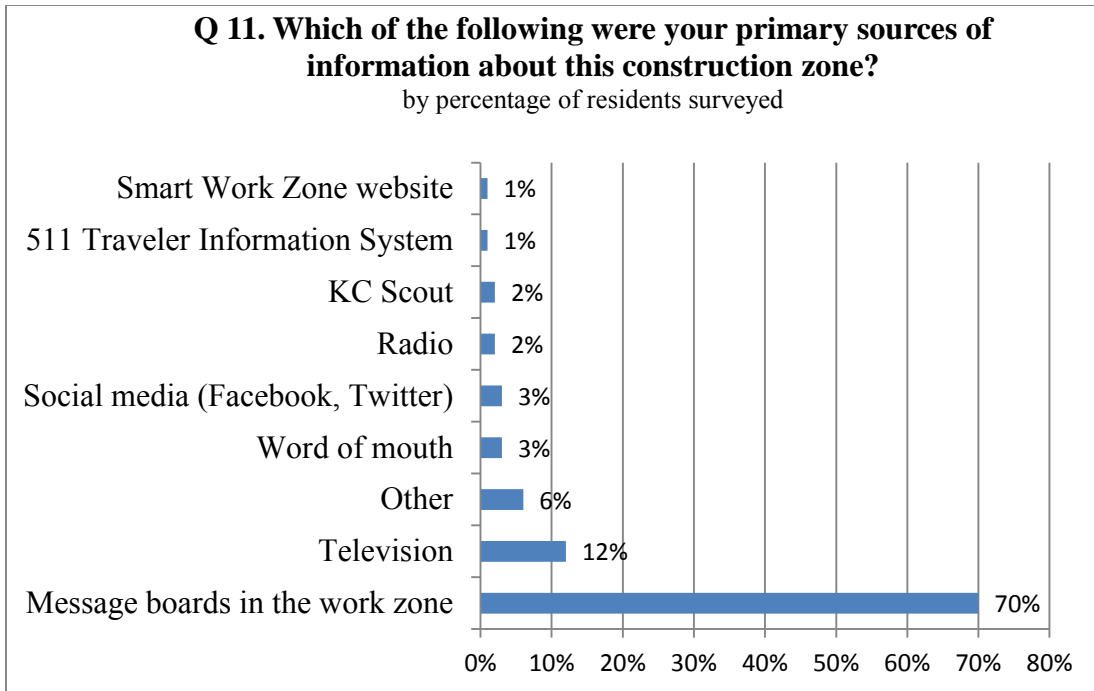


Figure 21. Chart. Primary sources of information about this construction zone

Table 19. Primary sources of information about this construction zone

Answer Choices	Responses, percent
Message boards in the work zone	70%
Television	12%
Other	6%
Word of mouth	3%
Social media (Facebook, Twitter)	3%
Radio	2%
KC Scout	2%
511 Traveler Information System	1%
Smart Work Zone website	1%

Q12 Before we end the interview, can you tell me which of the following categories best describes your age?

Answered 400 Skipped 0

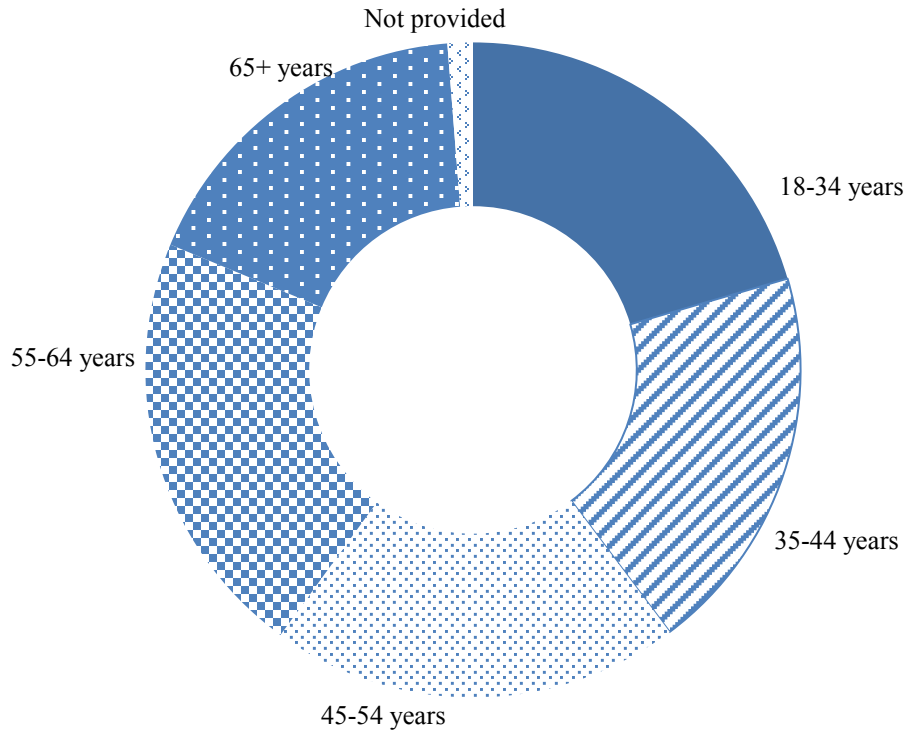


Figure 22. Chart. Age Categories

Table 20. Age Categories

Answer Choices	Responses	
	Number	Percent
18-34 years	82	20.50%
35-44 years	77	19.25%
45-54 years	81	20.25%
55-64 years	85	21.25%
65+ years	70	17.50%
Not provided	5	1.25%
Total	400	100%

Q13. Gender of Respondents

Answered 400 Skipped 0
by percentage of residents surveyed

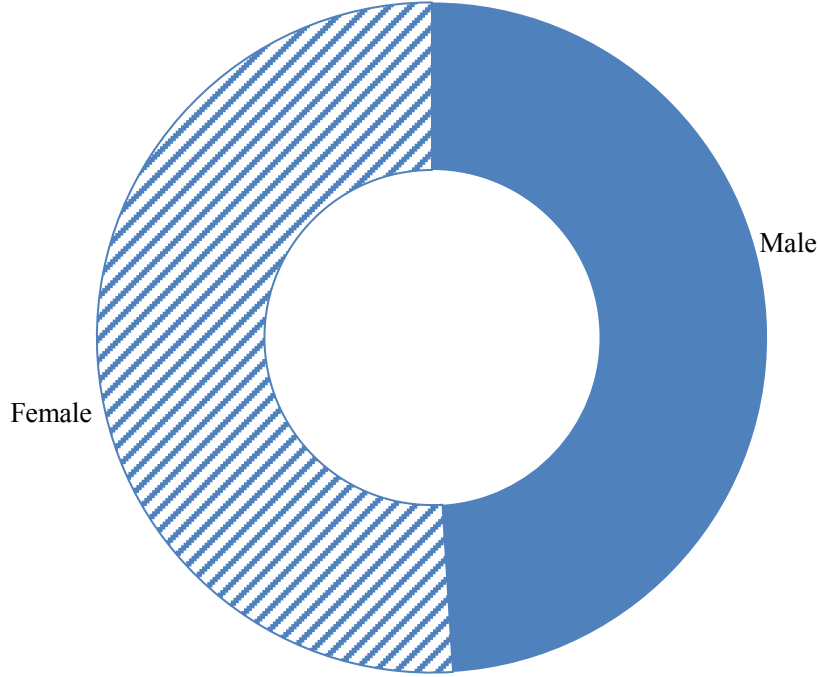


Figure 23. Chart. Gender of Respondents

Table 21. Gender of Respondents

Answer Choices	Responses	
	Number	Percent
Male	196	49.00%
Female	204	51.00%
Total	400	100%

ACKNOWLEDGMENTS

The project team acknowledges the invaluable insights and guidance of Highways for LIFE Team Leader Byron Lord and Program Coordinator Ewa Flom, who served as the technical panel on this demonstration project. Their vast knowledge and experience with the various aspects of construction, technology deployment, and technology transfer helped immensely in developing both the approach and the technical matter for this document. The team is also indebted to Chris Bruntz of the FHWA Kansas Division for his effective coordination effort and to KDOT Traffic Engineer Kristi Ericson. The project team was instrumental in making this project a success and provided the information that helped shape this report.

REFERENCES

1. *Transportation Management Plan, I-35 & Homestead Lane Interchange*. Prepared for Kansas Department of Transportation. Burns and McDonnell Engineering Company, Inc., Kansas City, MO. August 2011.
2. *Significant Facts and Trends*. Bureau of Transportation Planning, Kansas Department of Transportation. September 2013.