Northern Kentucky

ATDM

FINAL

Northern Kentucky ATDM Feasibility Study

Concepts, Feasibility, Benefits, and Costs

KYTC

October 2023

TEAM KENTUCKY TRANSPORTATION CABINET

HDR wsp PRIME AE

Executive Summary

Study Objective and Study Area

The objective of this study was to identify and evaluate Active Transportation and Demand Management (ATDM) strategies that could improve capacity, safety, reliability, and travel time on I-71/I-75, I-275, and I-471 in Northern Kentucky in the near-term. This document presents an assessment of the feasibility, benefits, and costs of implementing these strategies. A companion document provides a Concept of Operations for the three most promising deployments. The study area for the project covers the interstate highways north of Walton in Boone, Kenton, and Campbell Counties in Northern Kentucky. Strategies for the I-71-I-75 corridor were only looked at for existing relief until the Brent Spence Bridge (BSB) Corridor Project could be constructed. Since the BSB Corridor Project is now advancing, the report may assist in the development of maintenance of traffic plans.

Northern Kentucky ATDM Project Study Area

Potential ATDM Strategies

Six ATDM strategies were initially identified as having the potential to improve traffic operations, safety, and reliability in the study area: Comparative Travel Time, Queue Warning, Ramp Metering, Dynamic Shoulder Use, Dynamic Speed Advisory Signs, and Dynamic Lane Use Control. However, as they were vetted further, it became clear that the dynamic speed advisory and dynamic lane control systems were less promising than the other four. Therefore, the following four deployments were analyzed in detail.

Comparative Travel Time messaging uses Dynamic Message Sign (DMS) or hybrid static signs with DMS panels to display travel times for two unique but comparable routes. This can improve a driver's travel experience by allowing better enroute decision making. It also improves traffic operations by spreading demand across multiple routes. This makes more efficient use of available capacity, reduces congestion, and improves safety.

Queue Warning systems alert drivers about slowed or stopped traffic to prevent sudden slowing and to reduce the number and severity of rear-end or erratic lane change crashes. The advance warning about traffic congestion also facilitates better driver decision-making regarding route choice.

Ramp Metering uses traffic signals on entrance ramps to control the rate of vehicles entering the freeway. Creating space between vehicles improves merge operations, smooths mainline traffic, reduces mainline congestion, and improves safety.

Dynamic Shoulder Use is a deployment that allows a left or right freeway shoulder to be used as a through travel lane when additional highway capacity is needed. The shoulder is dynamically opened to traffic during peak travel periods or in response to congestion, incidents, or special events. Dynamic shoulder use can temporarily increase roadway capacity and postpone or eliminate the onset of congestion and its effects on travel time reliability and safety.

Deployment Analysis

Each of the deployments was evaluated to assess feasibility and to determine the potential benefits and costs. The feasibility assessment addressed physical and operational feasibility. Benefits were quantified for both mobility and safety. The mobility analysis was conducted using traffic operational analysis software and assumptions from research and case studies. The safety analysis was conducted using historic crash data, Crash Modification Factors, research, and case studies. Planning level cost estimates were prepared for each deployment, which included construction, operating and maintenance costs for 10 years, and a contingency. The results of the analysis were used to prepare a high-level Benefit-Cost (B/C) Analysis to assist in identifying and prioritizing the most beneficial projects.

Findings and Recommendations

The results of the analysis are summarized in the table below. As shown, the comparative travel time and queue warning systems both have few feasibility issues and high benefit/cost ratios. The ramp metering system on I-71/I-75 northbound has some potential feasibility challenges, but still offers a high benefit/cost ratio. Similarly, the I-471 northbound ramp metering system ranks as moderate for feasibility and yields a good benefit/cost ratio over a 10-year period. The remaining deployments all have more substantial feasibility concerns and low benefit/cost ratios, with the exception of the dynamic shoulder use lane on I-471 southbound. However, that improvement may be most effectively implemented as a new full-time auxiliary lane.

ATDM Deployment Summary Table

ATDM Strategy	Corridor(s)	Feasibility Concerns (Low to High)	Benefits[1] Operational Benefit	Benefits[1] Safety Benefit	Benefit Total	Total Cost[2]	B/C Ratio
Comparative Travel Time	Systemwide	Low	$ 28,326,000	N/A	$ 28,326,000	$ 3,237,000	**8.8**
Queue Warning	Systemwide	Low	$ 22,316,000	$ 4,936,000	$ 27,252,000	$ 5,474,000	**5.0**
Ramp Metering	I-71/I-75 NB	Low-Moderate	$ 4,593,000	$ 7,377,000	$ 11,970,000	$ 3,536,250	**3.4**
	I-471 NB	Moderate	$ 9,084,000	$ 1,315,000	$ 10,399,000	$ 3,536,250	**2.9**
	I-275 EB	High	$ 141,000	$ 4,209,000	$ 4,350,000	$ 4,243,500	**1.0**
Dynamic Shoulder Use	I-71/I-75 NB	Moderate-High	$ 11,472,000	N/A	$ 11,472,000	$ 24,725,000	**0.5**
	I-471 NB	Moderate-High	$ 8,417,000	N/A	$ 8,417,000	$ 10,321,000	**0.8**
	I-471 SB	Moderate[3]	$ 15,580,000	N/A	$ 15,580,000	$ 5,089,000	**3.1**[3]
	I-275 EB	High	$ 6,940,000	N/A	$ 6,940,000	$ 16,871,000	**0.4**

[1] *Benefits were calculated using a 10-year project lifecycle and a 7% discount rate*
[2] *Costs include capital and O&M costs*
[3] *This project may best be implemented as an additional full-time lane. See analysis.*

Deployment Prioritization

The deployments were prioritized considering the physical and operational feasibility, benefits, cost, and predicted B/C ratio.

Priority 1 - Comparative Travel-Time Deployment (Systemwide)*
Priority 2 - Queue Warning (Systemwide)
Priority 3 - Ramp Metering (I-71/I-75 NB)
Priority 4 - Ramp Metering (I-471 NB)
Priority 5 - I-471 SB - DSU Lane or New Full-Time Auxiliary Lane*
** To support Priorities 1 and 5, two upgrades are proposed to improve system interchange ramp flows.*

Next Steps in the ATDM Deployment Process

The next step in the process is to confirm the specific ATDM strategies that will advance to the System Requirements and High-Level Design phases of the Systems Engineering project development process. Comparative Travel Time and Queue Warning could move directly into these phases. The Ramp Metering system could also advance, but there are non-technical reasons to engage with and educate the public about this deployment before moving it forward.

Glossary

AADT – Annual Average Daily Traffic

AASHTO – American Association of State Highway and Transportation Officials

ATDM – Active Transportation and Demand Management

B/C – Benefit-Cost

BCA – Benefit-Cost Analysis

CCTV – Closed-Circuit Television

C-D – Collector-Distributor

CMF – Crash Modification Factor

COVID-19 – Coronavirus Disease 2019

CVG – Cincinnati/Northern Kentucky International Airport

DMS – Dynamic Message Sign

DOT – Department of Transportation

DSU – Dynamic Shoulder Use

EB – Eastbound

FHWA – Federal Highway Administration

HCM 6 – Highway Capacity Manual 6th Edition

HOV – High Occupancy Vehicle

HSIP – Highway Safety Improvement Program

HSM - Highway Safety Manual

ITS – Intelligent Transportation System

KSP – Kentucky State Police

KYTC – Kentucky Transportation Cabinet

LOS – Level of Service

MPH – Miles per Hour

MnDOT – Minnesota Department of Transportation

NCHRP – National Cooperative Highway Research Program

NPMRDS - National Performance Management Research Data Set

NB - Northbound

O-D – Origin-Destination

O&M – Operations and Maintenance

QWS – Queue Warning System

SB - Southbound

TRIMARC - Traffic Response and Incident Management Assisting the River Cities

TRB – Transportation Research Board

TSMO – Transportation System Management and Operations

TTI – Travel Time Index

USDOT – United States Department of Transportation

VHT – Vehicle Hours Traveled

VMT – Vehicle Miles Traveled

VPD – Vehicles per Day

WB – Westbound

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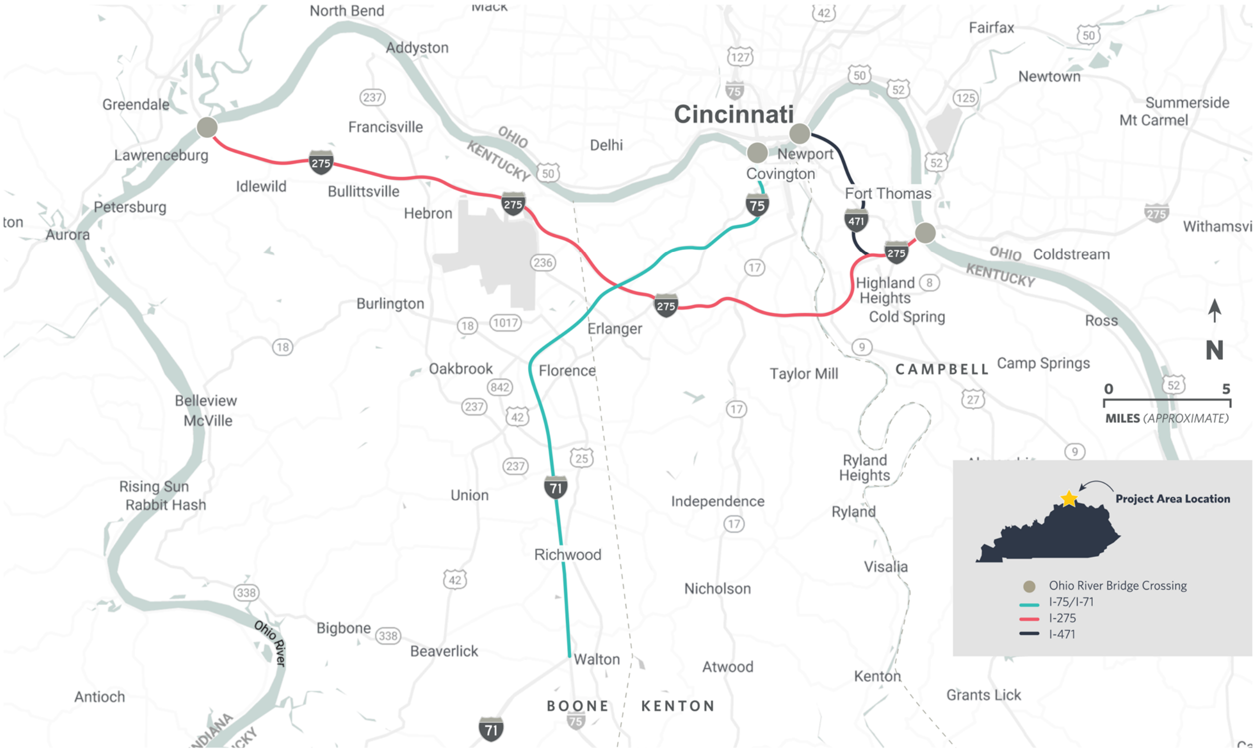
Study Objective and Methods

Study Objective and Study Area

The objective of this study was to identify and evaluate Active Transportation and Demand Management (ATDM) and Transportation System Management and Operations (TSMO) strategies that would improve capacity, safety, reliability, and travel time on I-71/I-75, I-275, and I-471 in Northern Kentucky. This document presents an assessment of the feasibility, benefits, and costs of implementing these strategies. A companion document provides a Concept of Operations for the three most promising deployments. Strategies for the I-71-I-75 corridor were only looked at for existing relief until the Brent Spence Bridge (BSB) Corridor Project could be constructed. Since the BSB Corridor Project is now advancing, the report may assist in the development of maintenance of traffic plans.

The study area covers the interstates north of Walton in Boone, Kenton, and Campbell Counties in Northern Kentucky. This area is the Kentucky portion of the Cincinnati metro region. The project study area is shown in **Figure 1**.

Figure 1: Northern Kentucky ATDM Project Study Area



Defining ATDM and TSMO

According to the Federal Highway Administration (FHWA), Active Transportation and Demand Management is the capability to improve the "trip reliability, safety, and throughput of the surface transportation system by dynamically managing and controlling travel and traffic demand, and available capacity, based on prevailing and anticipated conditions, using one or a combination of real-time operational strategies." ATDM uses transportation tools and assets to manage traffic flow and influence traveler behavior in real-time to achieve operational objectives, such as preventing or delaying breakdown conditions, improving safety, and maximizing system efficiency. By implementing ATDM, transportation agencies can monitor, control, and influence travel, traffic, and facility demand, and they can do this across the transportation system and over a traveler's entire trip.[1]

Another term for strategies that actively manage the transportation system is Transportation System Management and Operations (TSMO). 23 U.S. Code 101, as updated by the 2021 Bipartisan Infrastructure Law (BIL), defines TSMO as "integrated strategies to optimize the performance of existing infrastructure through the implementation of multimodal and intermodal, cross-jurisdictional systems, services, and projects designed to preserve capacity and improve security, safety, and reliability of the transportation system; and the consideration of incorporating natural infrastructure." The U.S. Code lists many examples of TSMO deployments, such as traffic detection and surveillance, freeway/corridor management, traveler information services, roadway weather management, and work zone and incident management. Active transportation and demand management is specifically listed as one of the primary TSMO strategies. Therefore, ATDM strategies are officially a subset of TSMO strategies. However, given the close relationship between the two concepts, either term may be used when referring to the strategies assessed in this study.

Study Scenarios and Time Periods

This study focused on assessing improvements to current traffic conditions. ATDM/TSMO strategies are typically intended to be implemented relatively quickly to address existing needs. For this study, pre-COVID (2019) traffic and safety data were used for the traffic operations and safety analyses.

The COVID-19 pandemic impacted traffic volumes, patterns, and trip purposes. Starting in March 2020, traffic exposure declined significantly as many areas had stay-at-home orders. The change in traffic exposure fluctuated throughout the remainder of 2020 and 2021. This study used 2019 traffic volumes as the baseline for the analysis assuming traffic volumes and patterns will return to those levels. In portions of the project area, traffic volumes have returned to near or even above 2019 levels.

While the base year for the analysis was 2019, the benefit and cost analysis timeframe used a 10-year time period, which is shorter than the typical 20-year period often used for large scale physical infrastructure upgrades. A 10-year timeframe is typically used when evaluating ATDM/TSMO improvements, as these types of implementations can have shorter life cycles due to the technology and operational elements involved. In general, it is preferred that the benefits exceed the costs over a short period of time.

Data and Analysis Methods

This study uses several data sources and analysis methods to evaluate the ATDM/TSMO strategies.

Data Sources

Speeds – National Performance Management Research Data Set (NPMRDS) speed data was used to examine traffic speeds throughout the network for all of 2019. This data set is provided by FHWA and supports the calculation of many different speed performance metrics. Streetlight Data travel time/speed data was also reviewed and examined as part of the study. (Streetlight Data is a big data resource and analysis tool that provides insight on transportation behavior. Streetlight Data can provide estimated travel time/speed, volume, route choice, and origin-destination data. See: https://www.streetlightdata.com/ for more information.)

Traffic Volumes – The project team used the extensive count data for the project area to develop estimated 2019 AM peak period (6-9 AM) and PM peak period (3-6 PM) balanced flow networks for both directions on all interstates. The 15-minute flow data that was available was used to convert the hourly volumes into the 15-minute flows needed for the traffic operations analysis.

[1] FHWA Office of Operations, Active Transportation and Demand Management (https://ops.fhwa.dot.gov/atdm/index.htm)

Origin-Destination Data – Streetlight Data was also used to evaluate traffic flow patterns such as the origins for traffic crossing a specific Ohio River bridge. The data was used to estimate how much traffic might shift from one route to another if drivers were provided with travel time information for alternative routes at key decision points.

Crash Data – Crash data for 2015-2019 was obtained from the Kentucky State Police (KSP) data set. This included crash locations, severity, type, weather, and other crash attributes.

Incident Data – Incident data for 2019 was obtained from Traffic Response and Incident Management Assisting the River Cities (TRIMARC). It includes the available information on all incidents in the study corridors, including vehicle breakdowns, work zones, and crashes.

Analysis Methods

Traffic Operations – FREEVAL models were set up for each direction of each Interstate to evaluate traffic conditions with and without the ATDM/TSMO deployments. These models evaluated traffic operations during the AM and PM peak periods. FREEVAL applies the Highway Capacity Manual 6th Edition (HCM 6) methods to evaluate travel time, queues, and congestion. It also uses local inputs for crashes/incidents, weather, and daily/monthly peaking to evaluate 240 synthetic weekdays in a typical year (12 months with 4 weeks/month and 5 days/week). The FREEVAL models were used to estimate the change in travel time for each deployment.

Safety Analysis – The safety analysis is based on the actual observed crashes in the study area and the application of crash modification factors (CMFs) or other crash adjustments based on ATDM/TSMO research.

Case Studies – Case studies from other cities were used to supplement the available research and further support the analysis.

Benefit-Cost Analysis – The travel time and crash elimination benefits of the ATDM strategies have been quantified and monetized to allow for a comparison to the cost estimates for implementing and maintaining the deployments. Recent USDOT values of time and KYTC crash costs were used in this process.

Study Area Needs

Focus and Context

The Northern Kentucky Interstate system consists of three highways: I-71/ I-75, I-471, and I-275. Each Interstate has its own unique characteristics regarding function, traffic patterns, configuration, geometry, speeds, congestion, and queues. This section highlights the needs in each corridor and begins to explore how ATDM/TSMO strategies could address those needs.

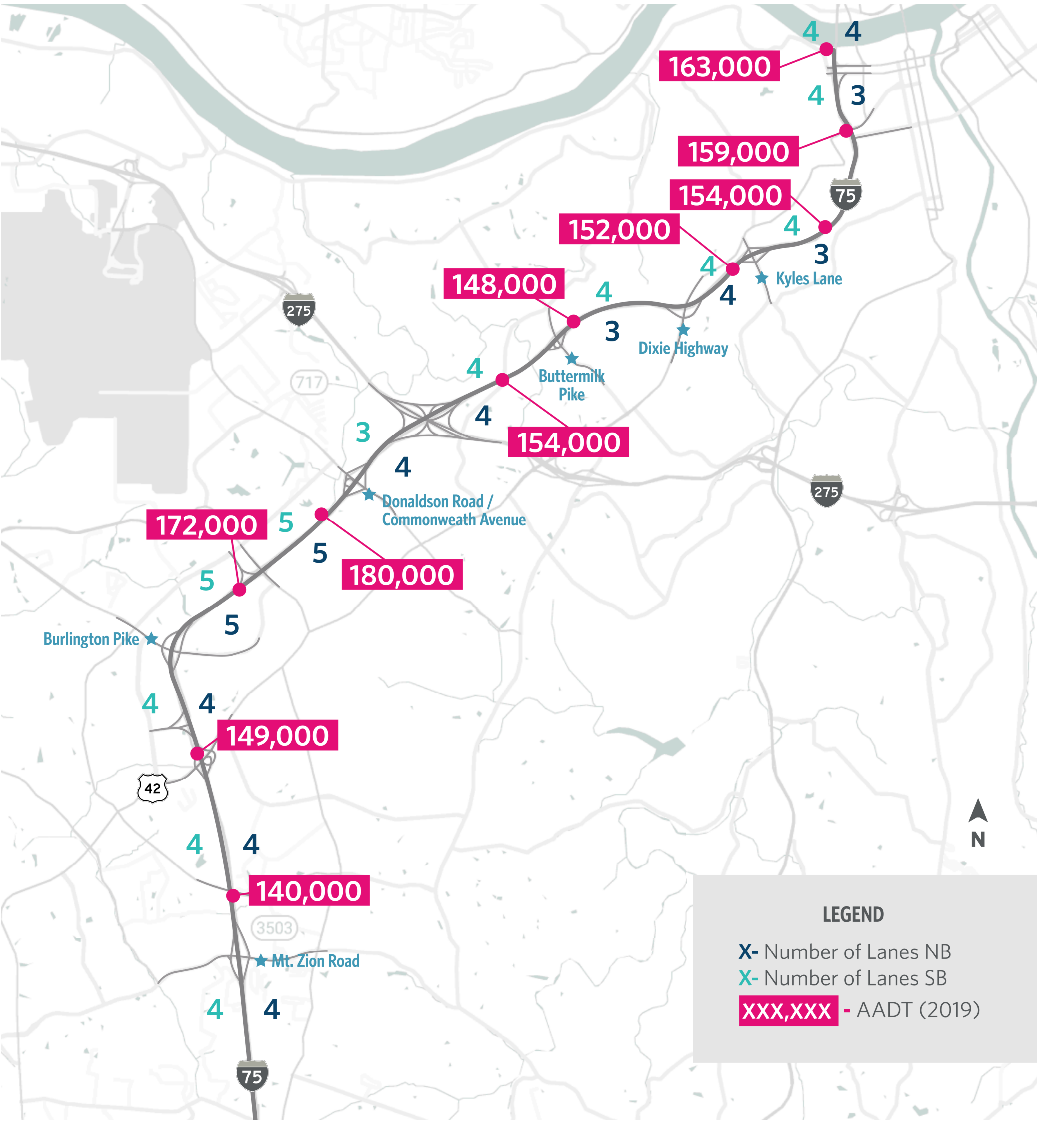
I-71/I-75 Corridor

The I-71/ I-75 study corridor extends from the merge point of the two interstates south of Florence in Boone County into Ohio via the Brent Spence Bridge in Covington.

I-71/I-75 Lanes and Volumes

I-71/I-75 has eight mainline lanes from the I-71/I-75 merge point north to I-275, with the exception of just south of I-275 where there are only three southbound mainline lanes due to the presence of a southbound collector-distributor (C-D) road. I-71/I-75 transitions to seven mainline lanes from I-275 north to the Ohio River (three northbound and four southbound). There are a number of auxiliary lanes that increase the number of lanes between interchanges. The 2019 traffic volumes on I-71/I-75 ranged from 140,000 TO 180,000 vehicles per day (vpd). The number of lanes (including mainline auxiliary lanes) and daily traffic volumes through the corridor are shown in **Figure 2**.

Figure 2: I-75/ I-71 Existing Lanes and Volumes



I-71/I-75 Operational Needs

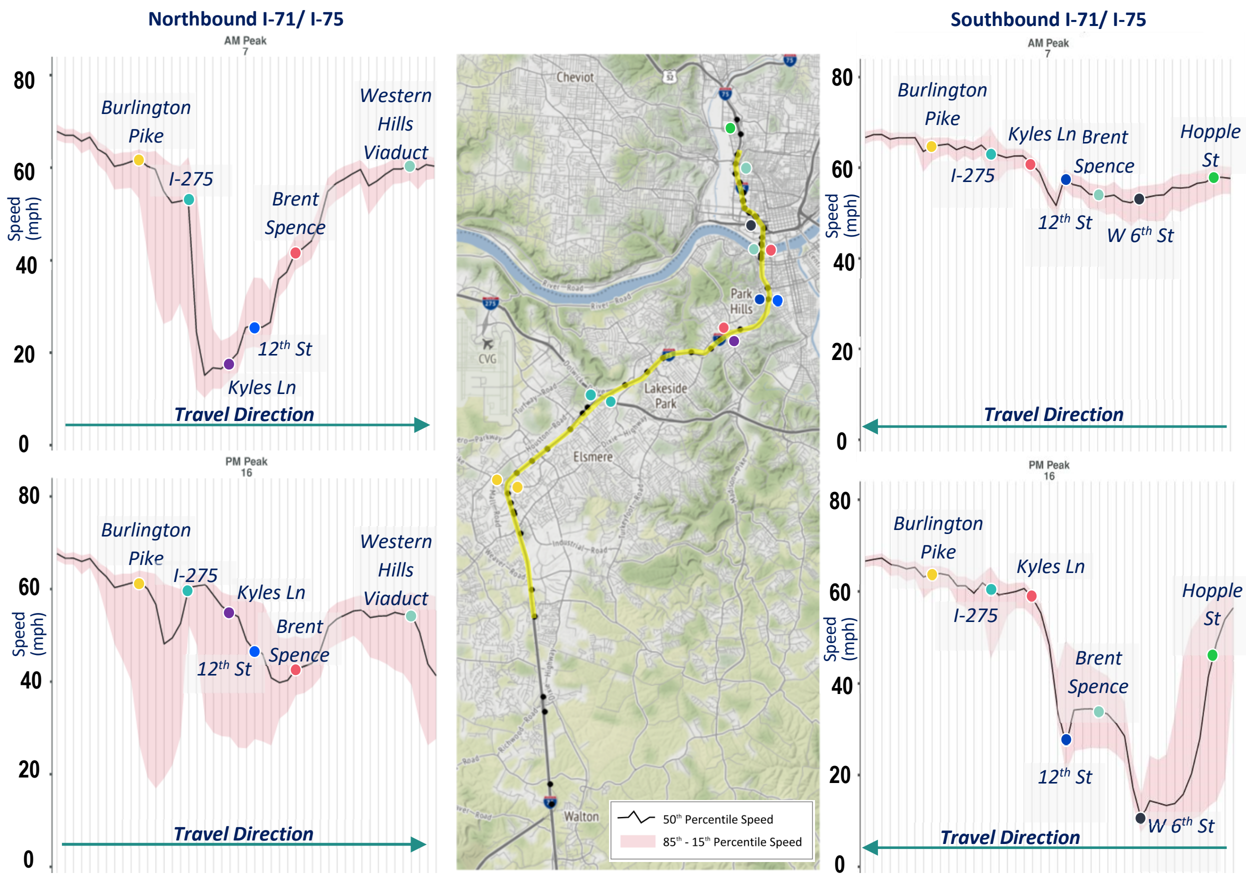
Peak period weekday travel speeds for 2019 are shown in **Figure 3**. The black lines indicate the 50th percentile travel speeds, while the pink band defines the range from the 15th percentile speed to the 85th percentile speed. The colored dots on the graphs match the dots on the map, highlighting key locations. Note the direction of travel for each graph.

AM Peak – As indicated by the upper left graph, northbound congestion extends from the Brent Spence Bridge back to the I-275 interchange during the AM peak with very low speeds in the vicinity of Kyles Lane. The 15th percentile speeds between Burlington Pike and I-275 are also low, indicating that incidents, weather, and other factors can have a substantial impact on travel in that part of the corridor. The southbound speeds during the AM peak are typically in the 50 mph to 65 mph range (upper right graph).

PM Peak – Northbound congestion during the PM peak (lower left graph) is exhibited on the approach to I-275 as well as from just north of I-275 to the Brent Spence Bridge. The 50th percentile speeds vary mainly between 40 mph and 60 mph, but the 15th percentile speeds drop down to 20 mph. Southbound congestion during the PM peak (lower right graph) is primarily between downtown Cincinnati and 12th Street, with speeds increasing substantially south of 12th Street reaching a 50th percentile speed of 60 mph near Kyles Lane.

Based on the existing congestion, there are improvement needs in the corridor, especially between Burlington Pike and the Brent Spence Bridge. This is the portion of the corridor that was studied to evaluate the feasibility, benefits, and costs of potential ATDM deployments.

Figure 3: I-71/I-75 Existing Peak Period Travel Speeds



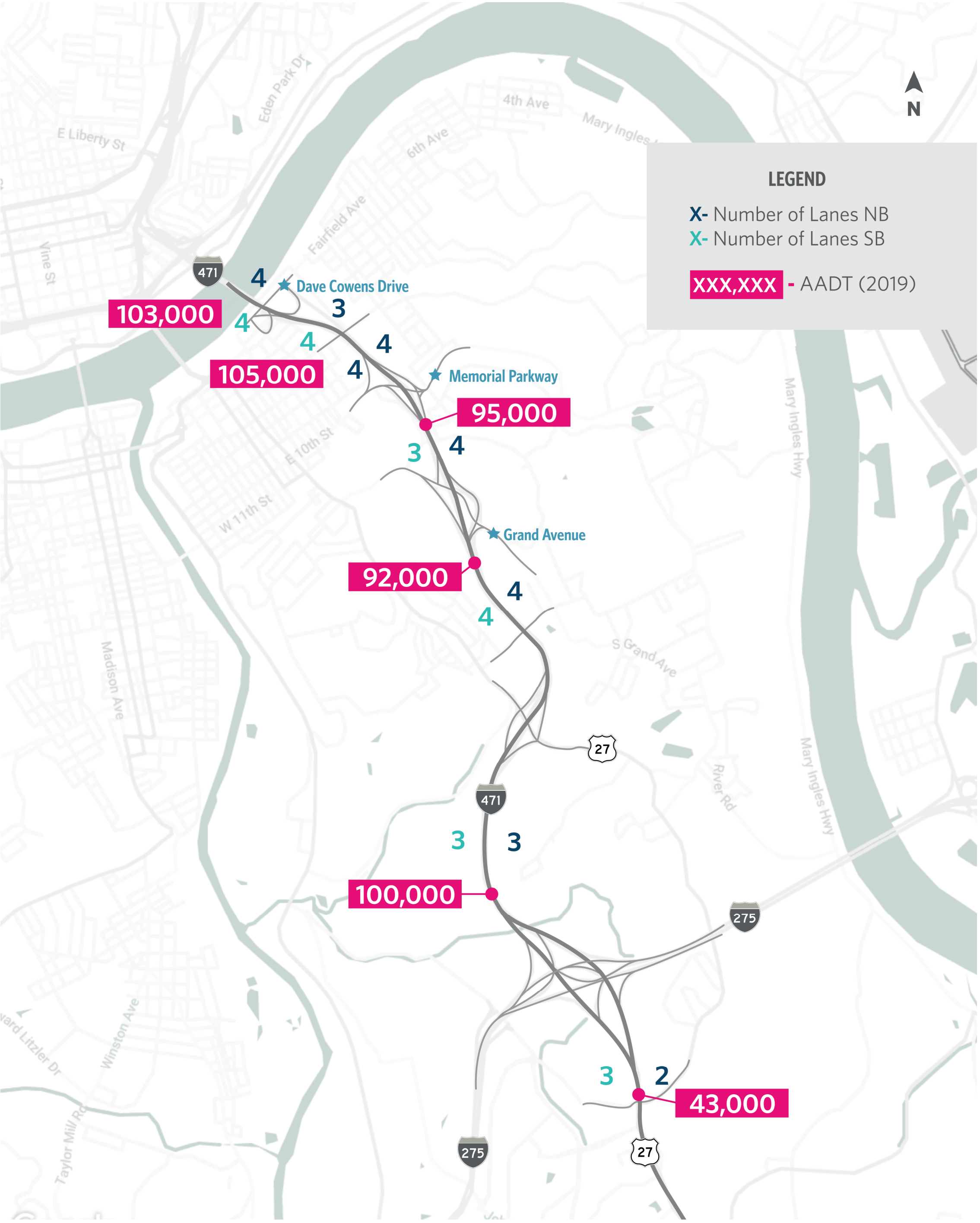
I-471 Corridor

The I-471 corridor runs north and south from US 27 in Highland Heights across the Ohio River via the Daniel Carter Beard Bridge to junction with Columbia Parkway and I-71.

I-471 Lanes and Volumes

The existing facility has between three and four lanes (including auxiliary lanes) and carries approximately 100,000 vehicles per day. The existing number of lanes and daily traffic volumes are shown in **Figure 4**.

Figure 4: I-471 Existing Lanes and Volumes



I-471 Operational Needs

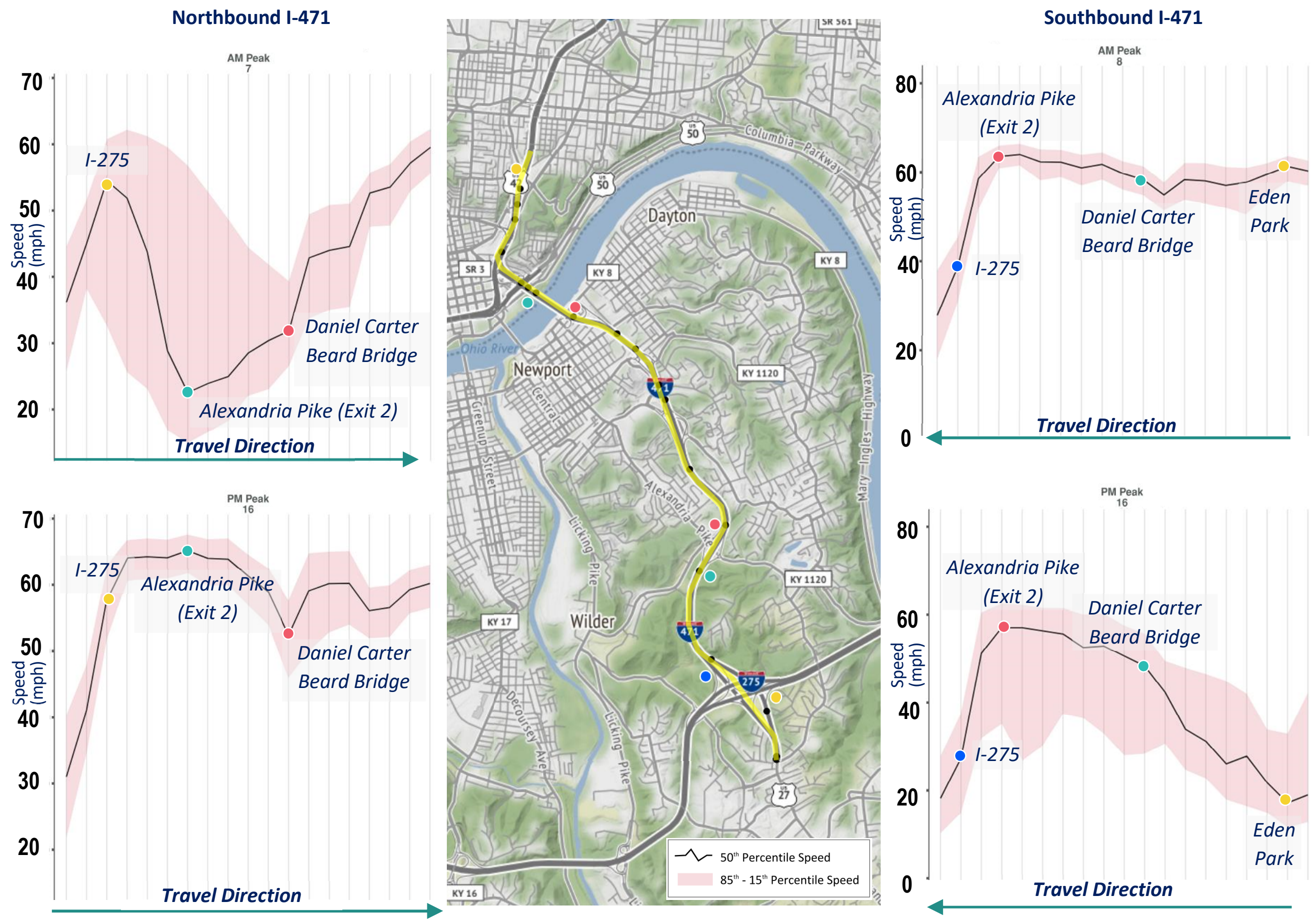
Peak period weekday travel speeds for 2019 are shown in **Figure 5**. The black lines indicate the 50th percentile travel speeds, while the pink band defines the range from the 15th percentile speed to the 85th percentile speed. The colored dots on the graphs match the dots on the map, highlighting key locations. Note the direction of travel for each graph.

AM Peak – As indicated by the upper left graph, northbound congestion extends from the Daniel Carter Beard Bridge back to the I-275 interchange with the lowest speeds near Alexandria Pike. The speed range highlighted by the shaded area is very wide, indicating that speeds vary considerably from day to day. The southbound speeds during the AM peak are typically in the 60 mph to 65 mph range with little variation (upper right graph).

PM Peak – Northbound congestion during the PM peak (lower left graph) shows up on the approach to the bridge over the Ohio River, with speeds dropping to near 50 mph. The 15th to 85th percentile band is not very wide, indicating that speeds are fairly reliable northbound in the afternoon. During the PM peak (lower right graph) southbound speeds generally increase from the bridge to Alexandria Pike, but they drop off south of the Alexandria Pike interchange, highlighting slower speeds and congestion on the approach to I-275.

Based on the existing congestion, there are improvement needs in the corridor, especially during the AM peak northbound and the PM southbound near I-275. The entire I-471 corridor was studied to evaluate the feasibility, benefits, and costs of potential ATDM deployments.

Figure 5: I-471 Existing Peak Period Travel Speeds



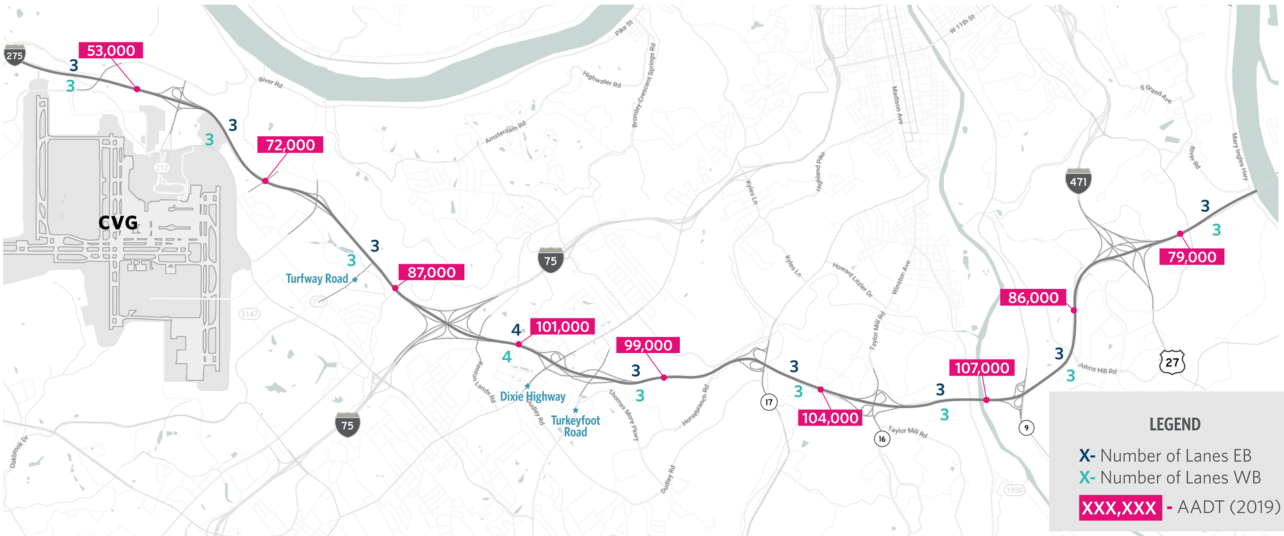
I-275 Corridor

The I-275 corridor traverses Northern Kentucky from the Carroll Lee Cropper Bridge over the Ohio River in the west to the Combs-Hehl Bridge over the Ohio River in the east. It provides an important link between I-71/I-75 and I-471 and connects numerous arterial highways. Beyond the study area, I-275 circles all the way around the Cincinnati region.

I-275 Lanes and Volumes

In the study area, I-275 primarily has three lanes in each direction, but there are locations with additional auxiliary lanes. The daily traffic along the corridor varies between 53,000 to 107,000, with the highest volumes between I-71/I-75 and I-471. The volumes drop off west of the Cincinnati/Northern Kentucky International Airport (CVG). **Figure 6** illustrates the number of lanes and the daily traffic volumes from CVG to the Combs-Hehl Bridge.

Figure 6: I-275 Existing Lanes and Volumes



I-275 Operational Needs

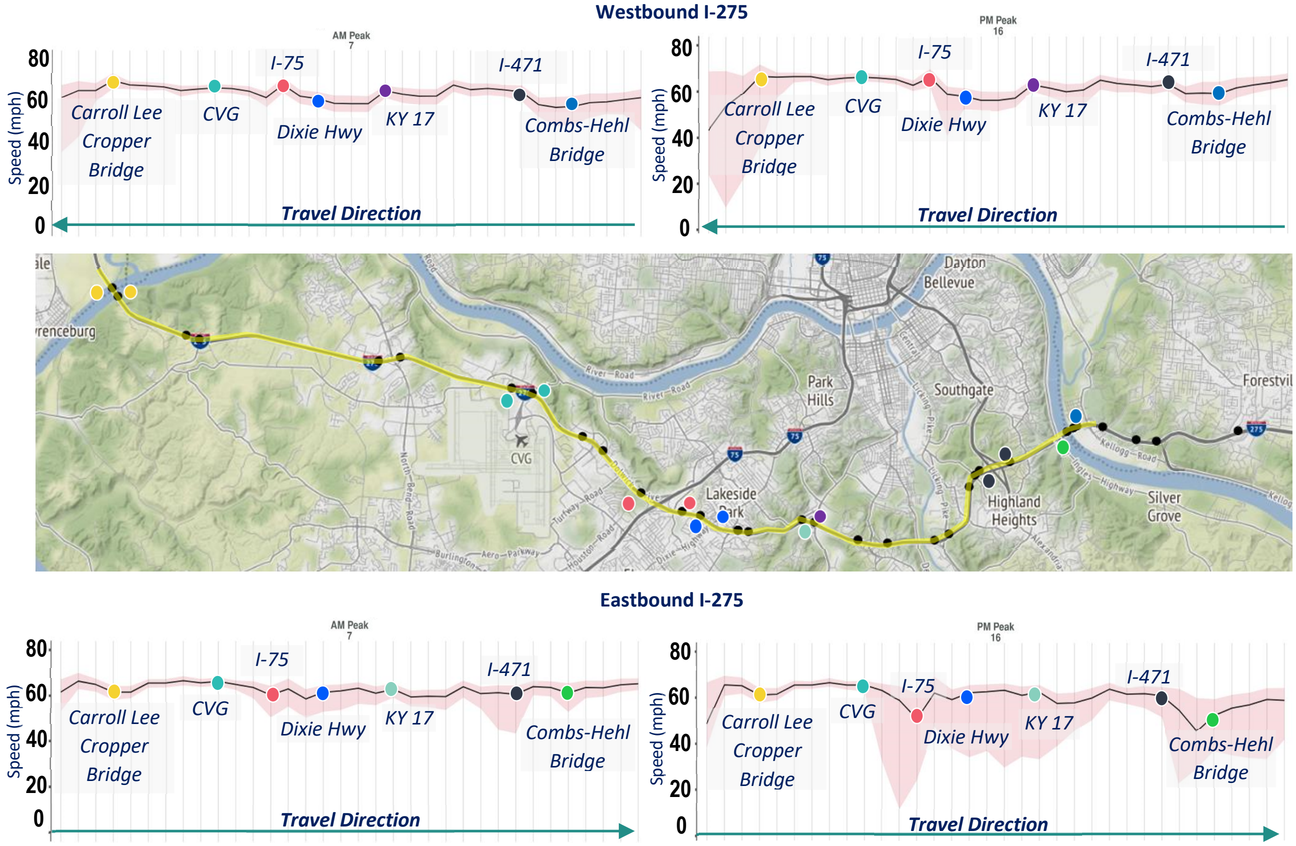
Peak period weekday travel speeds for 2019 are shown in **Figure 7**. The black lines indicate the 50th percentile travel speeds, while the pink band defines the range from the 15th percentile speed to the 85th percentile speed. The colored dots on the graphs match the dots on the map, highlighting key locations. Note the direction of travel for each graph.

AM Peak – As indicated by the upper left graph, westbound speeds tend to be 60 mph or higher during the morning peak period, with very little variability. Eastbound speeds also are generally around 60 mph (lower left graph), but with a little more variability, indicating that crashes, weather, and other incidents may have a larger impact on eastbound operations.

PM Peak – Westbound speeds in the afternoon are again in the 60-mph range, though the range of speeds increases on the approach to the I-75 interchange. Eastbound speeds in the PM peak drop below 60 mph in several places, and there is considerable variation in the eastbound speeds during this time period. This is the time and direction of most interest for ATDM deployments on I-275.

Based on the existing congestion, there may be opportunities to improve the system operations, especially during the eastbound PM peak period. The analysis focused mainly on the eastbound direction from I-75 to I-471, though there was additional consideration given to other portions of the corridor and the westbound direction.

Figure 7: I-275 Existing Peak Period Travel Speeds



System Interchanges

The system interchanges connecting the three study interstates are critical to traffic operations in the study area. They can substantially impact traffic conditions and are often constraint points when traffic demand exceeds the capacity of specific ramps. For this study they are critical in part because of how they can potentially help or hinder the effectiveness of a particular ATDM deployment.

I-71/I-75 & I-275

This is a four-level fully directional interchange between I-71/I-75 and I-275. The mainline on both corridors is three-lanes in each direction through the interchange. The system ramps vary between one and two-lane configurations. The following four ramps have two lanes: I-75NB to I-275 EB, I-275WB to I-75 SB, I-275EB to I-75NB, and I-75SB to I-275EB. The remaining ramps are all one-lane ramps.

The current configuration provides adequate capacity for the majority of current peak period volumes. One important exception to this is the I-75 NB to I-275 EB ramp. The two-lane diverge from I-75 northbound to I-275 serves over 3,700 in the morning peak hour. Over 2,700 of these vehicles are typically headed to I-275 eastbound. This high volume is mainly in the right ramp lane as the left lane goes to I-275 westbound. A low volume ramp joins from the KY 236 C-D road that adds a third lane to the ramp, but this additional lane does not significantly increase the system ramp capacity.

The capacity constraint of this movement could be limiting to ATDM deployments that attempt to shift traffic from I-75 northbound to I-275 eastbound to I-471 northbound. This topic is addressed later as there are TSMO approaches that could be considered to improve the capacity of this movement.

The reverse movement from I-275 WB to I-71/I-75 SB also experiences peak period congestion. This congestion is due in part to the capacity and weaving distances of the C-D Road system that the two-lane ramp ties into. Increasing the capacity of the C-D road is likely beyond the scope of typical TSMO upgrades.

I-275 & I-471

This is a three-level fully directional interchange between the two interstates. Through the interchange the I-275 mainline is three lanes in each direction while I-471 is two lanes in each direction. The system ramps vary between one and two-lane configurations. The I-275 WB to I-471 NB ramp, I-471 SB to I-275 EB ramp, and I-471 SB to I-275 WB ramp are two lanes while all others are one lane.

The current configuration and capacity are adequate to accommodate the existing traffic volumes with two exceptions. On I-471, approximately 800 feet before the I-471 SB exit to I-275 WB, a lane is added on the right side. This allows for a two-lane exit from I-471; however, both lanes drop when they merge with I-275 WB. The newly created right lane merges within the first 1,000 feet after the merge gore (that lane is only 3,800 feet long in total), and the left ramp lane merges approximately 2,000 feet after the merge gore. This creates poor lane utilization on the approach to the I-471 ramp, poor lane utilization on the ramp, and merging conflicts on I-275. Due to the configuration, there is little incentive to use the right ramp lane because it is so short. Using that lane requires three total lane changes, compared to remaining in the left exit lane and merging over only one lane on I-275. Due to the current configuration, the I-471 SB to I-275 WB ramp has approximately the same capacity as a single lane ramp even though it has two lanes.

The mirror ramp (I-275 EB to I-471 NB) is the other capacity constraint for this interchange. It is currently a one-lane, left-sided, flyover exit from I-275 EB. Due to the ramp capacity and geometry (horizontal and vertical) it is a source of periodic congestion. Ramp traffic often operates at a lower speed than the I-275 mainline due in part to the grade and curvature. This can cause queuing in the I-275 eastbound left lane approaching the ramp. This slow left lane traffic creates conflicts with higher speed mainline traffic attempting to utilize the left lanes for passing.

Both capacity constraints at the I-275/I-471 interchange could limit the effectiveness of certain ATDM strategies that shift traffic between routes if the shift causes the interchange to exceed its capacity.

Concept Development

ATDM Strategies

ATDM strategies cover a wide range of active traffic management, demand management, and other approaches. However, this study is focused on the Interstate system which narrows the focus considerably. Examples of ATDM strategies deployed in the US that could apply to Interstate operations and safety are listed in **Table 1**.

Table 1: Example ATDM Strategies for Interstate Operations and Safety

	Strategy	Description	Examples in the US
Active Traffic Management	**Dynamic Shoulder Use**	Allows the use of a shoulder lane during peak periods. It increases capacity when in use and discourages the use of non-Interstate routes.	Columbus, OH; Northern VA; Idaho Springs, CO; Minneapolis, MN
Active Traffic Management	**Ramp Metering**	Controls the rate of flow for vehicles entering the Interstate traffic stream from specific ramps. It can reduce congestion, increase average speeds, and reduce the potential for crashes.	Minneapolis, MN; Portland, OR; Houston, TX; Seattle, WA; Los Angeles, CA
Active Traffic Management	**Queue Warning**	These systems warn drivers in advance about queues and slow traffic. They can prevent crashes and help drivers make better decisions regarding vehicle speed and route choice.	Numerous regions including Northern KY.
Active Traffic Management	**Dynamic Lane Use Control**	Dynamically closes or opens individual lanes, providing advanced warning of the closure using Lane-Use Control Signals. The system must be actively monitored. It can reduce rear-end and other secondary crashes.	Columbus, OH; Northern VA
Active Traffic Management	**Dynamic Junction Control**	Actively adjusts lane access on mainline and ramp lanes in interchange areas based on traffic demand. For example, for off-ramps, this could mean switching between exit-only and shared through-exit movements.	Los Angeles, CA
Active Traffic Management	**Dynamic Regulatory Speed Limits or Dynamic Advisory Speeds**	Sets Interstate speed limits or advisory speeds based on safety and traffic conditions such as weather or congestion. Some of these deployments dynamic set regulatory speed limits, while others dynamically post advisory speeds. State law can dictate which is possible.	Weather Responsive - Knoxville, TN[R]; Mobile, AL[R]; Flagstaff, AZ[R]; Portland, ME[A]; Pittsburgh, PA[R] *(R = Regulatory, A = Advisory)*
Active Demand Management	**Comparative Travel Time (Dynamic Routing)**	Uses variable destination messaging to direct motorists to less congested facilities. Messages can be posted on dynamic message signs or on static message signs with dynamic inserts in advance of major routing decisions.	Numerous regions including Northern KY
Active Demand Management	**Dynamic HOV Lanes / Managed Lanes**	Dynamically changes the qualifications for driving in a high-occupancy vehicle (HOV) lane switching between two passengers and three passengers or removing all restrictions during certain times. Managed Lanes go beyond HOV lanes to include High Occupancy Toll (HOT) Lanes, Truck Only Lanes, Express Toll Lanes, and other similar facility types.	Managed Lanes are now present in many states including Georgia, Texas, Virginia, Florida, and Colorado.
Active Demand Management	**Dynamic Pricing**	Uses tolls that dynamically change in response to changing congestion levels. Real-time and anticipated traffic conditions can be used to adjust the toll rates to achieve mobility goals and other agency objectives.	Houston, TX, Salt Lake City, UT, Seattle, WA, Atlanta, GA, Los Angeles, CA
Active Demand Management	**Predictive Traveler Information**	Uses a combination of real-time and historical transportation data to predict upcoming travel conditions and conveys that information to travelers before and during travel to influence travel behavior.	San Francisco, CA

Sources: US DOT, Alabama DOT

Study ATDM Concepts

Six ATDM strategies were determined to be the most feasible and applicable and to have the greatest potential to improve traffic operations, safety, and reliability on the Interstate system in Northern Kentucky. Five of them were Active Traffic Management strategies and one was an Active Demand Management strategy.

The deployments that were explored further were: Comparative Travel Time, Queue Warning, Ramp Metering, Dynamic Shoulder Use, Dynamic Speed Advisory Signs, and Dynamic Lane Use Control. All six of these were initially considered for application in the project area. They were defined and benefits and drawbacks were presented. As they were vetted further for application in Northern Kentucky, it became clear that the dynamic speed advisory signs and dynamic lane control systems were not as promising as the other four.

Specifically, the dynamic lane control system requires a major system installation and extensive ongoing system monitoring. To effectively implement this system would be a major initiative and would go far beyond anything KYTC has done in this field before. It was not clear that a lane control system, without additional capacity, would be effective in improving mobility in a manner commensurate with the implementation and operational costs. There were also questions about whether it would provide safety benefits beyond what a queue warning system could provide for a fraction of the cost. The dynamic lane control system, therefore, became a possible upgrade that could be done in the future or as part of a much larger capacity project in the region.

The dynamic speed advisory system was also not viewed as a promising initial deployment. In Kentucky, state law complicates dynamically changing the posted regulatory speed, therefore the system could be limited to posting advisory speeds. Furthermore, these systems are best employed when they are part of larger overhead signage systems such as those used for dynamic lane control. Therefore, this system could be part of a future lane control system, but it did not make sense to do it as a stand-alone system. That left the remaining four strategies for further examination.

Comparative Travel Time

Comparative travel time messaging is the use of DMS or hybrid static signs with DMS panels to display travel times for two or more unique but comparable routes to a common destination. Based on the times displayed, motorists can easily gauge travel and traffic conditions for the signed routes and select in real-time the route with the least delay. Comparative travel time can improve a driver's travel experience by allowing better enroute decision making. It also improves traffic operations by spreading demand across multiple routes; more effectively using available capacity, reducing congestion, and improving safety.

Queue Warning

Queue warning systems alert drivers about slowed or stopped traffic to prevent sudden slowing and to reduce the number and severity of rear-end or erratic lane change crashes. These systems often have sensors along freeways that are regularly congested or experience frequent events such as crashes or other incidents, adverse weather and poor pavement conditions, or construction activity. However, algorithms using third party speed data (such as WAZE or HERE) can also be used to identify the congested areas and automatically populate the queue warning messages. When slowed or stopped traffic is detected, a warning message is displayed on a DMS, possibly coupled with flashing lights to indicate that the warning is in effect.

Ramp Metering

Ramp metering is the use of traffic signals, installed on freeway entrance ramps, that control the rate that vehicles enter the freeway. Ramp metering reduces the impact that traffic entering the freeway has on mainline traffic flow by storing vehicles (i.e., excess demand) on the ramp and releasing them one at a time rather than allowing closely spaced vehicle platoons to enter the freeway. By managing the rate that traffic can enter the freeway, vehicles can merge more smoothly with mainline traffic reducing merge related congestion.

Dynamic Shoulder Use

Dynamic shoulder use is an active traffic management approach for dynamically opening the shoulder to traffic on a temporary basis in response to increasing congestion, incidents, or special events. Dynamic shoulder use can temporarily increase roadway capacity and postpone or eliminate the onset of congestion and its effects on travel time reliability and safety. Dynamic shoulder use can also be restricted to particular classes of vehicles, such as HOVs or transit, to increase person throughput and encourage mode shift. Dynamic shoulder use deployments typically use overhead DMS to indicate whether the shoulder is open to traffic. These signs would be in conjunction with the other DMS and/or static signs needed to support the deployment. For deployments where the shoulder use times are fixed (not dynamic), static signs can be used to display the times of operation.

Deployment Analysis

Each of the deployments was evaluated to assess feasibility and to determine the potential benefits and costs. The data sets and methods outlined previously were used in the analysis.

Feasibility

The feasibility assessment focused on physical and operational feasibility. It is a planning-level feasibility analysis, so measurements were based on available planning-level data. For example, pavement widths and bridge widths were examined using KYTC's Highway Information System (HIS) data, aerial photography, and as-built plans. More detailed follow-up would be required for each project that is advanced to the System Requirements and High-Level Design phases of the Systems Engineering project development process (see the Next Steps in the ATDM Deployment Process chapter).

Benefits

The benefit analysis focused on annualized benefits from the mobility and safety analysis results.

Mobility Analysis

The mobility evaluation addressed both recurring and non-recurring congestion, covering traditional peak-period mobility as well as reliability related to incidents, weather, and other factors. Performance metrics included travel time, delay, and queues. The operations analysis was conducted using FREEVAL+ (Build 20210105 version 1.02). Base models were developed for each analysis corridor for the respective peak period (3 hours) and calibrated to peak hour observed speeds and congestion. A reliability analysis was generated for each base model using specifically tailored demand, weather, and incident data where applicable to generate annual results. The reliability analysis synthetically analyzes all of the weekdays in a year (240) using the input variables mentioned to provide detailed results. The base models and resulting reliability analysis provides the baseline for comparing the deployment scenarios.

Safety Analysis

The safety analysis used research results, Highway Safety Manual (HSM) methods, and other approaches to estimate the expected change in crashes with each deployment. This analysis used the actual crashes recorded between 2015 and 2019 as the safety baseline. The crash data was obtained from the KSP database and contains detailed information for each crash including information on location, time, severity, manner of collision, weather, roadway conditions, contributing factors, etc. The crash data was separated by facility and direction to determine crash statistics and rates for each facility. Additionally, safety benefit calculations were conducted independently for each corridor. The comprehensive crash costs used for calculating benefits were provided by KYTC and are the same values used for estimating safety improvements for Highway Safety Improvement Program (HSIP) projects.

Costs

Project costs were calculated for each deployment. They included construction, operations and maintenance, and a contingency. The costs were developed using the construction costs for major items and/or per mile construction costs. The operating and maintenance costs were estimated for a 10-year period. The final cost values are high-level planning costs, but they are reasonable for project assessment and project programming.

Benefit-Cost Analysis (BCA)

The benefit-cost analysis monetized the mobility benefits measured in total vehicle hours traveled. USDOT's recommended value of time was used for this monetization. The safety benefits were based on the value to society of the prevented crashes. This was determined using the projected crash reductions and the HSIP comprehensive crash costs for each level of crash severity.

The combined societal benefit (mobility plus safety) was compared to the total project cost including construction, operations and maintenance, and a contingency. A 10-year time horizon was used for the analysis. This is consistent with the shorter time frame typically used for operational and technology type projects. The benefits were therefore assumed to accrue over 10 years and the operating and maintenance costs were estimated for the same 10-year period.

Consistent with USDOT guidance, a 7% discount rate was applied to the 10-year stream of benefits and costs to yield a net present value for both the benefits and the costs that could be compared to yield the final benefit-cost ratio. A ratio of over 1.0 indicates that net present value of the benefits is greater than the costs, while a value below 1.0 indicates that the present value of the costs exceeds the benefits.

Comparative Travel Time

A basic assumption of this deployment is that if drivers have accurate real-time information at the decision-making point, they can make better routing decisions. This can yield systemwide benefits as drivers avoid congested and over-capacity routes. Even with mobile device routing applications, drivers still struggle to make the best decisions. Many drivers do not check route options before they start a trip they make frequently. In addition, conditions may change after they begin a trip. It is important that comparative travel time information be communicated via roadside signs to promote safe driving and discourage drivers from using mobile devices while driving.

Potential Deployment

Two potential independent deployments were identified as this strategy was defined and evaluated. The primary deployment (Phase I) had the most direct and immediate benefits. The secondary deployment (Phase II) could be implemented at the same time, or it could be implemented later, possibly in conjunction with other highway improvements. The DMS deployments and strategy will work in conjunction with existing DMS along I-71/ I-75 NB approaching the I-275 interchange and those along I-275 in both directions.

Primary Deployment (Phase I)

The primary comparative travel time deployment would be implemented in the vicinity of the I-71/I-75 and I-275 system interchange with the goal of assisting drivers in assessing the travel time impact of congestion on the approach to the Brent Spence Bridge. It would include Interstate mainline signs and arterial signs near the system interchange.

Interstate Mainline Signs - Three mainline signs are proposed for the northbound approach to I-71/I-75/I-275 system interchange (see **Figure 8**). A fourth sign is proposed for the eastbound I-275 approach to the same interchange. The signs would provide drivers with information about travel times to major destinations via alternative routes. For example, they could display the travel time to the I-71/I-471 interchange in Ohio via I-71/I-75 or via I-275 and I-471. The sign locations were selected to reach as many drivers as possible and provide them with adequate time to make and implement a routing decision. The signs would need to be single purpose signs as discussed below.

Arterial Signs at Interchanges - Seven arterial dynamic message signs are proposed at three interchanges where drivers must decide on whether to use I-71/I-75 or I-275 and I-471 to go north across the Ohio River. The purpose of these signs is to provide drivers with comparative travel time information before they enter the freeway system. The signs would ideally be visible far enough from the interchange entrance ramps for drivers to adjust their route selection. They would also have to be sized and located carefully enough to fit into the context of each interchange. The signs could also be used for the queue warning system and could display other messages when necessary. The three Phase I interchanges are:

1. I-71/I-75 and KY 236 (Commonwealth Avenue)*
2. I-275 and US 25 (Dixie Highway)
3. I-275 and KY 1303 (Turkeyfoot Road)

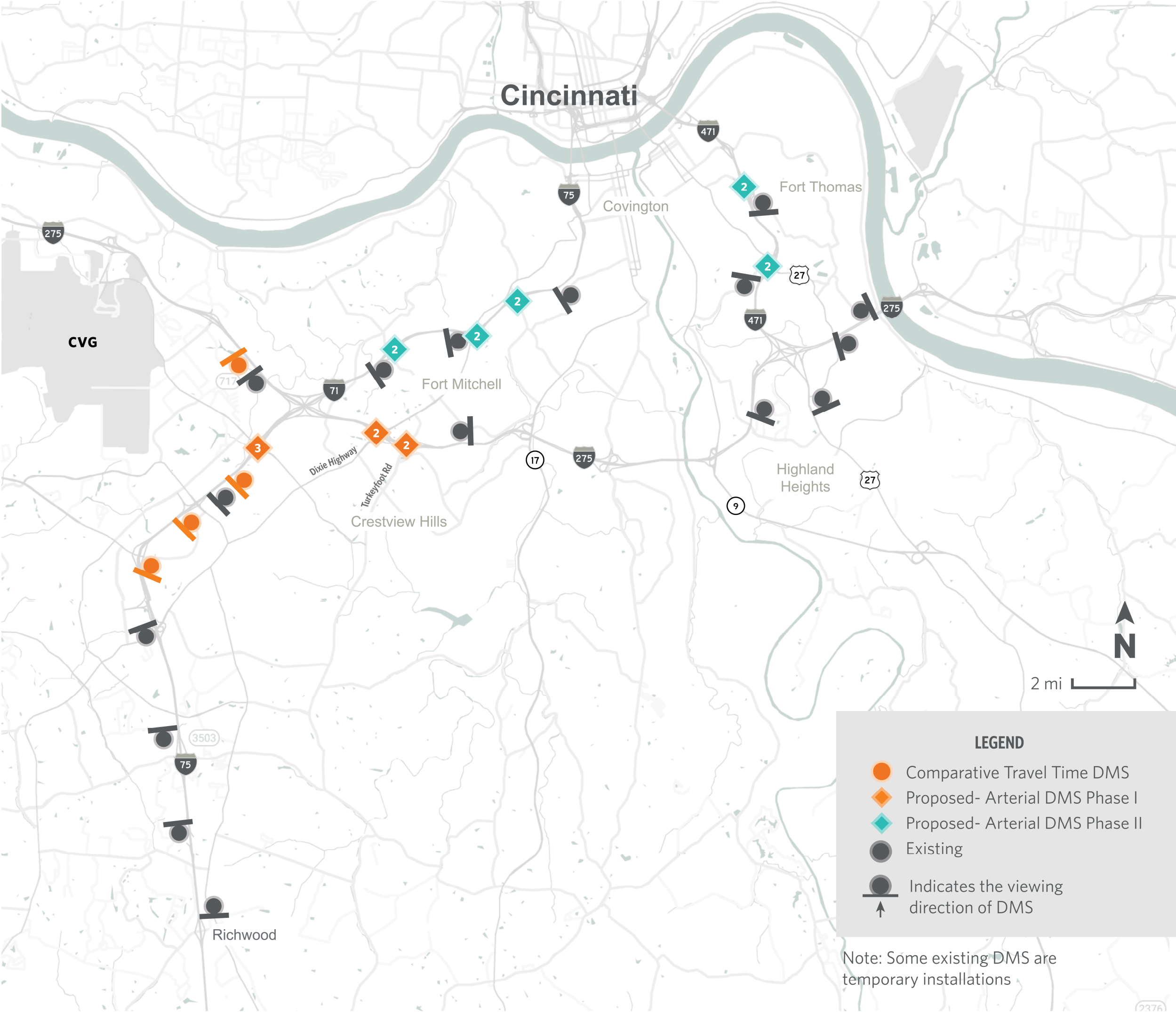
** Three signs, one on each side of the interchange and one on the NB on-ramp*

Secondary Deployment (Phase II)

A secondary deployment would provide ten arterial DMS at interchanges on I-71/I-75 north of I-275 and at interchanges on I-471. These could be installed as sufficient additional funding became available. The goal of these installations would be to convey the travel time implications of congestion on area Interstates so that drivers can make good regional route decisions. For example, the DMS at the I-471 interchanges could provide drivers with information that accounts for congestion on the Daniel Carter Beard Bridge. Like the other arterial DMS, these signs could be used for the queue warning system and could display other messages as well. The secondary interchanges are:

1. I-71/I-75 and KY 371 (Buttermilk Pike)
2. I-71/I-75 and US 25 (Dixie Highway)
3. I-71/I-75 and KY 1072 (Kyles Lane)
4. I-471 and KY 1892 (Grand Avenue)
5. I-471 and US 27 (Alexandria Pike)

Figure 8: Proposed Comparative Travel Time System DMS Installations



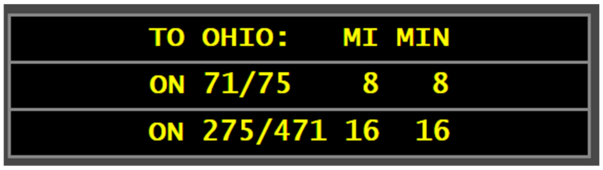
Sign Considerations and Types

To be effective, the mainline signs deployed for this strategy should have the primary purpose of displaying comparative travel time data. Currently, there is a DMS on northbound I-71/I-75 approaching the I-275 interchange in a good location for route choice decision making that displays comparative travel times. A typical message is shown on left side of **Figure 9**. One issue with the current situation is that when congestion or an incident occurs, the message is typically switched to a higher priority safety message as shown on the right side of **Figure 9**. Therefore, when drivers need the comparative travel time information, it is not possible to provide it due to the more important need to communicate safety risks.

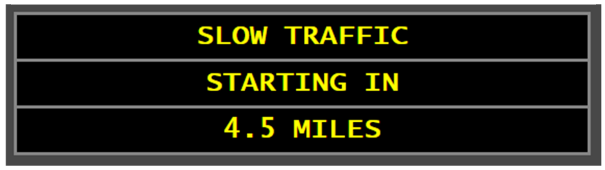
During an off-peak (Sunday evening) observation period, as congestion built up on the approach to the Brent Spence Bridge the slow traffic message was displayed. The travel time to I-71/I-471 in Ohio was shorter via I-275 and I-471 than on I-71/I-75 during part of the observation period. However, there was no way to inform drivers of the change. Therefore, it is necessary to install signs with a primary purpose of conveying comparative travel times.

Figure 9: DMS Messages on I-71/I-75 Approaching I-275

Message During Period Without Congestion



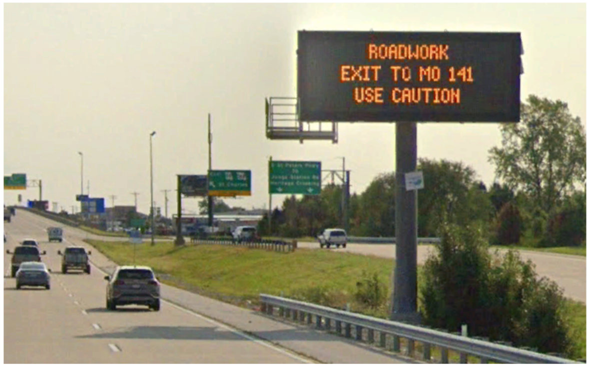
Message During Period With Congestion



Two types of messages are typically used to convey comparative travel time information: DMS and static signs with inserts (**Figure 10**). DMS are flexible and effective for communicating, but they are expensive and are often repurposed for other more important messages. DMS can be installed overhead, but for this application less expensive side mounted DMS could be effective. Static signs with dynamic inserts are less expensive than DMS. They are also single purpose signs, communicating travel times 24 hours a day and 7 days a week. However, they are not flexible and cannot accommodate changing routes or new destinations.

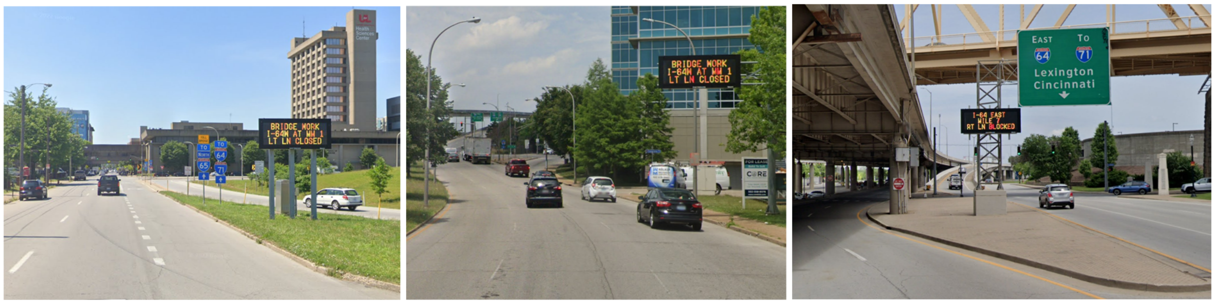
For purposes of this planning analysis, it was conservatively assumed that side mount DMS installations would be deployed to account for the potential of using high-cost installations. If static signs were used, the deployment cost would decrease, and the benefit-cost ratio would increase.

Figure 10: Side-Mount Dynamic Message Sign and Static Comparative Travel Time Sign with Dynamic Inserts



The arterial signs, like those installed in District 5, would also be side mount signs. They would need to be sized and designed to fit into the existing context of each interchange. Example signs from District 5 are shown in **Figure 11**. There are currently 10 permanent arterial DMS installations in and around downtown Louisville.

Figure 11: Example Side-Mount Arterial Dynamic Message Signs in District 5



Relationship to the Queue Warning Strategy

The Interstate mainline comparative travel time signs are assumed to be single purpose installations. However, the arterial DMS included with the comparative travel time strategy would certainly be used for a variety of other purposes. They could for example display safety and congestion related messages and could support the queue warning system. This relationship between the two systems is discussed further in the queue warning section.

Operations and Maintenance

The travel time data displayed must be accurate in real time for the public to trust it and take action based on what is displayed. KYTC and TRIMARC have access to excellent real-time data streams (every two minutes) that can be used to support this application. Specific destination points would need to be selected with travel times calculated from the viewing point of all comparative travel time signs. Cameras (existing or newly installed) could be used to verify that the signs are posting the correct times. While periodic system checks, data reviews, and sign maintenance would be necessary, this strategy does not have major operations and maintenance requirements after the initial installation and programming.

Analysis Assumptions

The Comparative Travel Time analysis focused on I-71/I-75 northbound and the potential for reducing systemwide delay by diverting more traffic to I-275 eastbound and I-471 northbound when the I-71/I-75 northbound corridor is heavily congested. A basic assumption of this deployment is that if drivers had better real-time information at the point of decision making that more of them would choose the route with the shorter travel time. Even with the advent of numerous routing applications (both in-vehicle and on mobile devices), the data clearly shows that drivers do not always choose the quickest route.

The analysis assesses the benefits of the primary deployment (Phase I), which includes the I-71/I-75 northbound mainline signage, I-275 eastbound mainline sign, and the three arterial DMS installations just south and east of the I-71/I-75/I-275 interchange. These locations are decision points where drivers often choose which way to head north. The analysis does not directly assess the benefits of the other arterial DMS installations. The benefits of those installations would be in addition to the benefits calculated in this section. The analysis also only considers the AM peak period. Benefits during other time periods would be in addition to the benefits estimated in this section. The analysis assumptions are summarized in **Table 2**.

Table 2: Comparative Travel Time Analysis Summary Table

Deployment Summary	DMS provide drivers with advanced notice of comparative travel times to destinations between alternative routes. Providing advanced warning before key decision points along a route allows drivers to make better route decisions without using handheld devices.		
Study Areas	Due to congestion and current DMS capabilities, this analysis focused on comparative travel times along I-75 NB as it compares with I-275 EB & I-471 NB for trips with a destination in Ohio		
Analysis Areas and Time Periods	I-75 NB AM Peak	I-471 NB AM Peak	I-275 EB AM Peak
Analysis Tool	FREEVAL+ (20210105 version 1.02)		
Methodology for Analysis	Assumption that I-75 NB AM mainline traffic approaching the system interchange would divert to I-275 EB + I-471 NB at: 3% for medium congestion scenarios; 8% for heavy congestion scenarios		

Based on the traffic volume data and the Streetlight Origin-Destination (O-D) data there are approximately 3,000 vehicles per hour during the AM peak that have an origin south of I-275 with a destination at the Brent Spence Bridge (crossing into Ohio). Using Streetlight in combination with speed/travel-time data, a sample of dates was selected for various periods of congestion during the AM peak to determine existing route choice and diversion patterns. **Table 3** shows the quintile travel-time ranges, Streetlight index trips, and the diversion percentage based on the level of congestion. As the travel times on I-71/I-75 increase, the traffic using the I-471 bridge generally increases from 6% in the first quintile, to 9% for the middle three quintiles, to 14% for the fifth quintile. This indicates diversions from I-71/I-75 to I-471 of approximately 3% and 8% observed depending upon the level of congestion. A sample of the O-D analysis portal is shown in **Figure 12**.

Table 3: Comparative Travel-Time Origin-Destination Assessment

Travel-Time Quintile	Travel-Time (min)	Brent Spence Bridge (I-75)		Daniel Carter Beard Bridge (I-471)		Total		
		Streetlight Index Trips	Percent	Streetlight Index Trips	Percent	Streetlight Index Trips	Percent	Additional Diversion
1	6.5-17.5	4,814	94%	283	6%	5,097	100%	**0%**
2	17.5-20	4,599	91%	444	9%	5,043	100%	**3%**
3	20-22	4,644	91%	472	9%	5,116	100%	
4	22-26	4,596	91%	439	9%	5,035	100%	
5	26-63.5	3,854	86%	605	14%	4,459	100%	**8%**

Feasibility

There are no known major physical or operational feasibility issues with this deployment. It appears that the mainline and arterial DMS could be installed in right-of-way and that utilities would be accessible or nearby. Sign locations and spacing would need to be evaluated in detail for the mainline locations. A review of the Phase I arterial DMS interchanges shows that there should be sufficient space for the proposed new installations.

Real-time travel time data (WAZE) is already being used by TRIMARC for comparative travel time and travel time/distance displays. This deployment would extend the current application and make it a permanent 24-7 operation, providing drivers with comparative travel time information at all times. It would also extend the system geographically to inform drivers on I-275 eastbound and on arterials before they reach the I-71/I-75 and I-275 interchange decision point. The main feasibility issues for this deployment would be operational (e.g., data, communication, and maintaining a 24-7 operation in Northern Kentucky).

Operational Analysis

The operational analysis was conducted using FREEVAL+ to analyze the impact of shifting Ohio-bound traffic volume from I-75 NB to I-471 NB via I-275 EB during the AM peak period. As I-75 NB during the AM peak is the primary source of recurrent congestion, this trip diversion to better utilize other facilities is the primary objective of the deployment. The O-D data for the existing diversions based on congestion were used to analyze the anticipated diversions with comparative travel time DMS, providing all drivers with better information. Diversions of an additional 3% and 8% of I-75 NB volume bound for Ohio were used based on the I-75 NB AM base model Travel Time Index (TTI) results. The average TTI for each three-hour period was calculated to determine the level of congestion for that morning peak period (for all 240 peak periods). The following TTI thresholds for I-75 NB AM were used for the diversion. The diversion percentage was assumed to be the same for the entire three-hour period and the diverted volumes were held constant for I-275 EB and I-471 NB to maintain the traffic volume changes:

- TTI < 1st Quartile TTI: no traffic diversion
- 1st Quartile TTI < TTI < 3rd Quartile TTI: 3% traffic diversion
- TTI > 3rd Quartile TTI: 8% traffic diversion

Table 4 provides the summary results of the Comparative Travel Time operational analysis. The relevant performance metric is the total annual vehicle hours traveled (VHT), which was monetized using USDOT values for travel time. As traffic diverts from I-71/I-75 it yields a travel time benefit for that corridor, but the diverted traffic adds to the travel time on the I-275 and I-471 corridors. However, there is a net system (public) benefit resulting from the shift in traffic from the over-capacity I-75 corridor to the other two corridors. This is demonstrated by the annual system-wide reduction of 140,000 VHT during the AM peak period.

Table 4: Comparative Travel Time Operational Analysis Results

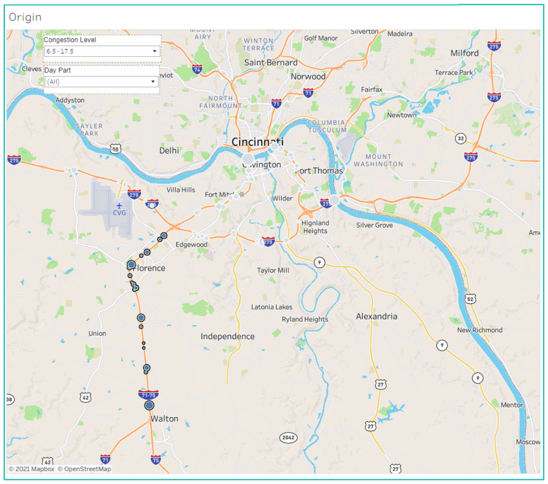
Roadway	Dir	Peak	Vehicle Hours Traveled (VHT)				**Annual User Cost Savings****
			Baseline	With Comparative Travel Time	Δ VHT	% Change	
I-75 w/ Pike St Ramp Project*	NB	AM	1,996,800	1,749,800	**-247,000**	**-12.4%**	$ 6,649,900
I-471	NB	AM	1,007,100	1,062,500	**+55,400**	**+5.5%**	$ (1,491,500)
I-275	EB	AM	587,200	638,800	**+51,600**	**+8.8%**	$ (1,389,200)
Annual Benefit			3,591,100	3,451,100	**-140,000**	**-3.9%**	**$ 3,769,200**

** Pike Street Ramp project is expected to be complete by December 2022*
***User travel-time costs are based on the 2021 USDOT Benefit-Cost Analysis Guidance (Benefit Cost Analysis Guidance 2021.pdf (transportation.gov))*

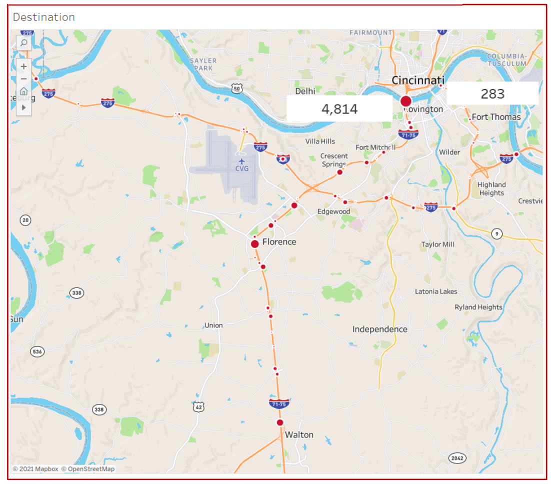
The comparative travel time deployment will benefit drivers not just during the AM peak period, but during any congested period when diverting some trips would benefit the system and reduce driver delay. Traveler information could also benefit drivers with origins at the Phase II arterial DMS interchanges. The system benefits during these other time periods and to the Phase II interchange drivers was not included in the quantified operational analysis. Therefore, the overall project benefits for the entire comparative travel time deployment are expected to be greater than what is shown above.

Figure 12: Travel-Time Origin-Destination Patterns

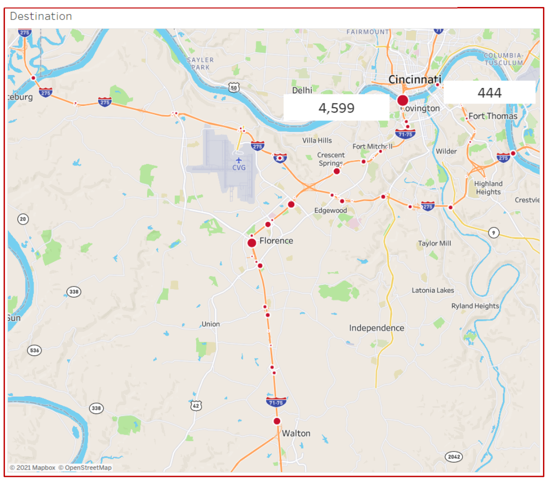
Origins – I-71/ I-75 South of I-275



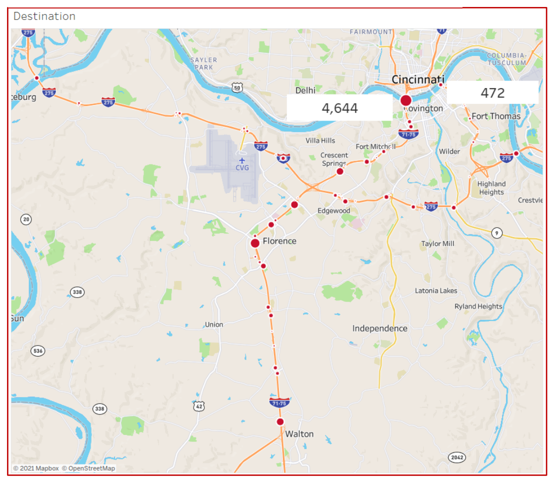
Q1: Travel Time 6.5 – 17.5 min



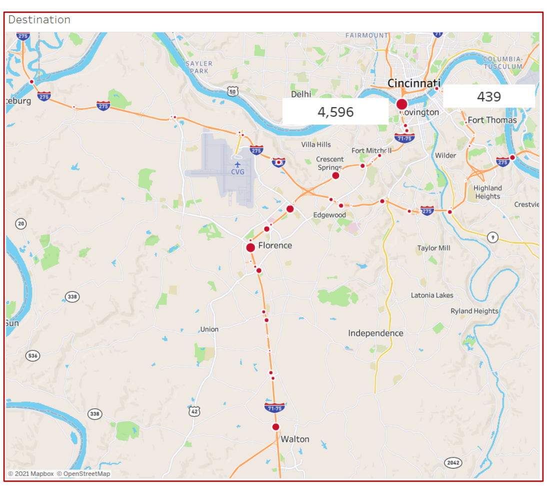
Q2: Travel Time 17.5 – 20 min



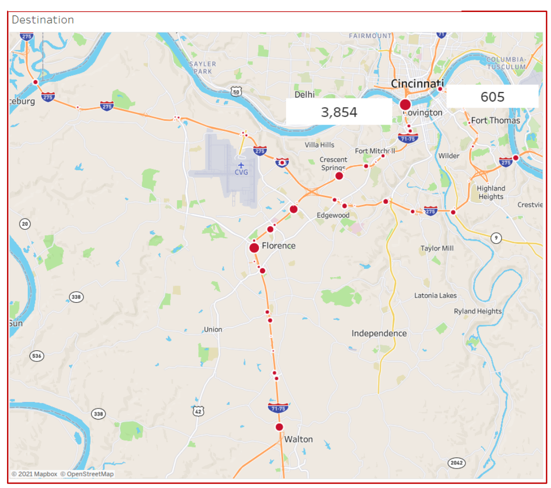
Q3: Travel Time 20 – 22 min



Q4: Travel Time 22 – 26 min



Q5: Travel Time 26 – 63.5 min



Deployment Cost

High-level cost estimates were developed for the Comparative Travel Time deployment. The costs include construction (in 2021-dollar value), 10 years of operations and maintenance (O&M), and contingency (15%). The construction costs associated with this deployment include the installation of Interstate mainline side-mount DMS and arterial side-mount DMS. This also includes the required communication and control equipment.

A total of four mainline signs would be installed, three on I-71/I-75 northbound south of the I-275 interchange and one on I-275 EB approaching I-71/I-75. The Phase I arterial DMS deployment would include three signs at the I-71/I-75 and Commonwealth Avenue (KY 236) interchange two signs each at the Dixie Highway (US 25) and Turkeyfoot Road (KY 1303) interchanges on I-275. The Phase II installation would include ten additional arterial DMS at three I-71/ I-75 interchanges: Buttermilk Pike (KY 371), Dixie Highway (US 25), and Kyles Lane (KY 1072); as well as two I-471 interchanges: Grand Avenue (KY 1892) and Alexandria Pike (US 27). Existing DMS signs could also be used for this deployment when they are not needed for other purposes. No costs were assigned to the use of existing signs. The cost of using existing cameras or installing new cameras for remote operational verification is assumed to be modest relative to the total project cost. The estimated comparative travel time deployment costs are shown in **Table 5**.

Table 5: Comparative Travel Time Deployment Cost

Roadway	Mainline Signs	Arterial Signs	Base Construction*	O & M (10yrs)	Contingency (15%)	Total
I-75 NB	3	9	$1,575,000	$180,000	$263,250	$2,018,000
I-471 NB	0	4	$ 300,000	$ 80,000	$ 57,000	$ 437,000
I-275 EB	1	4	$ 600,000	$ 80,000	$ 102,000	$ 782,000
Total	4	17	$2,475,000	$340,000	$422,250	$3,237,000

**Assumed $75,000 per arterial sign and $300,000 per mainline sign (all side-mount signs)*

High-Level Benefit-Cost Analysis

The operational benefits were compared against the costs at a corridor and system level for comparative travel time to develop benefit-cost (B/C) ratios for each. The benefits were calculated on an annual basis, but they were then adjusted to a 10-year project lifecycle using a 7% discount rate (as recommended by USDOT). The costs included construction, 10 years of O & M, and a contingency as outlined previously. The benefit-cost results are shown in **Table 6**. The safety benefits associated with the comparative travel time deployment are anticipated to be negligible and are not included in the analysis.

Table 6: Comparative Travel Time Benefit-Cost Summary

Roadway	Benefits (10yrs)*			Cost	B/C Ratio
	Operational Benefit	Safety Benefit	Benefit Total		
I-75 NB	$ 49,976,000	N/A	**$ 49,976,000**	**$ 2,018,000**	
I-471 NB	$ (11,209,000)	N/A	**$ (11,209,000)**	**$ 437,000**	
I-275 EB	$ (10,440,000)	N/A	**$ (10,440,000)**	**$ 782,000**	
Total – Combined System	$ 28,326,000	N/A	**$ 28,326,000**	**$ 3,237,000**	**8.8**

**Benefits are calculated based on a 10-year project lifecycle using a 7% discounting rate*

The I-71/I-75 NB corridor shows an operational benefit due to the reduction in VHT (fewer vehicles and higher speeds). The other two corridors have operational costs (negative benefits) resulting from the higher VHT (more vehicles and slower travel times). Combining the three values results in a net operational benefit and a deployment benefit-cost ratio of 8.8. This indicates that a net reduction in VHT is possible if drivers are provided with the information necessary to choose a faster alternative route. Better driver decision making can benefit the system overall, allowing the network to reach a new equilibrium with lower overall travel times (e.g., drivers avoiding the worst congestion, but not making the new route slower than the old one). It is therefore recommended that an expanded comparative travel time deployment be considered for the next phase of project development.

Queue Warning System

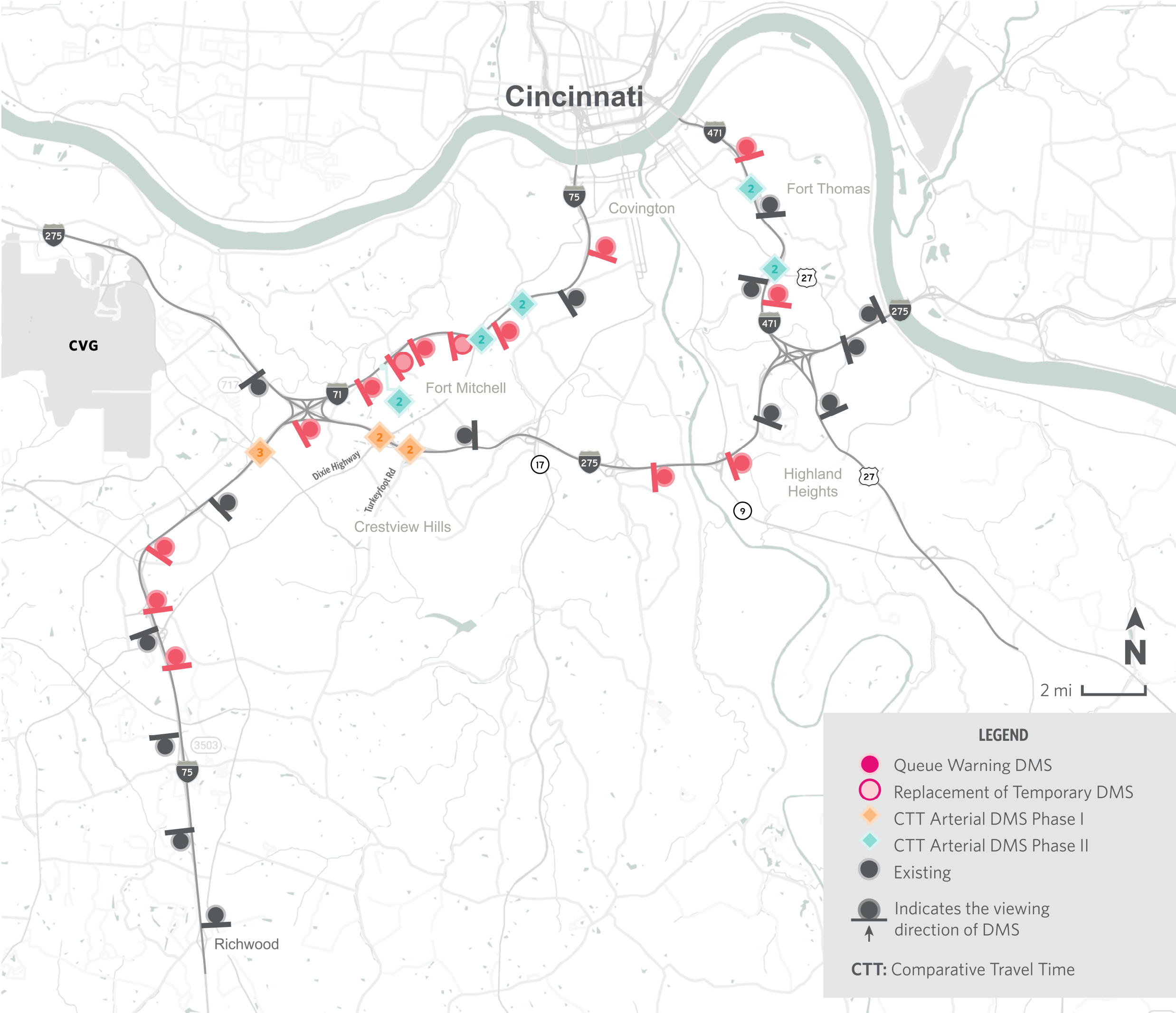
Queue warning systems (QWS) are designed to warn drivers in advance of queues, so that they are not surprised by slow-moving or stopped traffic. This helps to reduce the potential for, and severity of, rear-end collisions. It can also smooth the traffic flow at the boundary of the congested area and reduce the potential for secondary collisions. Well-designed queue warning systems can provide drivers with accurate and actionable information about the location of the slowed or stopped traffic even as the queue increases or decreases in length. This helps drivers to be better prepared and to make better decisions. Queue warning systems have been shown to be effective at improving safety at locations around the country.

Currently, a QWS is in place along I-71/ I-75 NB within the study area. The system uses a combination of permanent and temporary DMS. The system covers approximately nine miles leading up to the Brent Spence Bridge, but with large distances between signs. There was also a southbound temporary system with portable DMS leading up to the Richwood Road construction area. That deployment was recently removed when the construction was substantially complete. A HERE speed data feed is used in conjunction with an algorithm to identify slow-moving traffic and post messages to the northbound QWS signs. One of the issues with the current northbound system is that there is not the density of signs needed to cover the corridor to communicate effectively. Also, the DMS installations are sometimes needed to display other messages.

Potential Deployment

The proposed QWS deployment would upgrade and extend the current system and make it a permanent installation. The proposed QWS deployment would install up to 14 new side-mount DMS along the interstates in the study area as illustrated on **Figure 13**. As shown, the focus of these new signs is on I-75 NB, I-471 NB, and I-275 EB. The existing permanent DMS signs would also be used as part of the QWS, providing extensive system-wide coverage. With the new DMS in place, the QWS would cover some of the most congested areas of the Northern Kentucky Interstate system with mainline signs nearly every mile.

Figure 13: Proposed Queue Warning System DMS Installations

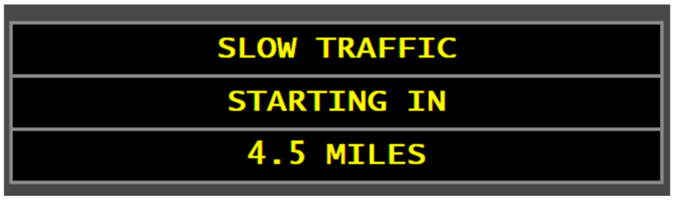


Current Queue Warning Operations

Figure 14 shows DMS messages currently being used in the study area during congested traffic conditions. Similar messaging would be used with the proposed deployment to alert drivers about the location of stopped or slow traffic.

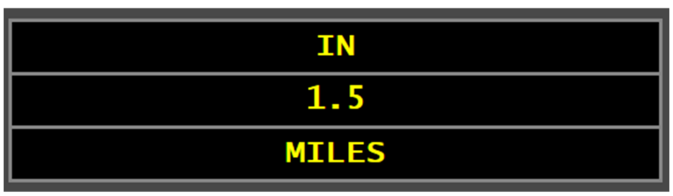
Figure 14: Queue Warning System DMS Messages

Example Queue Warning Sign 1



Example Queue Warning Sign 2A

Example Queue Warning Sign 2B



Example DMS messages obtained from TRIMARC's interactive live map

Operations and Maintenance

The queue and congestion data displayed must be accurate and timely to gain public trust and for drivers to act on the information. KYTC and TRIMARC have access to excellent real-time data streams (every two minutes) that can be used to support this application. Each sign location would need to be initially programmed to reflect its location to properly display the distances for queue warning notifications as the location and extent of queue is a dynamic calculation. While periodic system and data checks and sign maintenance would be necessary, this strategy does not have major operations and maintenance requirements after the initial installation and programming

Relationship to the Comparative Travel-Time Strategy

The Interstate mainline queue warning and comparative travel time installations were planned as entirely separate deployments so that both sets of information would be available to drivers during congested traffic conditions. This is necessary to achieve both the safety and travel time benefits of the two systems. It is not possible to use the same DMS for both deployments, because the safety messages associated with the queue warning system will take precedence over the travel time messages.

The arterial DMS are an area of potential overlap between the two systems. These signs could be used to support either deployment depending on the situation in the field. In many cases they would display information that is useful to drivers trying to make routing decisions, such as travel time, congestion, or lane closure information. However, they could also be used to provide various safety related messages including queue warning messages. Specific protocols would need to be set for use of these signs. For the purposes of this analysis, the costs and benefits of the arterial DMS (Phases I and II) were not included with the queue warning system.

Analysis Assumptions

The analysis assumptions are summarized in **Table 7**. The approach used is expected to yield a conservatively low benefit estimate as it only considers benefits during the peak periods in the study corridors listed. There would be additional benefits that would accrue during other times. As will be shown, this project shows a good cost-benefit ratio even with this approach.

Table 7: Queue Warning Analysis Summary Table

<table>
<tr><th></th><th colspan="4"></th></tr>
<tr><td>Deployment</td><td colspan="4">Queue Warning System (QWS) using Dynamic Message Signs to provide drivers with advance warning of the presence and location of the back of a queue. A QWS is anticipated to reduce secondary collisions, improve driver awareness, and positively impact driver decision-making.</td></tr>
<tr><td rowspan="5">Queue Warning Analysis Corridors</td><td>Corridor</td><td>Time Period</td><td>Start</td><td>End</td></tr>
<tr><td>I-75 Northbound</td><td>AM</td><td>KY 18 Interchange</td><td>Brent Spence Bridge</td></tr>
<tr><td>I-471 Northbound</td><td>AM</td><td>I-275 Interchange</td><td>Daniel Carter Beard Bridge</td></tr>
<tr><td>I-275 Eastbound</td><td>PM</td><td>I-75 Interchange</td><td>Combs-Hehl Bridge</td></tr>
<tr><td colspan="4">Note: Above corridors and time periods were analyzed for this evaluation, but the system would be in effect 24-hours a day and could be used in other locations where there are DMS installations.</td></tr>
<tr><td>Analysis Tool</td><td colspan="4">FREEVAL+ (20210105 version 1.02)</td></tr>
<tr><td>Methodology</td><td colspan="4">• Assumption that Queue Warning will reduce rear-end crashes by 5%
• Assumption of 3% demand diversion when the TTI > 2.50
    o 3% matches the assumed comparative travel time diversion</td></tr>
</table>

For the queue warning analysis, it was assumed that DMS would be spaced at approximately one-mile to one-half-mile increments in the study corridors and/or at strategic locations to notify drivers in advance of queues where line of sight issues may be present. It was also assumed that the existing DMS along the corridor would be utilized for this deployment. The deployment costs are only for new DMS installations, including upgrades of the temporary installations.

The quantitative analysis assumptions were based on several queue warning system research studies. Several research reports have documented the crash reduction benefits of queue warning systems. The following summaries provide the basis for the assumed 5% reduction in rear-end crashes and the 3% shift in traffic to an alternative route:

- 22% crash reduction and 54% near crash reduction based on a MnDOT before/after study of the I-94 system. [https://www.dot.state.mn.us/research/reports/2017/201720.pdf]
- 44% crash reduction at night during a work zone event in Texas with a Queue Warning System in place [http://www.ci.lorena.tx.us/DocumentCenter/View/1254/I35-Central-Texas-Expansion-Project_2015-Annual-Report]
- 14% reduction in queuing crashes and 11% reduction in injury crashes on a I-70/I-57 project in Illinois that used portable Queue Warning Systems during construction. [https://ops.fhwa.dot.gov/Publications/fhwahop14007/fhwahop14007.pdf]
- 15% reduction in queue-related crashes and 63% reduction in injury crashes from a Wisconsin work zone Queue Warning System along I-43. [https://www.traffictechnologytoday.com/news/incident-detection/wisconsins-queue-warning-system-helping-to-reduce-work-zone-collisions.html]
- 5-20% increase in traffic diversions to alternative routes based on DMS messaging, based on a Maryland study [Evaluation of Dynamic Message Signs and Their Potential Impact on Traffic Flow (maryland.gov)].

The assumptions used in the analysis represent a conservative approach to calculating benefits based on the observed results of other QWS deployments. The safety benefit of the project is the direct reduction in rear-end crashes (both primary and secondary crashes) related to queues on the Interstate. Using the historic crash data for the I-71/I-75 corridor, the rear-end crashes were tabulated for the existing (No-Build) scenario and for the Queue Warning (Build) scenario. The operational benefit of the deployment is the improved travel time resulting from the reduction in the rear-end crashes and the predicted shift in traffic.

Feasibility

There are no major feasibility issues with the queue warning system deployment. It is assumed that the side-mount signs can be installed in right-of-way and that utilities would be accessible or nearby. Sign placement for some locations could be challenging given the many other mainline signs, but it is expected that this can be resolved during the high-level design phase. TRIMARC is already using the available real-time data feeds to detect mainline congestion and queues for the existing queue warning systems in effect in the study area. This deployment would extend those systems and make them permanent. One issue would be making sure that the QWS is appropriately extended to all mainline and arterial DMS. The main feasibility issues are expected to be operational and not physical. Operational issues are addressed further in the Concept of Operations Report.

Operational Analysis

Queue Warning was analyzed in FREEVAL+ using the Reliability and ATDM analysis modules. The following modifications were made to the Build models to account for the benefit of the Queue Warning System.

- 5% reduction in rear-end crashes – the incident rates within the reliability module were reduced accordingly.
- 3% traffic demand diversion when the TTI > 2.50 – the ATDM strategies module implemented the traffic diversion based on the resulting TTI specifications.
  The 3% diversion value was established based on the O-D travel time analysis – see the Comparative Travel Time section for additional information.

The results of the operational analysis for each of the study corridors are shown in **Table 8**. The analysis predicts an annual travel time savings of between 20,000 and 53,000 hours per corridor for a total reduction of 110,300 hours per year. This translates into a 2.9% overall reduction in vehicle hours traveled (VHT). The annual user travel time cost savings range from approximately $500,000 to $1.4 million per corridor or $2.97 million overall.

Table 8: Queue Warning Operational Analysis Results

Roadway	Dir	Peak	Annual Vehicle Hours Traveled (VHT)				Annual User Cost Savings**
			Baseline	Queue Warning	Δ VHT	% Reduction	
I-75 (w/ Pike St. Ramp)*	NB	AM	1,996,800	1,943,800	53,000	2.7%	$1,426,900
I-471	NB	AM	1,007,100	987,000	20,100	2.0%	$541,100
I-275	EB	PM	832,800	795,600	37,200	4.5%	$1,001,500
Annual Benefit	**-**	**-**	**3,836,700**	**3,726,400**	**110,300**	**2.9%**	**$2,969,500**
I-75 (existing)	*NB*	*AM*	*2,713,600*	*2,623,200*	*90,400*	*3.3%*	*$2,433,800*

** Pike Street Ramp project is expected to be complete by December 2022*
***User travel-time costs are based on the 2021 USDOT Benefit-Cost Analysis Guidance (*Benefit Cost Analysis Guidance 2021.pdf (transportation.gov))

Since the Pike St. Ramp Improvements project is expected to be constructed and open to traffic by December 2022, that scenario was used for the benefit analysis. However, the results from the I-75 NB (existing) scenario are provided for reference. As shown, the queue warning benefits are expected to decrease with the completion of the Pike St. Ramp Improvements because that project is expected to remove one of the major bottlenecks in the corridor.

Safety Analysis

Crash data from 2015 to 2019 was examined to identify the rear-end crashes (by severity) that occurred during the AM and PM peak periods within the primary areas that would be covered by the proposed system. An average of approximately 280 total rear-end crashes were identified to have occurred during the peak periods in those areas.

The safety analysis assumed a 5% reduction in rear-end crashes where the QWS was present. As noted previously, based on the available QWS research, this appears to be a conservative assumption. The 5% reduction would result in the elimination of 14 crashes per year during those peak periods, or 140 crashes over the 10-year timeframe.

The KYTC comprehensive crash costs by severity were applied to estimate the annual crash cost savings by corridor. Taken together, the total crash cost savings for all corridors is $657,000 per year. The results of the safety analysis for the QWS are shown in **Table 9**.

Table 9: Queue Warning Safety Analysis Results

Roadway & Scenario		Avg. Annual Rear-End Crashes by Severity					TOTAL	Annual Cost Savings
		K	A	B	C	O		
Comp. Crash Cost		*$ 9,281,571*	*$ 537,913*	*$ 162,885*	*$ 102,957*	*$ 9,689*		
I-75 NB	Existing	0.40	1.00	8.80	12.00	154.40	176.60	
	Queue Warning	0.38	0.95	8.36	11.40	146.68	167.77	
	Reduction	**0.02**	**0.05**	**0.44**	**0.60**	**7.72**	**8.83**	**$ 420,770**
I-471 NB	Existing	0	0	2.40	4.80	58.80	66.00	
	Queue Warning	0	0	2.28	4.56	55.86	62.70	
	Reduction	**0.00**	**0.00**	**0.12**	**0.24**	**2.94**	**3.30**	**$ 72,740**
I-275 EB	Existing	0.20	1.0	1.60	3.00	31.20	37.00	
	Queue Warning	0.19	0.95	1.52	2.85	29.64	35.15	
	Reduction	**0.01**	**0.05**	**0.08**	**0.15**	**1.56**	**1.85**	**$ 163,300**

K – Fatal, A – Serious Injury, B – Injury, C – Possible Injury, O – Property Damage Only
Note: Fractional crashes are a result of using a 5-year average

It is important to note that this is a very conservative crash cost estimate as it only assesses the benefits during the peak periods and only in the primary QWS areas. It also uses a low 5% crash reduction assumption. It is very likely that the safety benefit of the QWS would be greater, and it may be as much as two to three times greater. However, as noted later in this section, even with this conservative benefit assessment the project has a high benefit-cost ratio.

Deployment Cost

The planning level cost estimates for the QWS include construction, operation and maintenance (O&M) for 10 years, and a 15% contingency. The QWS construction cost includes $300,000 per sign for installation of side-mount mainline DMS. This cost is assumed to include all necessary power and communication lines and equipment as well as any required system integration costs. A total of 12 signs were included in the cost estimate. No costs were assigned to the use of the existing overhead DMS. The QWS cost estimates by corridor are shown in **Table 10** (in 2021 dollars).

Table 10: Queue Warning System Estimated Deployment Cost

Roadway	Mainline Signs	Base Construction*	O & M (10yrs)	Contingency (15%)	Total
I-75 NB	10	$3,000,000	$400,000	$510,000	**$3,910,000**
I-471 NB	2	$600,000	$80,000	$102,000	**$782,000**
I-275 EB	2	$600,000	$80,000	$102,000	**$782,000**
Total	14	$4,200,000	$560,000	$714,000	**$5,474,000**
**Assumed $300,000 cost per mainline sign (side-mount signs)*					

High-Level Benefit-Cost Analysis

The QWS benefits (operational and safety) were compared against the costs at a corridor and system level to develop benefit-cost ratios for each. The benefits were estimated for a 10-year project lifecycle using a 7% discount rate (as recommended by USDOT). The costs, as discussed above, were also developed considering a 10-year time-period and were converted to 2021-dollars. The benefit-cost results are shown in Table 11.

Table 11: High Level Benefit-Cost Results – Queue Warning System

Roadway	Benefits			Cost	B/C Ratio
	Operational*	Safety*	**Total**		
I-75 NB	$ 10,723,000	$ 3,162,000	**$ 13,885,000**	**$ 3,910,000**	**3.6**
I-471 NB	$ 4,066,000	$ 547,000	**$ 4,613,000**	**$ 782,000**	**5.9**
I-275 EB	$ 7,527,000	$ 1,227,000	**$ 8,754,000**	**$ 782,000**	**11.2**
Entire System	$ 22,316,000	$ 4,936,000	**$ 27,252,000**	**$ 5,474,000**	**5.0**

**Benefits are calculated based on a 10-year project lifecycle using a 7% discounting rate*

As shown, Queue Warning is anticipated to have a positive benefit-cost ratio for each of the target corridors. The B/C ratios vary between 3.6 to 11.2 with a total combined system ratio of 5.0. The B/C ratios expressed are conservative estimates as the benefits are only tabulated for peak period conditions, but the deployment could be utilized throughout the entirety of the day as needed. It is therefore recommended that an expanded queue warning deployment be considered for the next phase of project development.

Ramp Metering

Ramp metering was considered as a corridor level strategy to improve mainline traffic flow in specific directions during peak traffic demand periods. Ramp meters are traffic signals located on Interstate entrance ramps. They control or meter the flow of entering traffic and create consistent gaps between merging vehicles. This strategy improves the mainline traffic operations because it limits the flow rate of entering vehicles and creates simple merging conditions, thereby reducing turbulence in the mainline traffic flow. Even though the on-ramp traffic is being metered, effective ramp metering systems do not create significant ramp delays or queues while vehicles wait to enter. Metering is typically only active during peak conditions and can be designed to accommodate a range of typical ramp demand volumes.

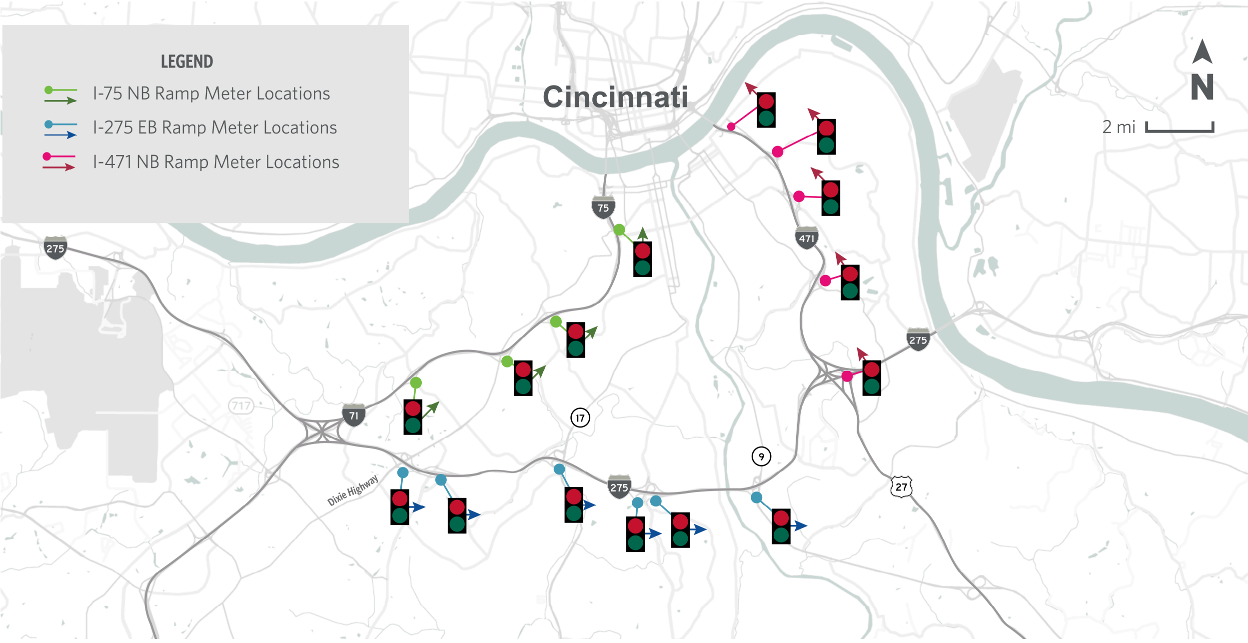
Ramp metering is designed to improve operations by controlling the traffic streams entering from the ramp terminals. To be most effective, it should be implemented on a congested corridor. It is also more effective if traffic volumes increase from interchange to interchange (more traffic entering than leaving), because many of the trips share a common destination. In Northern Kentucky this condition exists during the AM peak period on northbound I-71/ I-75 and on northbound I-471. That condition also exists to a lesser extent during the PM peak on I-275 EB. The reverse direction and peak periods were not as applicable because the volumes begin high and then decrease along the corridors, with more traffic exiting than entering at each interchange.

Potential Deployment

The Interstate system was examined to determine the most promising locations for implementing ramp metering. Based on both recurring and non-recurring congestion, the I-71/I-75 and I-471 northbound directions during the AM peak and the I-275 eastbound direction during the PM peak were identified as offering the best opportunities to reduce delay. **Figure 15** shows the proposed ramp metering locations that were identified for evaluation.

Ramp metering should be considered as a system or corridor level strategy, not as a spot or location improvement option. Controlling ingress to the mainline at the corridor level is necessary to achieve the full benefits of the strategy. Installing singular ramp meters may slightly improve the local operations but would not offer corridor level benefits. Another reason to implement them at the system or corridor level is driver expectations (for both mainline and on-ramp drivers). Broad application leads to drivers becoming familiar with ramp meters, integrating them into their daily routines. Spot locations could result in lower compliance and/or diversion to other ramps also negating the effectiveness. For this study, ramp metering was considered on a corridor level using system interchanges and the Ohio River bridges as termini points for the corridors.

Figure 15: Potential Ramp Metering Locations



Analysis Assumptions

Table 12 summarizes the approach used to evaluate the ramp metering deployment.

Table 12: Ramp Metering Analysis Summary Table

Deployment	Install and operate ramp meters on Interstate service interchange entrance ramps to improve mainline traffic flow and reduce crashes		
Study Areas	I-71/I-75 NB, I-471 (NB & SB), I-275 EB		
Analysis Areas & Time Periods	Corridor	Start of Ramp Metering	End of Ramp Metering
	• I-71/I-75 NB AM Peak	Buttermilk Pike Interchange	Pike Street On-Ramp (Covington)
	• I-471 NB AM Peak	Alexandria Pike Interchange	KY 8 Interchange
	• I-275 EB PM Peak	Dixie Hwy Interchange	KY 9 Interchange
Analysis Tool	FREEVAL+ (20210105 version 1.02)		
Methodology for Analysis	FREEVAL reliability analysis for weekday conditions for one year to assess the impact of an additional lane during the peak periods (2 hours per peak)		

Feasibility

A high-level feasibility analysis was conducted for each ramp based on the Ohio Department of Transportation ramp metering warrants (*Traffic Engineering Manual, Section 1303-11*). The warrants address ramp volume (warrant 1), mainline operational and safety performance (warrants 2-4), mainline volume (warrants 5-6), and adequate ramp geometry (warrants 7-8). The warrants were considered at a high level to determine if each was likely to be met based on the available information. The ramp acceleration and storage requirements were based on the ODOT guidance as outlined in the table notes. The results of the feasibility assessment are shown in **Table 13**.

As shown, ramp meters appear to be warranted and could be installed on three of the five I-71/I-75 ramps without substantial ramp modifications. The Kyles Lane ramp would likely need to be widened or have the shoulders reconstructed as part of the installation. The final ramp at Pike Street could be left unmetered since it will be a lane add condition once the current construction project in that area is complete. Alternatively, it could also be modified to accommodate a two-lane ramp meter configuration; however, this could be challenging given that the ramp is on structure where the meter would need to be placed (840 feet from Pike Street), and an additional 600 feet beyond that point is needed for the lane merge. Overall, however, the I-71/I-75 corridor scores well using the ODOT warrants.

The I-471 corridor has two ramps that warrant meters and can easily accommodate them. There is a third ramp (KY 1120) that warrants them and will require minor widening or shoulder reconstruction. At the northern end, the ramp from KY 8 is a lane add onto the bridge over the Ohio River and may not be necessary to meter. However, it has two lanes at the start of the ramp, and it could likely be redesigned to accommodate a two-lane ramp meter with limited widening and/or shoulder reconstruction. The southern end of the corridor begins with the ramp from US 27/KY 471, which is a two lane through movement to start I-471. While it appears possible to meter this non-Interstate mainline through movement, it is not clear that it is warranted or necessary. It may cause safety issues since drivers would not expect a through movement onto a freeway to be metered. This should only be metered if further analysis shows it to be necessary and beneficial.

The final corridor, I-275 does not appear to be currently warranted based on mainline performance. The volumes at either end are also below the warrant. The KY 17 and KY 9 loop ramps also present geometric challenges and may need to be extended or have shoulder width design exceptions to accommodate the ramp metering. For KY 17, the design issues are particularly challenging given the bridge over Banklick Creek and the railroad.

The actual ramp metering equipment installation along the on-ramps includes the ramp meters (signals), signs and striping, and detection for on-ramp and mainline volumes. The installation of the signal and detection equipment is not expected to present feasibility issues as they can be constructed within the existing right-of-way and utilities are likely to be present nearby.

Table 13: Ramp Metering Warrant and Geometry Feasibility Summary

	Ramps	Existing Ramp Lanes	Peak Hourly Volume	Total Ramp Length (ft)	Required Acceleration Length (ft)[3]	Required Storage Length[4]	Proposed Ramp Lanes	Meets Warrants? Ramp Volume	Mainline Performance	Mainline Volume	Ramp Geometry
	I-71/ I-75 NB		*AM*								
1a	Buttermilk Pk Loop (KY 371)	1	500	3730	560	420	1	Y	Y	Y	Y
1b	Buttermilk Pk On (KY 371)	1	330	2895	560	420	1	Y	Y	Y	Y
2	Dixie Hwy On (US 25)	1	690	1660	560	510	1	Y	Y	Y	Y
3	Kyles Ln On	1	1080[1]	1540	980	420	2	Y	Y	Y	W
4	Pike St On (US 25)	1	1833[1]	1760	Add Lane	840	2	Y	Y	Y	Z
	I-471 NB		*AM*								
1	US 27	2	1030	2110	Thru Lanes	600	2	Y	N	Y	Y / Z
2	Alexandria Pk On (US 27)	1	400	1715	960	420	1	Y	Y	Y	Y
3	Grand Ave On (KY 1892)	1	740	1950+Aux	960	570	1	Y	Y	Y	Y
4	Memorial Pkwy On (KY 1120)	1	800[1]	950+Aux	1380[2]	420	2	Y	Y	Y	W
5	Dave Cowens Dr On (KY 8)	1	890[1]	1330	Add Lane	420	2	Y	Y	Y	W / Z
	I-275 EB		*PM*								
1	Dixie Hwy On (US 25)	1	520	2230	960	420	1	Y	N	N	Y
2	Turkeyfoot Rd On (KY 1303)	1	970[1]	2000	1380	420	2	Y	N	Y	Y
3	Madison Pk Loop On (KY 17)	1	580	1300	960	420	1	Y	N	Y	E / Z
4	Taylor Mill Rd Loop (KY 16)	1	300	2100	960	420	1	Y	N	Y	Y
5	Taylor Mill Rd On (KY 16)	1	420	2000	960	420	1	Y	N	Y	Y
6	AA Hwy Loop On (KY 9)	1	300	900	960	420	1	Y	N	N	E / Z

Y = yes; N = No, W = widen ramp and/or reconstruct shoulder; Z = consider not metering; E = extend ramp (consider shoulder narrowing)

[1] *Volume exceeds capacity for 1-lane ramp meter per ODOT guidelines*
[2] *Acceleration distance met by auxiliary lane length*
[3] *Design speed = posted - 10 mph, 0 mph start for 1 lane, 25 mph start for 2 lane, 600 ft for 2 lane merge (ODOT guidelines)*
[4] *Minimum 420 feet + additional required storage, adjusted for US 27 (ODOT guidelines)*

Operational Analysis

The operational analysis was conducted using FREEVAL+. There are several ramp metering methods available within FREEVAL+; some are directly coded into the network while others are controlled within the ATDM module. For the purposes of this study, examining the potential benefits of the deployment at a high level, a straightforward ramp metering system was implemented within the analysis. The following analysis assumptions were used for all corridors:

- All service interchange entrance ramps within a study corridor have ramp meters
- Ramp meters operate at a fixed rate (900 vehicles per hour (vph) for one-lane, 1800 vph for two-lanes)
- Metering starts 15 minutes before baseline congestion and continues through the peak period
- Assumed 3% capacity increase for merge segments while meters are active (per FREEVAL/HCM methodology)

Ramp metering is difficult to analyze using deterministic traffic analysis tools as these types of tools are not able to examine the changes in vehicle-vehicle interactions due to ramp metering. FREEVAL+ has the ability to account for ramp metering at a high-level through the control of mainline vehicle demand and assumptions related to the capacity increase attributed to improved merge operations with metering. Knowing the limitations, FREEVAL+ is able to provide high-level results for a ramp metering system compared to a baseline scenario without ramp metering. **Table 14** shows the results of the FREEVAL+ analysis for each corridor and applicable peak period.

Table 14: Ramp Metering Operational Analysis Results

Roadway	Dir	Peak	VHT				Annual User Cost Savings**
			Baseline VHT	Ramp Metering VHT	Δ VHT	% Reduction	
I-71/I-75 (w/ Pike St Ramp)*	NB	AM	1,996,800	1,974,100	22,700	1.1%	$ 611,100
I-471	NB	AM	1,007,100	962,200	44,900	4.5%	$ 1,208,800
I-275	EB	PM	587,200	586,500	700	0.1%	$ 18,800
						Annual Benefit	**$ 1,838,700**

** Pike Street Ramp project is expected to be complete by December 2022*
***User travel-time costs are based on the 2021 USDOT Benefit-Cost Analysis Guidance (Benefit Cost Analysis Guidance 2021.pdf (transportation.gov))*

The model predicted that ramp metering would reduce VHT on I-71/I-75 northbound in the AM peak by just over 1%, resulting in an annual user cost savings of $0.6 million. The prediction for I-471 northbound shows a higher 4.5% reduction in VHT, resulting in approximately $1.2 million in annual user cost savings. The I-275 models showed virtually no benefit from the addition of ramp metering, which is consistent with the ODOT warrant findings that indicated the corridor may not have enough congestion to warrant metering yet.

It is important to note that these are high-level results, and they may be underpredicting the actual benefits. **Figure 16** shows Table 1-2 from the *FHWA Ramp Management and Control Handbook* which documents several ramp metering systems in operation in the US. All of the deployments resulted in travel time improvements that were greater than those shown by the FREEVAL+ analysis. If even the lowest of these reported results (8% increase in average speed) was assumed to apply that would substantially increase the reported travel time savings benefits.

Figure 16: Summary of Ramp Metering Mobility Benefits

Location	Benefit
Portland, OR	A 173% increase in average travel speed.
Minneapolis, MN	A 16% increase in average peak hour travel speed and a 25% increase in peak period volume.
Seattle, WA	A 52% reduction in average travel time and a 74% increase in traffic volume.
Denver, CO	A 57% increase in average peak period travel speed and a 37% decrease in average travel time.
Detroit, MI	An 8% increase in average travel speed and a 14% increase in traffic volume.
Long Island, NY	A 9% increase in average travel speed.

Source: FHWA Ramp Management and Control Handbook (Table 1-2)

It is useful to note that the benefits of ramp metering are related to the specifics of each system (ramp locations, number of lanes, volumes, flow patterns, etc.). In addition, as outlined by the ODOT warrants, there are minimum necessary levels of congestion and volume (mainline and ramp) that are needed for the ramp meters to be effective.

Safety Analysis

The safety analysis for ramp metering is based on the safety performance from documented safety benefits from previous ramp metering studies. The FHWA Ramp Management and Control Handbook presents the safety benefits of ramp metering systems for six US locations (**Figure 17**). These studies show significant crash reductions with ramp metering using various reporting methods (total crashes, crash rate, crash type, or crash severity). Based on these studies, it was assumed that 10% of rear-end and sideswipe crashes could be prevented with the implementation of ramp metering. This is a conservative estimate of the safety benefits within the ramp metering areas. **Table 15** shows the results of the analysis with consideration of crash type, severity, time of crash (AM peak only), and travel direction. In total, 38 crashes per year could be prevented in the three corridors, with a total crash cost savings of over $1.5 million. The largest safety benefits would accrue to the I-71/I-75 corridor.

Figure 17: Summary of Ramp Metering Safety Benefits

Location	Benefit
Portland, OR	43% reduction in peak period collisions.
Minneapolis, MN	24% reduction in peak period collisions.
Seattle, WA	39% reduction in collision rate.
Denver, CO	50% reduction in rear-end and side-swipe collisions.
Detroit, MI	50% reduction in total collisions and 71% reduction in injury collisions.
Long Island, NY	15% reduction in collision rate.

Source: FHWA Ramp Management and Control Handbook (Table 1-1)

Table 15: Ramp Metering Safety Analysis Results

Roadway and Scenario		Crash Severity K	A	B	C	O	TOTAL	Annual Cost Savings
Comp. Crash Cost		*$ 9,281,571*	*$ 537,913*	*$ 162,885*	*$ 102,957*	*$ 9,689*		
I-71/I-75 NB	Existing	0.40	1.20	11.00	15.00	219.00	246.60	
	Ramp Metering	0.36	1.08	9.90	13.50	197.10	221.94	
	Crash Reduction	**0.04**	**0.12**	**1.10**	**1.50**	**21.90**	**24.66**	**$ 981,600**
I-471 NB	Existing	0.00	0.00	3.20	5.40	69.40	78.00	
	Ramp Metering	0.00	0.00	2.88	4.86	62.46	70.20	
	Crash Reduction	**0.00**	**0.00**	**0.32**	**0.54**	**6.94**	**7.80**	**$ 174,900**
I-275 EB	Existing	0.40	1.20	2.40	4.00	45.40	53.40	
	Ramp Metering	0.36	1.08	2.16	3.60	40.86	48.06	
	Crash Reduction	**0.04**	**0.12**	**0.24**	**0.40**	**4.54**	**5.34**	**$ 560,100**

K – Fatal, A – Serious Injury, B – Injury, C – Possible Injury, O – Property Damage Only

Deployment Cost

High-level cost estimates were developed for the ramp metering deployment. The costs are broken down between base construction, ramp upgrades, intelligent transportation systems (ITS) and closed-circuit television (CCTV), operations and maintenance (O&M), and contingency. All costs were calculated in 2021 dollars. The base construction costs are for the installation of the ramp meters (signals and loop detectors), while the ramp upgrade costs are for the pavement needed to accommodate additional storage for queuing at the ramp meters. It was conservatively assumed that all ramps that were evaluated would be metered. It was also assumed that Buttermilk Pike (KY 371) would require separate installations for each ramp. The ramp metering costs are shown in **Table 16**.

Table 16: Ramp Metering Deployment Costs

Roadway	Base Construction*	Ramp Upgrades**	ITS / CCTV	O & M (10yrs)	Contingency (15%)	Total
I-71/I-75 NB	$ 1,000,000	$ 500,000	$ 325,000	$ 1,250,000	$ 461,250	**$ 3,536,250**
I-471 NB	$ 1,000,000	$ 500,000	$ 325,000	$ 1,250,000	$ 461,250	**$ 3,536,250**
I-275 EB	$ 1,200,000	$ 600,000	$ 390,000	$ 1,500,000	$ 553,500	**$ 4,243,500**

**Assumed $200,000 per meter for base ramp metering equipment and installation*
***Assumed $100,000 per meter for ramp upgrades to accommodate metering (storage, taper, shoulder, etc.)*

High-Level Benefit-Cost Analysis

The operational benefits were compared against the costs at the corridor and system level to develop benefit-cost ratios for each. The benefits were initially calculated on an annual basis but were totaled for a 10-year project lifecycle using a 7% discount rate (as recommended by USDOT). The costs were developed based on capital construction (using 2021 dollars) and assumed 10-year lifecycle O & M costs. The benefit-cost results for ramp metering are shown in **Table 17**.

Table 17: Ramp Metering Benefit-Cost Summary

Roadway	Benefits			Total Cost	B/C Ratio
	Operational Benefit*	Safety Benefit*	Benefit Total		
I-71/I-75 NB	$ 4,593,000	$ 7,377,000	$ 11,970,000	**$ 3,536,250**	**3.4**
I-471 NB	$ 9,084,000	$ 1,315,000	$ 10,399,000	**$ 3,536,250**	**2.9**
I-275 EB	$ 141,000	$ 4,209,000	$ 4,350,000	**$ 4,243,500**	**1.0**

**Benefits are calculated using a 10-year project lifecycle and a 7% discount rate*

Even with the conservative assumptions employed in the analysis, the I-71/I-75 and I-471 corridors are predicted to have B/C ratios of 3.4 and 2.9 respectively. It is expected that the actual operational benefits of a ramp metering system would be greater than those calculated using the FREEVAL+ model, which would result in higher B/C ratios. The I-275 corridor yielded a B/C ratio of 1.0 indicating that it may not be a good candidate for ramp metering at present. However, as traffic grows in this corridor it may become viable in the future. Given the analysis and feasibility findings, it is recommended that I-71/I-75 and I-471be considered for the next phase of project development for ramp metering.

Dynamic Shoulder Use

Dynamic shoulder use (DSU) was considered as a potential deployment primarily where there is recurring congestion. Recurring congestion occurs at the same time and in the same location nearly every weekday and is typically due to traffic demand exceeding highway capacity. DSU deployments are often designed to address recurring congestion, with the shoulder being made available for use during typically congested times. However, as indicated by the name, they can also be implemented in a dynamic fashion to address non-recurring congestion based on real-time traffic conditions. DSU provides additional roadway capacity by providing an additional travel lane within the shoulder to address congested periods without the need for widening the roadway to add a permanent travel lane.

Potential Deployment

The proposed DSU deployment was studied with a focus on addressing areas of recurrent congestion throughout the three interstate corridors within the study area. To determine the viability, an initial screening of each corridor was conducted by peak period, and direction. The screening focused on identifying recurring peak speed drop locations that could be improved by a DSU lane. Speed drops were defined using the 50th percentile (median) and 15th percentile weekday speed profiles. These were presented in the Study Area Needs Chapter of this report. The screening analysis results are summarized in **Table 18**.

Table 18: Dynamic Shoulder Use Screening Analysis

Corridor	Time Period	Direction	Screening Results	Study Further?
I-71/I-75 *(Refer to Fig. 3)*	AM Peak	Northbound	Substantial recurring congestion. Speed drop occurs north of I-275 and continues to Covington; Median speed drops below 20 mph. DSU could potentially benefit the corridor.	Yes
		Southbound	High median speeds, above 50 mph throughout corridor	No
	PM Peak	Northbound	Speed drops south of I-275 and from Buttermilk Pike to Covington, but median speeds stay above 40 mph. Potential benefits are greater in the AM. PM peak should be explored if an AM peak DSU is determined to be feasible.	No
		Southbound	Major speed drops occur in Ohio. Second speed drop occurs near 12th St. at the bottom of the hill. Speeds increase rapidly from there to Kyles Lane. *See Note A Below.*	No *See Note A*
I-471 *(Refer to Fig. 5)*	AM Peak	Northbound	Substantial recurring congestion. Median speed drops to nearly 20 mph near Alexandria Pike. Speeds increase only modestly to Daniel Carter Beard Bridge (approx. 30 mph).	Yes
		Southbound	Median speeds of near 60 mph through most of the corridor.	No
	PM Peak	Northbound	High median speeds. Median speed drops to 50 at the bridge. Potential benefits are much greater in the AM peak.	No
		Southbound	Median speeds increase from 50 mph at the bridge to 60 mph at Alexandria Pike and then decrease to 25 mph on the approach to I-275. There are also frequent weekday slowdowns (15th percentile band). Possible DSU benefits.	Yes
I-275 *(Refer to Fig. 7)*	AM Peak	Westbound	Median speeds often exceed 60 mph throughout.	No
		Eastbound	Median speeds often exceed 60 mph throughout.	No
	PM Peak	Westbound	Median speeds often exceed 60 mph throughout.	No
		Eastbound	Median speeds drop below 60 and the 15th percentile speed drops below 40 from east of the CVG airport to east of KY 17 (Madison Pike) and again on the approach to the Combs-Hehl Bridge. Possible DSU benefits from I-275 to KY 9.	Yes *See Note B*

Note A for Table 18: *Follow-up Screening for I-71/I-75 Southbound During the PM Peak* **-** Southbound I-71/I-75 was assessed further during the screening process to determine if a shoulder use lane (either left or right side) would benefit traffic operations without negatively impacting safety during the PM peak hour. Several challenges were identified with deploying DSU beginning in the vicinity of the Covington area speed drop at the bottom of the hill.

1. There is a large volume of truck traffic in the right two lanes (trucks are restricted to the right two lanes) and there are two sequential on-ramps (from 4th Street and then from 12th Street). There is a substantial amount of lane changing in the area as faster light-duty vehicles move to the left lanes and slower truck traffic moves to the right lanes. Adding a DSU lane could make this situation more complex.
2. Speed in this area is impacted by the grade as well as the lane changing. DSU would not increase the slow truck speeds due to the grade.
3. Existing speeds increase very quickly from 12th Street to Kyles Lane. A DSU lane would not likely increase the speeds faster (from a median speed of below 30 mph near 12th Street to a median speed of over 60 mph at Kyles Lane, less than two miles downstream).

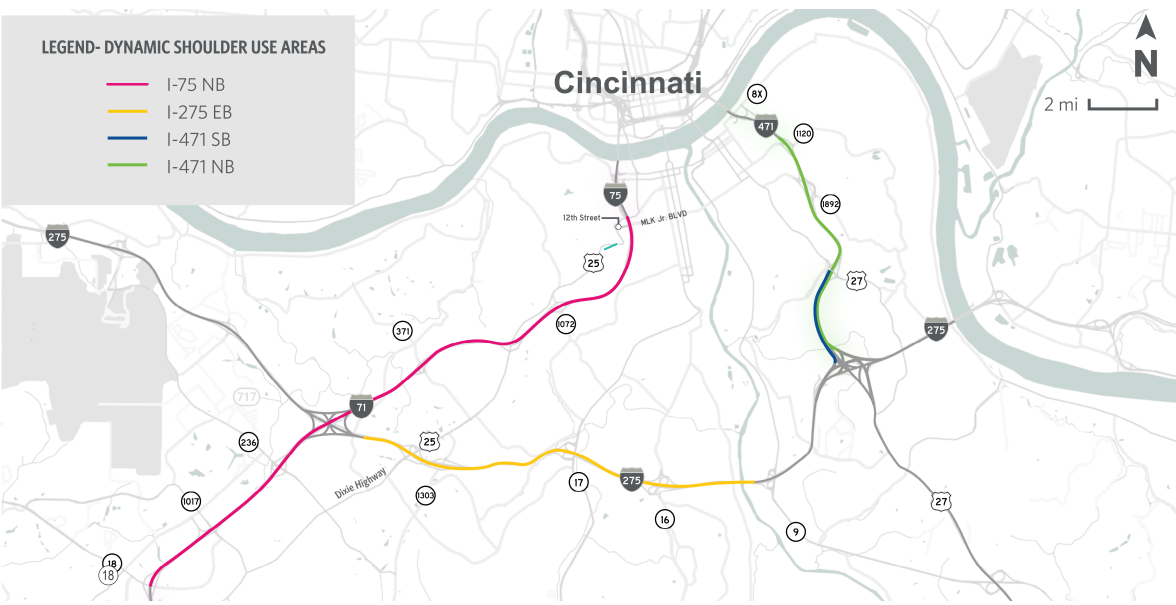
In summary, the southbound I-71/I-75 direction was set aside from further consideration because it raised several safety concerns and it was not clear that it would yield substantial operational benefits given the grade, truck restrictions, ramp locations, and lane change maneuvers. Other locations and directions provided more promising DSU options.

Note B for Table 18: *Follow-up Screening for I-275 Eastbound During the PM Peak approaching the Combs-Hehl Bridge* – Congestion on the eastbound bridge approach is due in part to the two consecutive merges from I-471 NB and SB and the reduction to three lanes in the vicinity of the US 27 (Alexandria Pike) overpass. This three-lane capacity constraint continues over the Combs-Hehl Bridge. The eastbound bridge has an approximately 10-foot right shoulder and a 5-foot left shoulder. If a DSU lane was installed, that could potentially result in 2-foot left and right shoulders for the entire length of the bridge, which is over 0.5 miles. The DSU would likely end at the US 52 (Kellogg Road) off-ramp. This width limitation raises safety concerns and could result in several operational and safety challenges. It was decided that this section would not be studied further for DSU at this time.

Follow-up Screening for I-275 Eastbound During the PM Peak between CVG Airport and I-71/I-75 – Congestion on this portion of I-275 is typically related to the exit ramps leading to I-71/I-75. In particular, the single lane ramp leading to southbound I-71/I-75 can become a capacity constraint. While a DSU lane was considered for this portion of I-275, it would not solve the downstream ramp capacity issue and therefore would not offer any real congestion relief. There are proposed long-term improvements to the I-71/I-75 and I-275 interchange that could potentially address this issue.

Based on the screening analysis, four corridors were selected for the Dynamic Shoulder Use (DSU) evaluation as presented in **Figure 18** and summarized in **Table 19**. The evaluation assessed feasibility, operational and safety benefits, expected costs, and provided a high-level benefit cost comparison.

Figure 18: Dynamic Shoulder Use Areas



Analysis Assumptions

The analysis assumptions for dynamic shoulder use are summarized in **Table 19**. The analysis examined the peak period impacts of the DSU deployment because the primary goal of the DSU lane would be to alleviate recurrent congestion. As mentioned, DSU can be utilized outside of typical recurrent congestion and be implemented as needed based on traffic conditions; however, the benefits of that are not quantified within this study. As discussed qualitatively in this section, there are potential safety impacts from a DSU implementation which should be assessed if the deployment is considered further.

Table 19: Dynamic Shoulder Use Analysis Summary Table

Deployment	*Dynamic Shoulder Use* - Upgrade the corridor such that either the left or right shoulder could be operated as a travel lane when additional capacity is needed.			
Dynamic Shoulder Use Corridors	Corridor	Time Period	Start	End
	I-75 Northbound	AM	KY 18 Interchange	12th St Exit (Covington)
	I-471 Northbound	AM	I-275 Interchange	Memorial Pkwy Interchange
	I-471 Southbound	PM	US 27 Interchange	I-275 Interchange
	I-275 Eastbound	PM	I-71/I-75 Interchange	KY 9 Interchange
Analysis Tool	FREEVAL+ (20210105 version 1.02)			
Methodology	FREEVAL reliability analysis for weekday conditions for one year to assess the impact of an additional lane during the peak periods (2 hours per peak)			

Feasibility

There are many factors that must be considered when determining if a DSU lane is feasible on an Interstate. Some of these factors include the existing lane and shoulder widths, presence and width of bridges, right-of-way, topography, and the location and design of ramps. FHWA's *Use of Freeway Shoulder for Travel* (2016) was used as a guide for the feasibility analysis.

Typical Section Guidance

One of the main issues for DSU implementation is the typical section. According to FHWA's guidance a "shoulder width of 12 or more feet is generally preferred for part-time shoulder use." However, the guidance also indicates that 10 to 12-foot shoulders can be used if trucks are prohibited from the shoulder use lane. One caveat to the 10-foot width is the need to provide a minimum 1.5-foot offset to obstructions/barriers.

As stated in the guide, shoulder width design exceptions are typically required for all DSU lanes:

> Designating the paved freeway shoulder for part-time travel use will typically require a design exception since there will typically be little or no untraveled shoulder beyond the portion of the shoulder used for part-time travel, and this will not meet the minimum width requirements. (FHWA, pg. 85)

The guidance also specifically calls out bridges and notes that:

> The minimum width of a shoulder on a bridge that should be used as a travel lane is 11.5 feet. This dimension enables vehicles to remain 1.5 feet from the bridge rail and still have 10 feet of shoulder on which to maneuver. It is not necessary for the shoulder to be the same width on a bridge as on the approaching roadway; however, it does need to be 11.5 or more feet wide. Design exceptions may be needed for the narrow lane width. (FHWA, pg. 85)

Proposed Typical Section

A preferred 13-foot, minimum 12-foot, dynamic use shoulder was used for the feasibility assessment. The assessment assumed trucks would be prohibited from the shoulder use lane. This width is adequate per the FHWA design guidance and would provide space for an 11-foot lane and a 2-foot buffer in the wider sections and a 10-foot lane/2-foot buffer (or 10.5-foot lane/1.5-foot buffer) in the narrower sections. In practice, this could allow the 12-foot left side shoulder on portions of all three interstates to be used with little or no modifications. However, it is important to note that drainage inlets next to the barrier (when present) would be in the 2-foot buffer. Given the limited width, it would not be possible to prevent water from intruding on the shoulder lane during major rain events. Therefore, a left side shoulder so close to the barrier may need to be closed during major rain events, which would limit its usefulness. There could also be issues related to snow removal and the cross-slope of the shoulder.

One reason for the 12-foot minimum was that a review of as-built plans for the three Interstates indicated that it may be necessary to consider the narrower option to make the best use of the existing typical sections (including lanes, shoulders, barriers, and drainage structures). A wider typical section could require adding one to two feet to long stretches of highway. The typical section does maintain 12-foot lanes for all existing through lanes.

The next critical design decision was related to the required width of the opposite shoulder. All of the interstates being studied have six or more lanes; therefore, the minimum shoulder width is 10 feet on both sides of the highway (except on 200-foot or longer bridges). The DSU lane side would have a typical 12 to 13-foot shoulder except when the shoulder lane is in use. This would require a design exception but is in line with FHWA's design guidance for DSU lanes. The opposite shoulder should however be 10 feet, or a second design exception would be required. The proposed typical section for a left side DSU lane would therefore be as shown in **Figure 19** and the right side DSU lane typical section would be as shown in **Figure 20**.

Figure 19: Left-Side Dynamic Shoulder Use Lane Example Typical Section

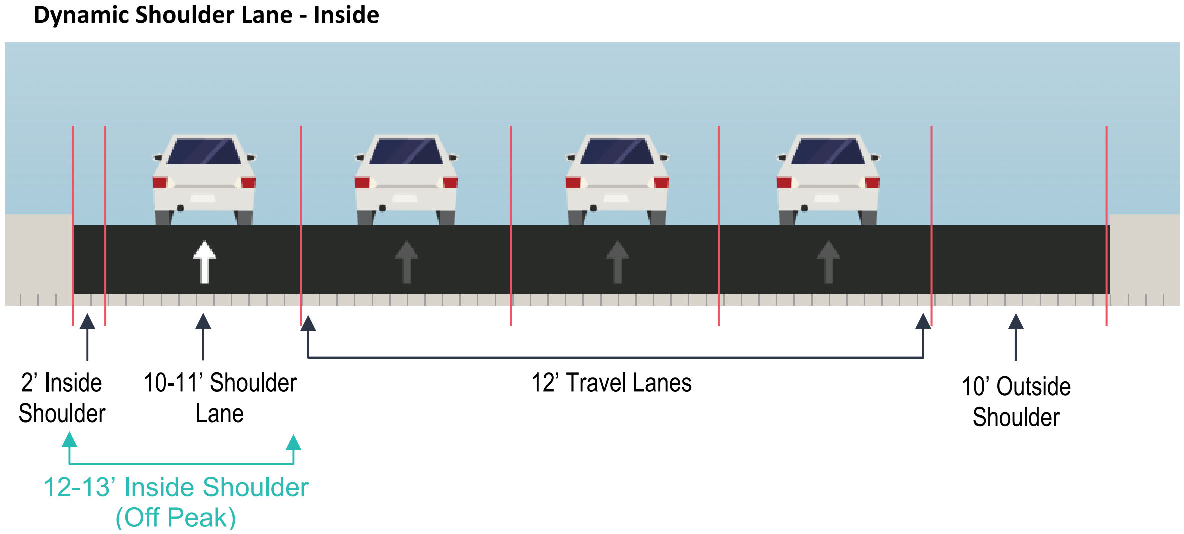
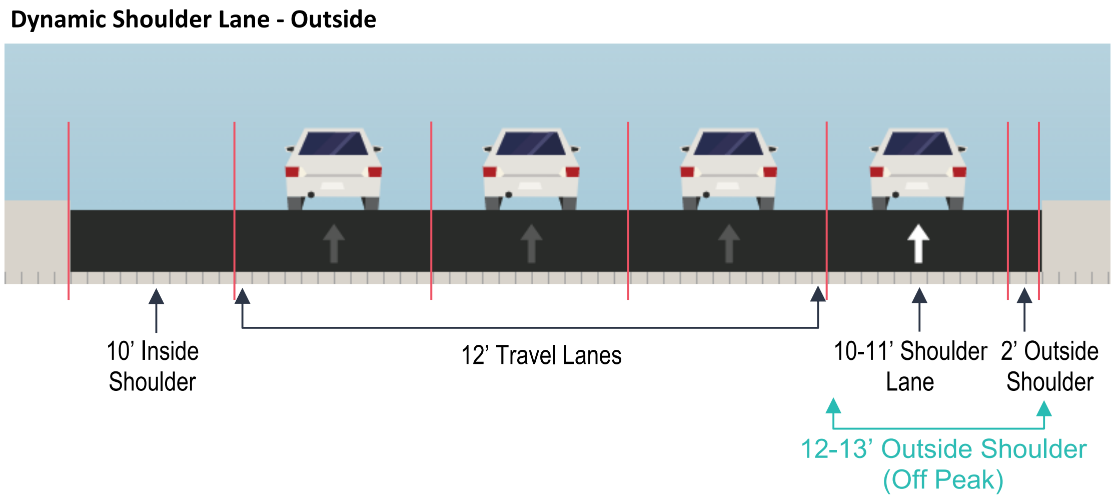


Figure 20: Right-Side Dynamic Shoulder Use Lane Example Typical Section



For bridges under 200 feet long, the AASHTO guidance requires that the typical section on the Interstate be applied to the bridge. However, for bridges 200 feet and longer the AASHTO Green Book requires the same approach shoulder widths and median barrier if it is a single structure, but the AASHTO Interstate Standards only requires a 4-foot offset to the bridge rail, parapet, or barrier on either side. Therefore, for a long bridge, the side opposite to the shoulder use lane could be 4 feet per the Interstate Standards.

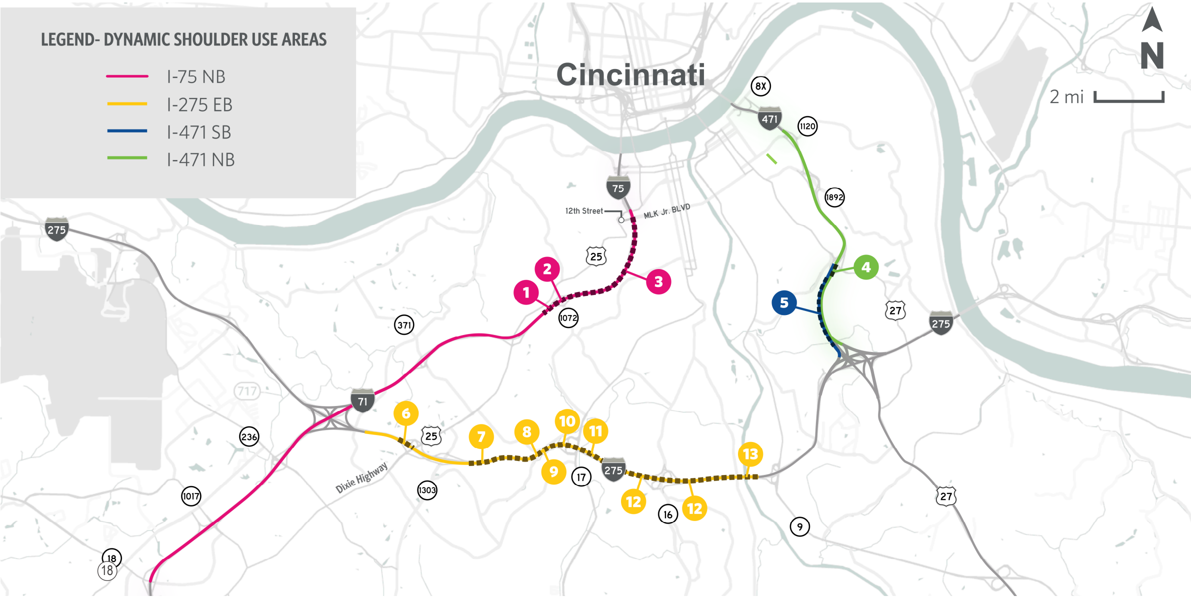
Using the above design criteria results in the width requirements below for adding a DSU lane to a three lane Interstate segment. These widths meet the minimum FHWA shoulder use guidance widths.

- Typical highway section or a short bridge - 58 to 59 feet (edge to edge or barrier to barrier)
- Long bridge (200 feet or more) - 52 to 53 feet (edge to edge or barrier to barrier, based on Interstate Standards)

Typical Section Width Evaluation

All four corridors were examined to identify locations with less than the required width as outlined in the typical section discussion. Measurements were obtained using aerial photography, as-built plans, and bridge inventory data**. Figure 21** shows a map of the major constraint locations. **Table 19**, **Table 20**, and **Table 21** highlight the major constraint segments.

Figure 21: Dynamic Shoulder Use Feasibility Constraint Areas



I-75 Dynamic Shoulder Use Width Issues

For I-75, the DSU lane could go on either the left or right side if it was started south of I-275 and extended to the 12th Street off-ramp. The left side appears to offer a simpler application because there are wide shoulders leading up to I-275 and 12-foot shoulders for some distance north of I-275 and the DSU lane would not interact with the ramps. Regardless of the side selected mainline widening would be required from Kyles Lane to 12th Street (approximately 2 miles) as shown in **Table 20.** This section would need to be widened by approximately 2 feet to achieve the minimum width (more under Kyles Lane).

There are several other areas (such as near KY 236 and areas between KY 371 and Kyles Lane) where approximately 1-foot widening would be needed to meet the desired 13-foot width, but a 12-foot DSU section (10-foot lane with 2-foot shoulder) could be used to avoid widening in those areas. While not shown in **Table 20**, these areas would need to be investigated in more detail if this concept were advanced. In addition, that approach could exacerbate potential issues related to drainage/ponding and snow removal.

Table 20: I-75 Northbound Dynamic Shoulder Use Critical Width Constraints

Location	Approx. Length (ft)	Approx. Width (ft)			Constraint	Potential Resolution
		Pavement	Available Non-DSU Shoulder	Required Non-DSU Shoulder		
1. KY 1072 (Kyles Lane) Interchange Area	1,430	56	8		-	Widen 2ft+
2. KY 1072 (Kyles Lane) Bridge over I-71/I-75	110	52	4	10	Underpass*	Widen 6ft
3. KY 1072 (Kyles Lane) to 12th St / MLK Jr. Blvd	9,100	56	8		-	Widen 2ft+

* Haunched beams may require a design exception and trucks may need to be prevented from using a left side DSU lane.

I-471 Northbound Dynamic Shoulder Use Width Issues

For I-471 northbound, the DSU lane would likely be added to the right side to tie together the existing auxiliary lanes. This would result in less widening and would allow for a connection all the way to the SR 8 off-ramp. There would however be changes needed to effectively design the merge and diverge areas. If a left side approach was taken it would require widening all three of the auxiliary lane sections, two of them by 3 feet and the northern one by 9 feet. This would include widening the structure at the SR 8 off-ramp, with additional widening to tie the lane back in, north of the off-ramp. This was therefore deemed infeasible and the right side DSU constraints are presented in **Table 21**.

By using a right side DSU, approximately 800 feet of 2-foot widening would be required south of the bridge over US 27, but most of the rest of the corridor could be implemented using the minimum 10-foot DSU lane. Alternatively, a little over two miles of I-471 could be widened by 1-foot (or more) to provide a wider lane and/or buffer. The right side DSU lane approach assumes that the through lanes would be shifted left to use the extra shoulder width currently in the median. This shift would have implications related to pavement markings, pavement wear, rumble strips, drainage, crown, and cross-slope that would have to be examined in detail. The right side DSU lane would also include physical improvements in each merge and diverge area such as possible minor shoulder widening, acceleration/deceleration lane changes, and/or ramp modifications.

Table 21: I-471 NB Dynamic Shoulder Use Critical Width Constraints

Location	Approx. Length (ft)	Width (ft)			Constraint	Potential Resolution
		Pavement	Available Non-DSU Shoulder	Required Non-DSU Shoulder		
4. South of bridge over US 27	800	57	8	10	-	Widen 2ft

The locations below could be accommodated using the narrower typical section or by adding 1-foot to the highway width						
I-275 On-Ramp to US 27 Off-Ramp	*3,900*	*58*	*9*	*10*	-	*Widen by 1ft or use 10ft DSU lane*
North of US 27 Bridge at Interchange	*1,000*	*58*	*9*		-	
South of Bridge over Grand Avenue	*3,650*	*58*	*9*		-	
Bridge over Chesapeake to SR 1120 Auxiliary Lane	*2,300*	*58*	*9*		-	

I-471 Southbound Dynamic Shoulder Use Width Issues

For I-471 southbound, the DSU lane would likely be added to the right side to create an auxiliary lane from the US 27 on-ramp to the I-275 off-ramp. For the 3,000 feet between the end of the taper for the US 27 on-ramp and the start of the taper for the I-275 off-ramp, approximately two feet of width would need to be added to widen the existing shoulder (**Table 22**). Additional adjustments would be needed within the ramp areas as well.

Table 22: I-471 SB Dynamic Shoulder Use Critical Width Constraints

Location	Approx. Length (ft)	Width (ft)			Constraint	Potential Resolution
		Pavement	Available Non-DSU Shoulder	Required Non-DSU Shoulder		
5. US 27 On-Ramp to I-275 Off-Ramp	3,000	57	8	10	-	Widen 2ft

I-275 Eastbound Dynamic Shoulder Use Width Issues

The portion of I-275 EB that was considered for a DSU lane has two main existing typical sections (excluding structures). The first has a left side barrier with a 12-foot left shoulder and a 10-foot right shoulder (west of Turkeycock interchange). The 12-foot left side shoulder accommodates drainage inlets where needed in the left 2 feet. The second typical section has a depressed median on the left side with 10-foot left and right shoulders (east of Turkeycock interchange). There are modifications to these sections near interchanges and on bridges.

The section with the 12-foot shoulder could accommodate a DSU lane if the minimum 12-foot width was used. However, if a left side lane was implemented, drainage and snow removal could present challenges. The section with the two 10-foot shoulders would need to be widened by two or more feet. There are also interchange areas and bridges that do not have sufficient width to accommodate a DSU lane without widening and/or design exceptions. Several of the major limitations are listed in **Table 23**.

The constraints include over 3.5 miles of mainline widening (by 2 or more feet) plus three bridges that would require widening and/or design exceptions. The first is the short bridge over Horsebranch Road, but the other two are long multi-span structures over Madison Pike and the Licking River. These bridges have minimum curb-to-curb widths of 51 feet based on the bridge inspection reports, which would leave 3 feet for on the non-DSU lane shoulder (below the 4-foot minimum). This is a design constraint regardless of whether a left or right side DSU is considered. The bridge over Madison Pike must also accommodate an acceleration lane from a loop ramp. Based on an initial review, it is not clear that there is sufficient width for the acceleration lane and the DSU lane. While design exceptions could be pursued, the current length and width of these bridges present operational, safety, cost, and Federal approval concerns for the deployment of a DSU lane on I-275 eastbound.

In addition to the issues outlined in **Table 23**, much of the corridor would have the minimum 10-foot DSU lane. There would also be improvements associated with several of the exit and entrance ramps as well as drainage improvements. Overall, this corridor presents several substantial challenges.

Table 23: I-275 EB Dynamic Shoulder Use Critical Width Constraints

Location	Approx. Length (ft)	Width (ft)			Constraint	Potential Resolution
		Pavement	Available Non-DSU Shoulder	Required Non-DSU Shoulder		
6. US 25 Off-Ramp to Bridge over Dixie Hwy	1,350	66	6	10	Steep slope	Widen 4ft+
7. Turkeyfoot On-Ramp to Bridge over Horsebranch Rd	4,800	56	6	10		Widen 2ft+
8. Bridge over Horsebranch Rd	150	56	6	10	Bridge	Widen 2ft+
9. Bridge over Horsebranch Rd to Madison Pike Off-Ramp	900	56	6	10		Widen 2ft+
10. Madison Pike Off-Ramp to Madison Pike On-Ramp	1,600	56	6	10		Widen 2ft+
11. Bridge over Madison Pike (Center)	1,700	Varies 51 min	Varies 3 min	4	Bridge, Accel lane	Widen bridge or design exception(s)
12. Bridge over Madison Pike to Bridge over Licking River	11,100	56-57	7-8	10	-	Widen by 2 to 3ft+
13. Bridge over Licking River	1,500	51	2	4	Bridge	Widen bridge or design exception(s)

Required Improvements and/or Design Exceptions

As shown, each corridor has several constrained width locations that will require either widening or a design exception to allow for a DSU lane. For the purposes of this study, it was assumed that FHWA would consider design exceptions for structures. Emergency pull-off locations may be required in advance of and/or after some of the narrower locations to improve safety. For other constraint locations it was generally assumed that pavement widening would be required. Design exceptions would require close coordination with and approval from FHWA. They would require detailed documentation of the existing and potential future safety issues related to the design exception.

Other Design Issues

There are several other design issues that must be considered in the discussion of repurposing the pavement width (and possibly adding to it) to accommodate a shoulder use lane. One of these is drainage. When a shoulder use lane is two feet from a barrier the drainage system (cross-slope, grade, inlets, and conveyance) must be such that there would be no standing water in the travel way. This is a concern in a number of locations. Another issue is snow removal. With a narrow shoulder there is no way to move the snow out of the DSU lane. The snow would need to melt or be removed before the lane could be reopened. If the opposite side shoulder is also narrow (e.g., on a bridge), then there could be issues with snow removal on both sides of the roadway.

Other issues include the cross-slope, joints, and pavement design/depth. For example, the change in cross-slope at the lane edge can present safety and operational issues and it may be necessary to reconstruct that part of the roadway. A final issue is the ramp merge and diverge areas. There are design treatments for how these can be handled in the case of a right-side DSU, but often additional pavement width is required to allow them to function safely and effectively. These issues present challenges and increased costs for the different corridors.

Operational Feasibility Issues

In addition to the physical feasibility considerations there are also operational feasibility considerations. DSU lanes would require new ITS infrastructure as well as ongoing operations and maintenance activities. Before opening a DSU lane each day, it would need to be inspected and cleared of any debris and/or vehicles. While an inspection can be done using cameras, it is best practice to have a safety service patrol check the lane every day before it opens. Any disabled vehicles in the DSU lane must be cleared well in advance of operation. Outside of the operating hours monitoring (using some form of vehicle detection) would be needed to ensure that drivers were not using this lane either purposefully or accidentally. These activities would require staff, equipment, and clear deployment protocols.

This type of deployment presents a significant technological change to the roadway network that would require education for local/ regional users. Unlike the other deployments, this is a more specialized improvement that has direct impacts on the mainline of the system.

Feasibility Summary

While there are many hurdles to the approval of DSU lanes in the four identified corridors, it was determined that they could potentially be designed, constructed, and implemented if three criteria were met: 1) sufficient construction funding was allocated, 2) certain design exceptions were approved, and 3) an operational and management plan was developed and implemented. The remainder of this analysis is based on these assumptions. The analysis that follows explores whether it is worthwhile to pursue these projects further. As will be shown, it does not appear that the cost is worth the investment at present.

Operational Analysis

A DSU operational analysis was conducted to assess the benefits of part-time shoulder use lanes that would operate for two hours during weekday peak periods. Based on shoulder use literature, it was assumed that the DSU lane would function at approximately 70% of the capacity of a typical Interstate travel lane (this is appropriate given the constrained nature of many of the DSU lane typical sections under consideration in this analysis). The analysis was conducted using the ATDM module within FREEVAL+. This module allows the DSU lane to be operational during customized time intervals and it models the shoulder lanes using the lower 70% lane capacity. **Figure 22** through **Figure 25** show the result contours for the Dynamic Shoulder deployment on each of the corridors. The result contours show the LOS results for a typical day for baseline and DSU conditions. In general, the dynamic shoulder lanes are able to provide the additional capacity when present, which reduces congestion along the corridor. However, they do not solve all of the bottleneck issues and have moderate impacts on overall corridor delays.

I-71/I-75 Northbound (AM Peak) - Two sets of analyses were conducted. The first used the existing configuration and showed that the extent of queues approaching Covington could be reduced with a DSU lane. However, with the proposed Pike Street Ramp improvements expected to be in place before a DSU lane could be implemented the second set of runs is more informative. This set of model runs showed the considerable benefit of the proposed Pike Street project (compare the two baseline model runs). It also showed a diminished benefit from the DSU lane once the Pike Street Ramp project is complete. There is some upstream benefit, but there is a diminished level of service downstream as more traffic is moved faster to the downstream bottleneck, which is the three-lane section north of the 12th Street exit.

I-471 Northbound (AM Peak) – This corridor also showed some benefits with faster speeds and shorter queues on the Kentucky side of the Ohio River. However, the same issue of a downstream bottleneck arises. The DSU lane cannot reach the KY 8 on-ramp or the bridge; therefore, traffic again is facilitated in reaching downstream bottlenecks that cannot be addressed.

I-471 Southbound (PM Peak) – This short DSU lane which would run from Alexandria Pike to I-275 could benefit operations in that area. Two issues that arise however are 1) whether a full-time auxiliary lane should be added instead of a DSU lane and 2) for this improvement to be effective it may be necessary to modify I-275 westbound such that the left lane on the I-471 southbound ramp continues as a lane add and not a merge.

I-275 Eastbound (PM Peak) – This DSU lane also resolves much of the congestion in the corridor. However, as noted previously there are several design hurdles that must be overcome for this corridor to be implemented. In addition, the total delay in the corridor is moderate and therefore the total benefits are the lowest of the four corridors.

Figure 22: I-75 NB Dynamic Shoulder Use Result Contours

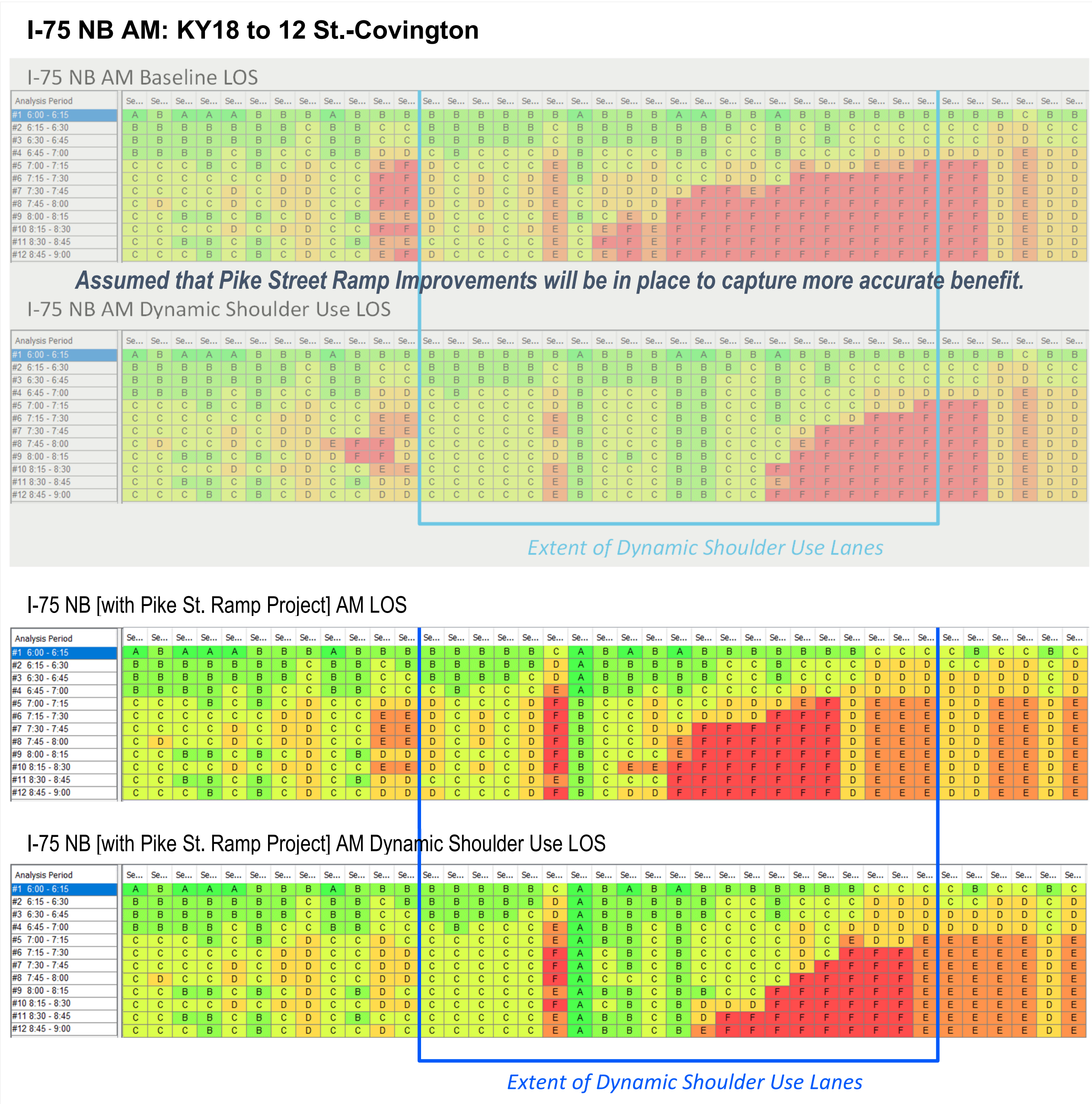


Figure 23: I-471 NB Dynamic Shoulder Use Result Contours

I-471 NB: 275 to Memorial Parkway

I-471 NB AM Baseline LOS

Analysis Period	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Seg. 8	Seg. 9	Seg. 10	Seg. 11	Seg. 12	Seg. 13	Seg. 14	Seg. 15	Seg. 16	Seg. 17
#1 6:00 - 6:15	A	B	B	A	B	B	B	B	B	B	B	B	B	B	B	B	B
#2 6:15 - 6:30	B	B	B	A	B	C	C	C	B	B	B	B	C	C	C	C	B
#3 6:30 - 6:45	B	B	B	A	C	D	C	D	C	C	C	C	C	C	C	E	C
#4 6:45 - 7:00	B	B	B	A	C	D	C	D	C	C	C	C	C	D	C	D	C
#5 7:00 - 7:15	B	B	B	A	C	D	C	D	C	C	C	C	C	D	C	D	C
#6 7:15 - 7:30	B	C	C	A	C	D	D	D	C	C	C	C	C	D	C	E	C
#7 7:30 - 7:45	B	C	C	A	C	D	D	D	C	C	D	D	D	F	F	E	C
#8 7:45 - 8:00	B	B	B	A	C	D	C	D	C	D	F	F	F	F	F	F	C
#9 8:00 - 8:15	B	C	C	A	C	D	D	D	C	F	F	F	F	F	F	E	C
#10 8:15 - 8:30	B	B	B	A	C	D	C	D	C	F	F	F	F	F	F	F	C
#11 8:30 - 8:45	B	B	B	A	C	C	C	D	C	F	F	F	F	F	F	F	C
#12 8:45 - 9:00	B	B	B	A	C	C	C	C	C	B	E	F	F	F	F	F	D

I-471 NB AM Dynamic Shoulder Use LOS

Analysis Period	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Seg. 8	Seg. 9	Seg. 10	Seg. 11	Seg. 12	Seg. 13	Seg. 14	Seg. 15	Seg. 16	Seg. 17
#1 6:00 - 6:15	A	B	B	A	B	B	B	B	B	B	B	B	B	B	B	B	B
#2 6:15 - 6:30	B	B	B	A	B	C	C	C	B	B	B	B	C	C	C	C	B
#3 6:30 - 6:45	B	B	B	A	C	D	C	D	C	C	C	C	C	C	C	E	C
#4 6:45 - 7:00	B	B	B	A	C	D	C	D	C	C	C	C	C	D	C	D	C
#5 7:00 - 7:15	B	B	B	A	C	C	C	C	B	B	B	C	C	D	C	D	C
#6 7:15 - 7:30	B	C	C	A	C	C	C	C	C	B	C	C	C	D	C	E	C
#7 7:30 - 7:45	B	C	C	A	C	C	C	C	C	C	C	C	C	F	F	E	C
#8 7:45 - 8:00	B	B	B	A	C	C	C	C	B	C	C	C	F	F	F	F	C
#9 8:00 - 8:15	B	C	C	A	C	C	C	C	C	C	C	F	F	F	F	E	C
#10 8:15 - 8:30	B	B	B	A	C	C	C	C	B	B	D	F	F	F	F	F	C
#11 8:30 - 8:45	B	B	B	A	C	B	B	C	B	B	C	F	F	F	F	F	C
#12 8:45 - 9:00	B	B	B	A	C	B	B	B	B	B	B	B	F	F	F	F	D

Extent of Dynamic Shoulder Use Lanes

Figure 24: I-471 SB Dynamic Shoulder Use Result Contours

I-471 SB: US 27 to I-275

I-471 SB PM Baseline LOS

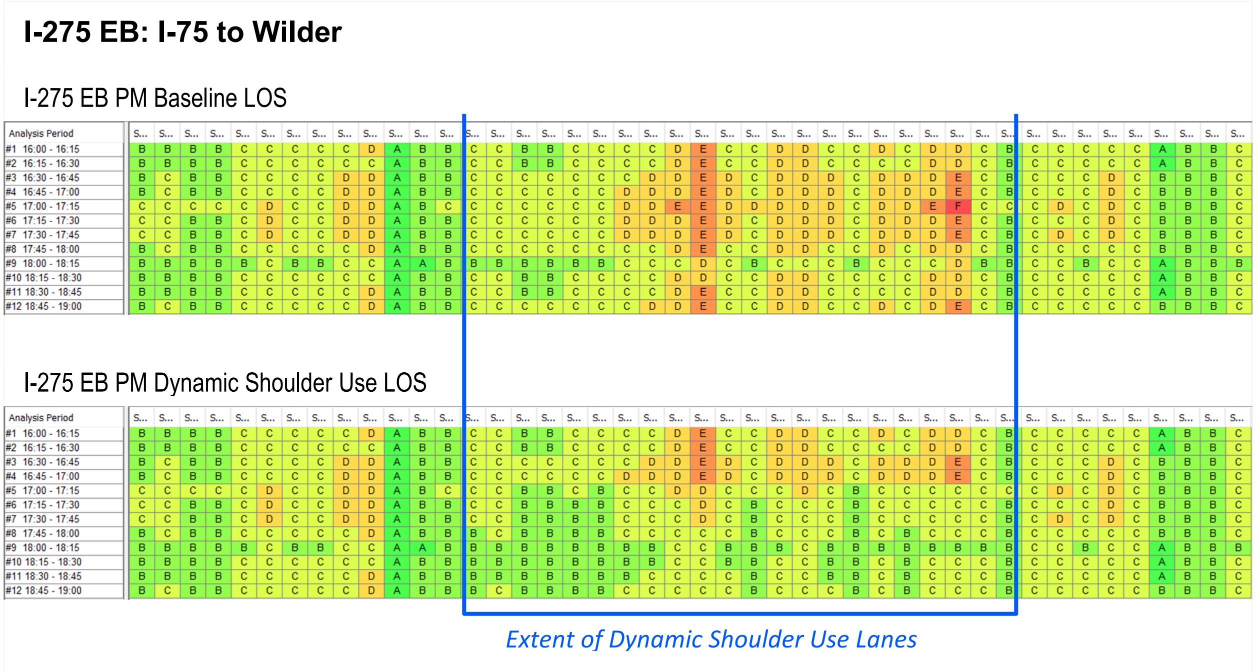
Analysis Period	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Seg. 8	Seg. 9	Seg. 10	Seg. 11	Seg. 12	Seg. 13	Seg. 14	Seg. 15	Seg. 16	Seg. 17	Seg. 18	Seg. 19
#1 16:00 - 16:15	C	C	B	B	C	C	C	C	C	B	C	C	C	B	B	A	A	A	A
#2 16:15 - 16:30	C	C	B	B	C	C	C	C	C	B	C	C	C	B	B	A	A	A	A
#3 16:30 - 16:45	D	D	C	C	C	C	C	D	C	C	C	C	D	B	B	A	A	A	A
#4 16:45 - 17:00	C	D	C	C	C	C	C	D	C	C	C	C	D	B	B	A	A	A	A
#5 17:00 - 17:15	C	D	C	C	D	C	D	D	C	C	C	C	D	B	C	A	A	A	A
#6 17:15 - 17:30	D	D	C	C	D	D	D	D	D	D	D	D	D	B	C	A	A	B	A
#7 17:30 - 17:45	D	E	C	C	D	D	E	E	D	D	D	D	E	C	C	A	A	B	A
#8 17:45 - 18:00	E	E	D	D	D	D	E	F	D	D	D	D	E	C	C	A	A	B	A
#9 18:00 - 18:15	D	E	C	D	D	D	E	E	D	D	D	D	E	C	C	A	A	B	A
#10 18:15 - 18:30	D	E	C	C	D	D	D	E	D	D	D	D	D	C	C	A	A	B	A
#11 18:30 - 18:45	C	D	C	C	C	C	D	D	C	C	C	C	D	B	B	A	A	A	A
#12 18:45 - 19:00	C	C	B	B	C	C	C	C	C	B	C	C	C	B	B	A	A	A	A

I-471 SB PM Dynamic Shoulder Use LOS

Analysis Period	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg. 7	Seg. 8	Seg. 9	Seg. 10	Seg. 11	Seg. 12	Seg. 13	Seg. 14	Seg. 15	Seg. 16	Seg. 17	Seg. 18	Seg. 19
#1 16:00 - 16:15	C	C	B	B	C	C	C	C	C	B	C	C	C	B	B	A	A	A	A
#2 16:15 - 16:30	C	C	B	B	C	C	C	C	C	B	C	C	C	B	B	A	A	A	A
#3 16:30 - 16:45	D	D	C	C	C	C	C	D	C	C	C	C	D	B	B	A	A	A	A
#4 16:45 - 17:00	C	D	C	C	C	C	C	D	C	C	C	C	D	B	B	A	A	A	A
#5 17:00 - 17:15	C	D	C	C	D	C	D	D	C	C	C	C	C	B	B	A	A	A	A
#6 17:15 - 17:30	D	D	C	C	D	D	D	D	D	D	C	C	C	B	B	A	A	B	A
#7 17:30 - 17:45	D	E	C	C	D	D	E	E	D	D	C	C	D	B	B	A	A	B	A
#8 17:45 - 18:00	E	E	D	D	D	D	E	F	D	D	C	C	D	C	B	A	A	B	A
#9 18:00 - 18:15	D	E	C	D	D	D	E	E	D	D	C	C	D	B	B	A	A	B	A
#10 18:15 - 18:30	D	E	C	C	D	D	D	E	D	D	C	C	C	B	B	A	A	B	A
#11 18:30 - 18:45	C	D	C	C	C	C	D	D	C	C	B	B	C	B	B	A	A	A	A
#12 18:45 - 19:00	C	C	B	B	C	C	C	C	C	B	B	B	B	B	A	A	A	A	A

Extent of Dynamic Shoulder Use Lanes

Figure 25: I-275 EB Dynamic Shoulder Use Result Contours



DSU Operational Analysis Summary Results

The results of the operational analysis for DSU by corridor are shown in **Table 24**. There are quantifiable annual benefits to running a DSU lane during the peak periods on the four study corridors. Surprisingly, the highest benefit was observed for the short I-471 southbound deployment. This is due to the fact that the backup in that area could be cleared if the lane were present and there were no downstream bottleneck. The more congested I-75 and I-471 northbound corridors both have lower benefit assessments due to the fact that the DSU lane is not able to be implemented past major downstream bottlenecks.

Table 24: Dynamic Shoulder Use Operational Analysis Results

Roadway	Dir	Peak	Annual Vehicle Hours Traveled (VHT)				Annual User Cost Savings**
			Baseline	Dynamic Shoulder Use	Δ VHT	% Reduction	
I-75 (w/ Pike St Ramp)*	NB	AM	1,996,800	1,940,100	56,700	2.8%	$ 1,526,500
I-471	NB	AM	1,007,100	965,500	41,600	4.1%	$ 1,120,000
	SB	PM	560,500	483,500	77,000	13.7%	$ 2,073,100
I-275	EB	PM	832,800	798,500	34,300	4.1%	$ 923,500
Annual Benefit	**-**	**-**	**4,397,200**	**4,187,600**	**209,600**	**4.8%**	**$ 5,643,100**
I-75 (existing)	*NB*	*AM*	*2,713,600*	*2,671,200*	*42,400*	*1.6%*	*$ 1,141,500*

** Pike Street Ramp project is expected to be complete by December 2022*
***User travel-time costs are based on the 2021 USDOT Benefit-Cost Analysis Guidance (*[Benefit Cost Analysis Guidance 2021.pdf](#) (transportation.gov))

Deployment Cost

High level cost estimates were developed for the DSU deployments. The costs are divided into base construction, technology costs (ITS, DMS, CCTV), and operations and management. **Table 25** shows the cost breakdown for each of the corridors in 2021 dollars. The construction costs are based on a per-mile cost of construction to improve the existing shoulder for vehicular travel. The improvements would address segments between interchanges as well as ramp merge and diverge areas. The cost includes pavement rehabilitation, resurfacing, striping, and drainage improvements. The per-mile estimate was derived based on the total cost calculations for one corridor which was then applied to the other applicable corridors.

The technology cost is an upfront capital cost for the installation and integration of all system elements. The operations and maintenance (O&M) costs shown are the present value of 10 years of future costs to operate and maintain the system. The technology and O&M costs assume a basic system with no advanced technological or operational features. The contingency is a fixed 15% of the other cost items. As shown, the total project cost ranges from $5 million to $25 million depending on the corridor.

The base construction cost does not take into consideration several large cost items related to deployment feasibility constraints. For example, it does not include cost estimates for bridge widening, retaining walls, extensive widening, or additional right-of-way. For purposes of this initial assessment, it is assumed that safety measures would be implemented (emergency pull off locations, active monitoring, and quick clearance) and that design exceptions would be granted for structures along each corridor. It is also assumed that no new right-of-way would be required. If these assumptions were determined to be unreasonable during the next phase of project development, then the project construction costs could go up substantially.

While these additional costs are important considerations, as will be shown, the order of magnitude of the costs already outweighs the benefits, so the additional costs appear unlikely to change the study findings.

Table 25: Dynamic Shoulder Use Deployment Cost

Dynamic Shoulder Use Deployment Cost

Roadway	Length (miles)	Base Construction*	ITS / DMS / CCTV	O & M (10yrs)	Contingency (15%)	Total
I-75 NB	9	$ 16,000,000	$ 3,150,000	$ 2,350,000	$ 3,225,000	**$ 24,725,000**
I-471 NB	3.5	$ 6,220,000	$ 1,225,000	$ 1,530,000	$ 1,346,250	**$ 10,321,000**
I-471 SB	1.5	$ 2,670,000	$ 525,000	$ 1,230,000	$ 663,750	**$ 5,089,000**
I-275 EB	6	$ 10,670,000	$ 2,100,000	$ 1,900,000	$ 2,200,500	**$ 16,871,000**

**Base Construction cost is based on an assumed per mile cost of $ 1,778,000 for general roadway improvements to accommodate Dynamic Shoulder Use. This does not capture the full extent of structure costs or feasibility constraint mitigation areas.*

High-Level Benefit-Cost Analysis

The DSU operational benefits were compared against the total project deployment and operation costs at a corridor level. The benefits were calculated on an annual basis and then totaled for a 10-year project lifecycle using a 7% discount rate (as recommended by USDOT). The project costs include all estimated project deployment and O&M costs for the 10-year lifecycle (in 2021-dollars). The resulting benefit-cost analysis is presented in **Table 26** and shows that most of the corridors are predicted to have costs that exceed benefits resulting in ratios below 1.0.

Table 26: Dynamic Shoulder Use Benefit-Cost Summary

Roadway	Benefits			Total Cost	B/C Ratio
	Operational Benefit*	Safety Benefit*	**Benefit Total**		
I-75 NB	$ 11,472,000	N/A	$ 11,472,000	**$ 24,725,000**	**0.5**
I-471 NB	$ 8,417,000	N/A	$ 8,417,000	**$ 10,321,000**	**0.8**
I-471 SB	$ 15,580,000	N/A	$ 15,580,000	**$ 5,089,000**	**3.1**
I-275 EB	$ 6,940,000	N/A	$ 6,940,000	**$ 16,871,000**	**0.4**

**Benefits are calculated based on a 10-year project lifecycle using a 7% discounting rate*

The three corridors with ratios below 1.0 do not appear worthy of further investigation at present. There are other more promising deployments that could benefit these corridors. That does not mean that DSU should never be implemented in the area, but it may need to be part of a larger effort that involves bridging the congestion points throughout the I-71/I-75 and I-471 corridors on both sides of the river. In fact, a theoretical DSU assessment conducted to test what would happen if the downstream congestion areas could be eliminated showed considerable benefits with the DSU lanes. Thus, as major upgrade projects are investigated in the region, dynamic shoulder use could continue to be considered as a cost-effective way to provide peak period capacity in key locations without widening the entire length of the highway.

The one corridor that showed a ratio of greater than 1.0 was I-471 southbound. This segment had high benefits and the fewest constraint locations and the lowest associated cost. This shows that there could be a benefit to providing additional capacity from Alexandria Pike south to I-275 westbound especially if it is possible to provide an additional lane for that traffic on I-275. However, it may be beneficial to consider adding a full-time auxiliary lane instead of a DSU lane. To accommodate the DSU lane, construction (reconfiguration of the existing surface and pavement widening) would be required as well as an ITS installation with significant maintenance. The addition of another travel lane would incur additional construction costs beyond those estimated for the dynamic shoulder use lane, but it would provide the benefit of additional capacity through the entire day and avoid implementation, education, and maintenance of the ITS components. A follow-up project could look further into the design and operational issues to decide the best approach for that location.

Additional Safety Considerations

Safety was not included in the analysis at this time. However, TRB recently published *Safety Performance of Part-Time Shoulder Use on Freeways, Volume 1: Informational Guide and Safety Evaluation Guidelines* (NCHRP, 2021). This document indicates that DSU lanes often increase crashes in their deployment areas. The document publishes CMFs for fatal and injury crashes for part-time shoulder use lanes. The CMFs are based on the lane width, number of mainline lanes, whether or not there are pull-offs, and the proportion of the time the lane is in use. The research also publishes expected severity distributions. The report indicates that for some deployments the crash severity tends to shift away from fatal and serious injury crashes even as minor injury and property damage crashes increase. The combination of factors taken together could yield either an increase or decrease in crashes. One of the main factors is the number of hours that the shoulder lane is open. If it is only open two hours per weekday, then it serves as a wide shoulder for 94% of the hours each week. Thus, in some cases there can be a safety benefit to a deployment that results in a wide shoulder that is available most of the time. But in the case where an already existing wide shoulder is used as a DSU lane, an increase in crashes may result. In addition, the research showed that dynamic shoulder operations have a 7% lower crash frequency than static shoulder use operations. A summary of the safety performance findings from the report is provided in **Figure 26**.

Figure 26: NCHRP 17-89 Part Time Shoulder Use Safety Performance Findings

Topic	Finding
Overall effect on crash frequency and severity	PTSU sites are associated with higher FI and PDO crash frequency than sites without PTSU in most cases. However, the proportion of FI crashes that are severe (K or A severities) decreases in most cases.
Shoulder open versus shoulder closed	An hourly analysis found that a PTSU site with the shoulder open is associated with 138% more crashes than the same site with the shoulder closed.
Shoulder closed versus no PTSU	No difference in safety performance between a PTSU site with the shoulder closed and a site without PTSU.
Left-side versus right-side PTSU	No difference in safety performance of left-side and right-side PTSU facilities, but further research is needed.
Dynamic signs versus static signs	No difference in safety performance of sites with dynamic signs and sites with static signs.
Dynamic operation versus static operation	Converting S-PTSU to D-PTSU results in a 7.3% decrease in crash frequency.

Summary and Conclusions

The analysis considered a range of potential Active Transportation and Demand Management strategies, selecting the four most promising for more detailed evaluation.

Comparative Travel Time – Signs displaying travel times in real-time for alternative routes to a common destination, facilitating informed driver decision making and leading to improved travel times, reduced congestion, and fewer crashes.

Queue Warning – System with signs to alert drivers about slowed or stopped traffic ahead of them to prevent sudden slowing to reduce the number and severity of rear-end or erratic lane change crashes.

Ramp Metering - Traffic signals on entrance ramps to control the entry rate, improving mainline flow and safety.

Dynamic Shoulder Use - Opening the shoulder to traffic on a temporary basis to increase roadway capacity and postpone or eliminate the onset of congestion. Times can be fixed or variable depending on the application.

Each ATDM deployment was examined to assess feasibility, benefits, and cost. A planning-level B/C ratio was also calculated for each deployment on each corridor, or for the entire system in the case of the comparative travel time. The results of the analysis are summarized in **Table 27**.

Table 27: ATDM Deployment Summary

ATDM Strategy	Corridor(s)	Feasibility Concerns (Low to High)	Benefits[1] Operational Benefit	Benefits[1] Safety Benefit	Benefits[1] Benefit Total	Total Cost[2]	B/C Ratio
Comparative Travel Time	Systemwide	Low	$ 28,326,000	N/A	$ 28,326,000	$ 3,237,000	**8.8**
Queue Warning	Systemwide	Low	$ 22,316,000	$ 4,936,000	$ 27,252,000	$ 5,474,000	**5.0**
Ramp Metering	I-75 NB	Low-Moderate	$ 4,593,000	$ 7,377,000	$ 11,970,000	$ 3,536,250	**3.4**
	I-471 NB	Moderate	$ 9,084,000	$ 1,315,000	$ 10,399,000	$ 3,536,250	**2.9**
	I-275 EB	High	$ 141,000	$ 4,209,000	$ 4,350,000	$ 4,243,500	**1.0**
Dynamic Shoulder Use	I-71/I-75 NB	Moderate-High	$ 11,472,000	N/A	$ 11,472,000	$ 24,725,000	**0.5**
	I-471 NB	Moderate-High	$ 8,417,000	N/A	$ 8,417,000	$ 10,321,000	**0.8**
	I-471 SB	Moderate[3]	$ 15,580,000	N/A	$ 15,580,000	$ 5,089,000	**3.1**[3]
	I-275 EB	High	$ 6,940,000	N/A	$ 6,940,000	$ 16,871,000	**0.4**

[1] Benefits were calculated using a 10-year project lifecycle and a 7% discount rate
[2] Costs include capital and O&M costs
[3] This project may best be implemented as an additional full-time lane. See analysis.

The comparative travel time and queue warning deployments are expected to yield public benefits far in excess of the deployment cost over a 10-year period. The ramp metering deployments on two of the three corridors are also predicted to yield public benefits that exceed the deployment costs. In contrast, the dynamic shoulder use deployments are not predicted to yield sufficient benefits to warrant the investment. The one exception is the I-471 southbound DSU section leading to I-275; however, this segment may be better implemented as a full-time lane.

The benefit analysis was conducted independently for each deployment, but multiple deployments could function concurrently on the same roadway segment. The combined benefits associated with multiple deployments would be less than the sum of the individual benefits as there are overlapping benefits, but it would be greater than the individual benefit of any one deployment.

Deployment Prioritization

The deployments were prioritized based on the predicted B/C ratio, implementation cost, physical and operational feasibility, and estimated benefits. Topics such as driver acceptance and awareness were also considered. The resulting list provides a prioritized list and explanation of the deployments for consideration:

Priority 1 - Comparative Travel-Time Deployment (Systemwide)
The comparative travel time deployment had the highest B/C ratio of any strategy at 8.8. It is also expected to be one of the easiest to deploy, operate, and maintain. A summary of the deployment is that it uses DMS installations to communicate travel times for alternative routes to drivers before they make important routing decisions. Four mainline signs are proposed, three on I-71/I-75 approaching I-275 and one on I-275 approaching I-71/I-75 as shown in **Figure 8**. An additional 17 arterial DMS installations are also proposed (in two phases). This is an expansion of a strategy that is already available in the area, but in a limited form. Given the high level of benefits, feasibility, and moderate cost, this deployment is recommended as the first priority for advancement to the system requirements and high-level design phases.

As part of this comparative travel time deployment, it would be beneficial to consider improvements to the Interstate-to-Interstate movements at the I-71/I-75/I-275 and I-275/I-471 system interchanges. These are needed to better accommodate diverted traffic flows. Some improvements may be possible as management and operational upgrades without major interchange and bridge construction. See TSMO Interchange Priorities A and B below.

Priority 2 - Queue Warning (Systemwide)
The queue warning system also had a high systemwide B/C ratio of 5.0. It is expected to be moderately easy to implement, operate, and maintain. It would build on the current QWS in the region. It would add 14 mainline side-mount DMS installations to fill in the gaps in the existing DMS to cover many of the most congested areas (**Figure 13**). The increased sign density would allow the system to better inform drivers about slow or stopped traffic ahead, closed lanes and shoulders, and other safety messages. This is an expansion of a strategy that is already in operation in the I-71/I-75 corridor. Given the predicted benefits, feasibility, and cost, this deployment is recommended as the second priority for advancement to the system requirements and high-level design phases.

Priority 3 - Ramp Metering (I-71/I-75 NB)
Ramp metering in the I-71/I-75 NB corridor offered the greatest public benefit and had the highest B/C ratio of the ramp metering deployments. This corridor has the most significant recurrent congestion, which primarily occurs north of the I-275 interchange where the ramp metering is proposed. The deployment would include metering the northbound on-ramps at up to four interchanges (**Figure 15**). It is anticipated to improve mainline operations and reduce crashes/ incidents associated with merging. There are no ramp metering systems in Kentucky, so this would introduce a new concept to many local/regional drivers. However, from a driver's perspective the signals would operate like a typical arterial traffic signal, so the level of education needed would be minimal to moderate. The ramp metering deployment would require ongoing monitoring and maintenance activities. Installing ramp meters on this corridor prior to others could serve as a pilot to determine benefits and impacts prior to implementation on other corridors.

Priority 4 - Ramp Metering (I-471 NB)
Ramp metering on the I-471 NB corridor has expected benefits that are a little lower than the I-71/I-75 NB corridor and it is expected to have a similar cost. Based on those results and the lesser severity of existing recurrent congestion it is recommended that this deployment be prioritized below the I-71/I-75 NB corridor. The ramp metering approach would be similar in that it would meter the NB on-ramps (**Figure 15**). This would result in metering at up to five interchanges. As with I-71/I-75 NB there are anticipated operational and safety benefits associated with the implementation of this deployment. If this is implemented after the I-71/I-75 NB ramp metering, there would be little to no education required for the public to effectively use the system properly. It would however require ongoing monitoring and maintenance.

Priority 5 - I-471 SB - DSU Lane or New Full-Time Auxiliary Lane
The I-471 SB segment is the only one of the DSU deployments that showed a positive B/C ratio at just over 3.0. This is a short section between the US 27 interchange and the I-275 interchange. While it yielded a positive B/C ratio it is

recommended that the installation of an additional travel lane (auxiliary lane) between the two interchanges be considered as an alternative to the DSU lane. Due to the limitations in length, need for pavement widening and resurfacing, and introduction of new technology it may be impractical to implement this deployment if it is only used in this one location. DSU would require monitoring, maintenance, and enforcement for proper operation. In conjunction with this project, it would be important to improve the capacity of the southbound to westbound ramp movement at the I-471/I-275 interchange. This would be needed to accommodate the traffic demand (see TSMO Interchange Priority B below.)

Dynamic Shoulder Use Lanes as Part of Major Interstate Upgrades
Even though the DSU lanes did not show substantial benefits when implemented on the existing Interstate system, it is still recommended that DSU be considered as part of larger regional projects. As mentioned, there were clear benefits if the DSU lane was allowed to extend past the downstream bottlenecks. These types of deployments could be considered as part of larger improvement projects to maximize peak hour flow, while limiting construction costs.

The following projects are system interchange upgrades that would support the above improvements as noted in the text.

TSMO Interchange Priority A - Northbound I-71/I-75 to Eastbound I-275 Ramp - It is recommended that modifications be explored to increase the capacity of this northbound to eastbound ramp movement. Additional evaluation would be required to consider operations, safety, design feasibility, and cost. Possible concepts include:

Concept A1 would Re-align the two exiting lanes with the two lanes that head to I-275 eastbound (**Figure 27**). This would convert the left lane into a shared I-275 westbound and eastbound lane, while the right lane would remain a dedicated I-275 eastbound lane. This would require modifications to the KY 236 (Commonwealth Avenue) on-ramp so that it would merge into the right ramp lane instead of being a lane add. The ramp from KY 236 could be metered to space out entering vehicles and maintain the Interstate ramp flow. The project would require changes to the pavement, barrier, and striping.

Concept A2 would convert the existing two-lane KY-236 C-D into a single lane C-D (**Figure 28**). The volume on this C-D is modest and could be accommodated in a single lane (which could be metered). The additional width could be used to create a third exit lane that would tie into the right ramp lane to I-275 EB. This would require moving the barrier and reconstructing the merge and diverge points on the mainline and the C-D. Gore points would be moved, and angles of departure would need to be adjusted. It is also possible that the ramp bridge (over KY 236 ramp) may have to be widened or reconstructed.

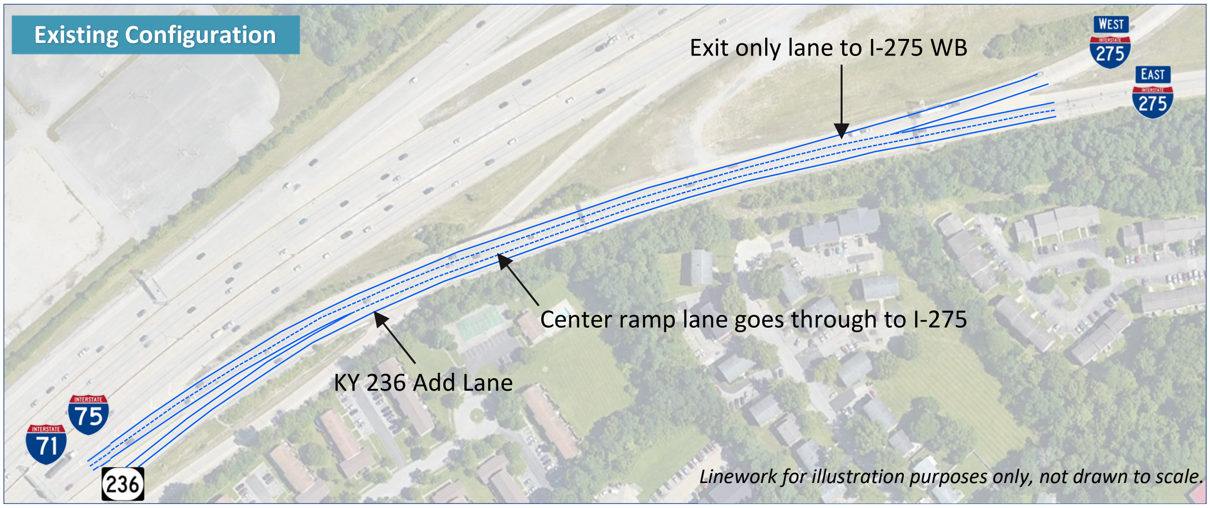
TSMO Interchange Priority B - I-471 Southbound to I-275 Westbound - It is recommended that modifications be explored to increase the capacity of this southbound to westbound ramp movement. Additional evaluation would be required to consider operations, safety, design feasibility, and cost. Possible concepts include:

Concept B1 would adjust the left lane on the I-471 SB to I-275 WB ramp to be a lane add on I-275 (**Figure 29**). This would require dropping one lane on I-275 WB prior to the ramp merge. One proposal is to drop a lane at the split to I-471 northbound, making it a major diverge. The peak hour volume drops to a two-lane flow after that diverge.

Concept B2 would taper out the right lane on I-275 westbound in the middle of the interchange to reduce it to two through lanes. This option could be adjusted to implement a dynamic lane control system that would only close the right lane when traffic is heavy coming from I-471 (e.g., in the PM peak period).

Other Interchange Movements - There is a need to increase the capacity for the I-275 eastbound to I-471 northbound movement, but there is no low- or modest-cost approach to increase the capacity of that single lane flyover. One or more new bridges appear to be required to address this need. Similarly, there is no low-cost approach to increase the capacity of the I-275 westbound to I-71/I-75 southbound movement. This connection is limited by downstream constraints and would have to be improved as part of the larger system interchange improvement project.

Figure 27: Concept A1 - Potential I-71/ I-75 to I-275 Reconfiguration



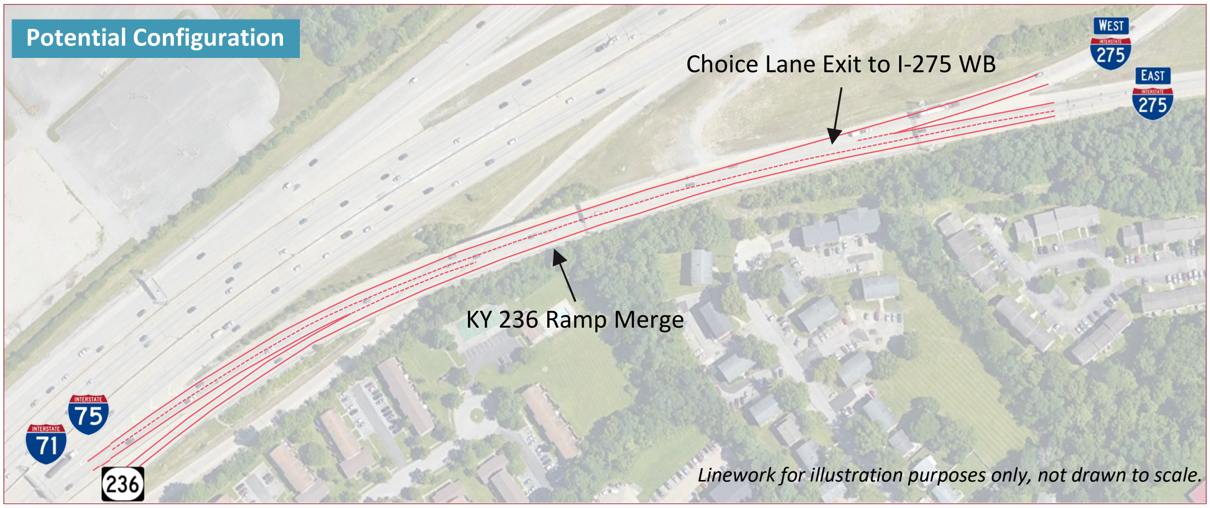


Figure 28: Concept A2 - Potential I-71/ I-75 to I-275 Reconfiguration

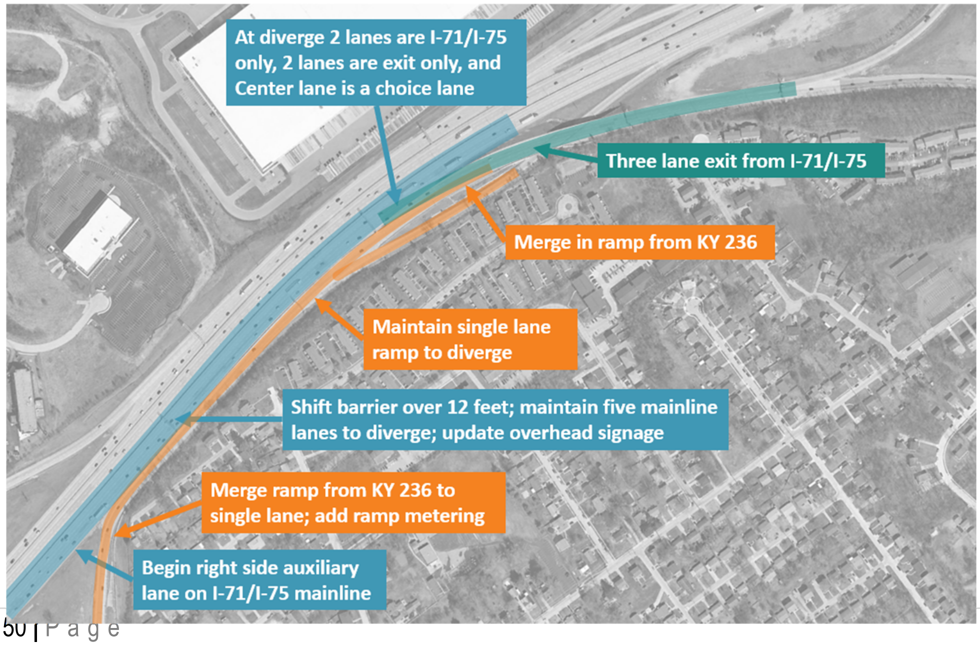
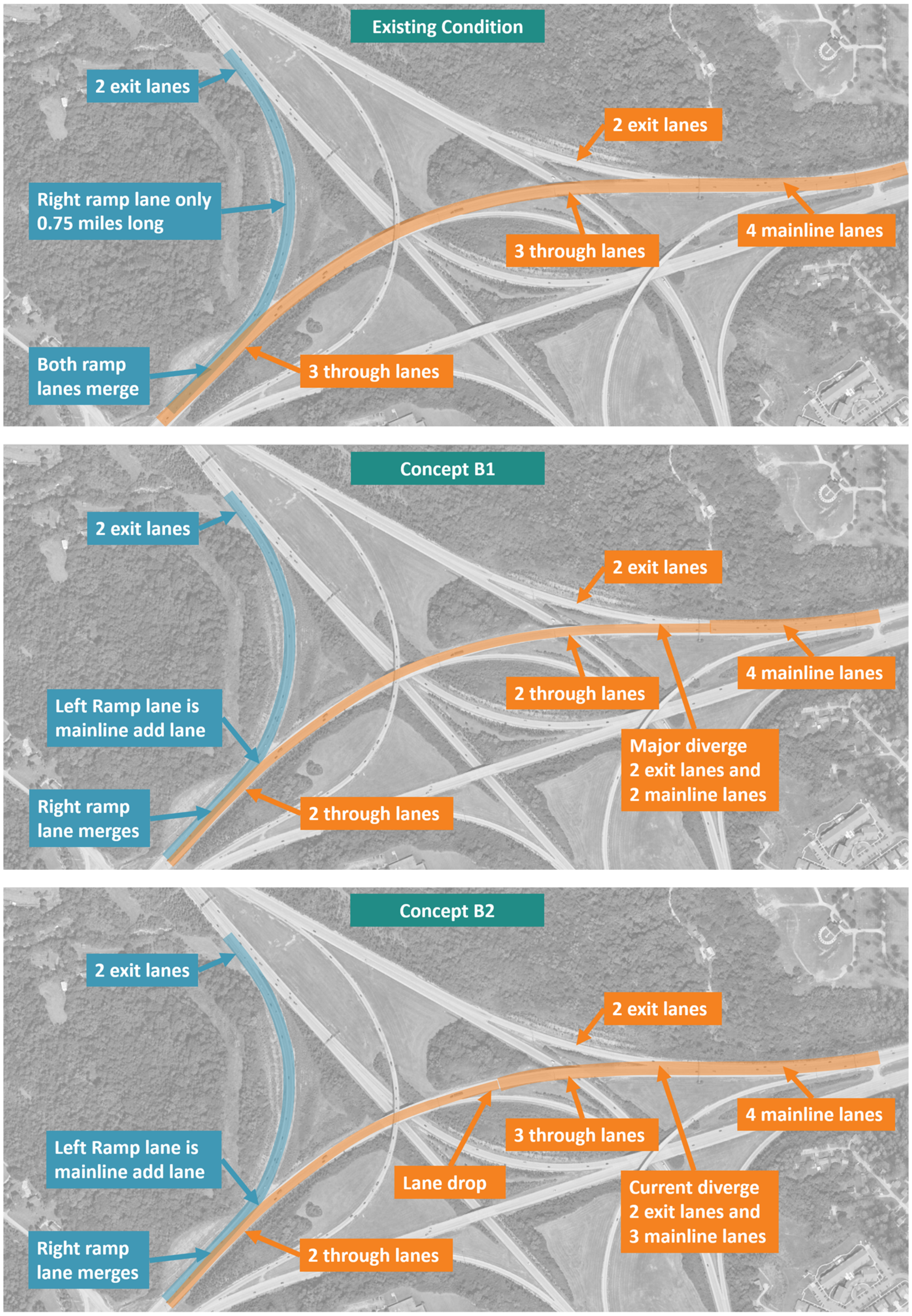


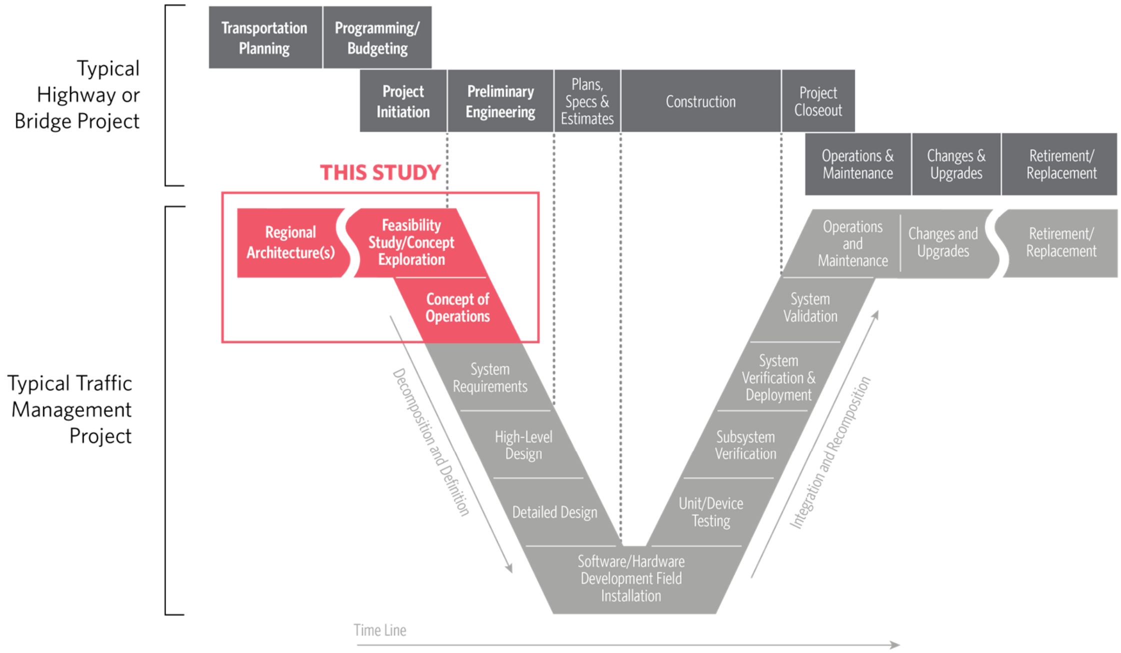
Figure 29: Concept B1 and B2 - Potential I-471 SB to I-275 WB Reconfiguration



Next Steps in the ATDM Deployment Process

The deployment of an ATDM strategy follows the Systems Engineering development process of “V” diagram shown in the bottom of **Figure 30**. This process is somewhat different from the typical highway or bridge project process shown at the top of **Figure 30**. Details about this process can be found here: [FHWA Systems Engineering and ITS Project Development]

Figure 30: Systems Engineering “V” Diagram



The upper left part of the “V” covers the initial planning and project programming phases. Then the work begins to shift from the high-level user view of the system to the detailed design and specifications. It is necessary to move incrementally through this process to thoroughly decompose the system into all of its individual subsystems and elements with clear definitions for each. This leads to specific requirements for each system, subsystem, and element.

At the bottom of the “V” the work shifts to system development and implementation. This involves detailed testing and verification steps for each element, subsystem, and the overall system. The upper right steps involve the ongoing operations and maintenance that is so critical to the success of an ATDM strategy.

This study has completed the upper left three steps in the “V” diagram. Early in the study process, a document was prepared and submitted addressing the key components of the regional architecture. This current document presents the results of the Feasibility Study/Concept Exploration phase. Several potential deployments have been identified as feasible and beneficial.

A companion Concept of Operations (ConOps) document has also been submitted. The purpose of the ConOps is to convey a high-level view of how the ATDM and TSMO strategies could be deployed. It presents the functionality of the proposed system of strategies and forms the basis of the project’s system engineering, design, and implementation phases. The ConOps provides an overview of the ATDM concepts; describes current conditions; how the deployment strategies will function in the near-term once the system concept is operational; and identifies current and future responsibilities of project stakeholders.

The next step in the process is the confirmation of the specific ATDM strategies that will be advanced to the System Requirements and High-Level Design phases of project development. The Comparative Travel Time and Queue Warning systems could move directly into these phases given the groundwork that has been laid by the work to date. The Ramp Metering system could also advance, but there are non-technical reasons to engage with and educate the public about this deployment before moving it forward.