



Applicability of Zipper Merge Versus Early Merge in Kentucky Work Zones

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Kentucky Transportation Center
College of Engineering, University of Kentucky Lexington, Kentucky

in cooperation with
Kentucky Transportation Cabinet
Commonwealth of Kentucky

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Kentucky Transportation Center • University of Kentucky
176 Raymond Building • Lexington KY 40506 • 859.257.6898 • www.ktc.uky.edu



Research Report
KTC-17-27/SPR16-526-1F

Applicability of Zipper Merge Versus Early Merge in Kentucky Work Zones

Erin Lammers, EIT
Research Engineer

Jerry Pigman, PE, MSCE
Program Manager

Brian Howell, PE, PMP
Research Engineer

and

Adam Kirk, PE, PhD
Research Engineer

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

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16. Abstract In an effort to improve work zone safety and streamline traffic flows, a number of state transportation agencies (STAs) have experimented with the zipper merge. The zipper merge differs from a conventional, or early, merge in that vehicles do not merge into the lane that remains open immediately after being notified of a lane closure. Rather, vehicles continue to occupy all lanes until they reach the taper, at which point — and directed by signage — vehicles take turns merging into the open lane, creating a zipper pattern. At the request of the Kentucky Transportation Cabinet (KYTC), Kentucky Transportation Center (KTC) researchers reviewed the performance of the zipper merge as documented in case studies from other states and analyzed two instances of the zipper merge being implemented in Kentucky. Previous studies found zipper merges are optimal on roadways with heavy traffic, whereas the conventional merge is preferable for uncongested and low-volume roadways. The case studies used a blend of quantitative and qualitative, observational data; researchers investigated the performance of zipper merges installed on Interstate 275's Carroll Copper Bridge and KY 9's Taylor Southgate Bridge. For the I-275 bridge, KTC researchers were able to compare the early merge configuration to the zipper merge. Here, the zipper merge brought about minor, although statistically insignificant, improvements in traffic flow and roadway safety. Analysis of the zipper merge on the Taylor Southgate Bridge relied more heavily on qualitative data, as the zipper merge was installed from the outset of the study and no comparison to an early merge could be made. The zipper merge appeared to improve traffic flow, reduce backups, and minimize the area impacted by construction. While neither case study offers definitive evidence that the zipper merge is significantly more effective than the early merge, they offer limited support for its use. On this basis, researchers suggest its continued implementation on other KYTC projects. Implementing the zipper merge elsewhere in Kentucky will enable further data collection and potentially identify locations and situations for which the zipper merge is the most appropriate merging method.			
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1 Introduction

1.1 Background

Work zones are prevalent throughout Kentucky’s highway system and the nation. In most cases, they require closing lanes of traffic so workers can make needed repairs. The resulting roadway congestion is an ongoing challenge that results in significant costs. With highway maintenance activities continuing to present congestion and safety challenges, there is an increased need to better manage traffic flow within work zones. Recognizing these challenges, the Kentucky Transportation Cabinet (KYTC) initiated a research project to determine a method for improving traffic flow conditions within work zones. KYTC’s goal is to “provide a safe environment” and ensure “a minimum delay to the traveling public.” Most recently, this includes an examination of work zone merging practices.

Traditional merging methods have often resulted in unsatisfactory driver behavior that is detrimental to the safety of the driving public and construction workers. These methods include, most notably, the early merge method, which is a popular and common merge technique used by many state departments of transportation (DOTs). In this merge, drivers are notified of approaching work zone construction and choose to merge at the earliest available opportunity. For typical roadways where one lane is closed and one lane remains open, this means the lane that is closed ahead goes unused longer than is necessary. This technique frequently results in the formation of an excessively long queue in the open travel lane, potentially affecting safety and travel times. Long queue length may also spillover at the highway’s intersection with entrance and/or exit ramps and interfere with their operations. Early merge queues also tend to produce queue jumpers: drivers choosing to continue driving through the closed lane until merging into the open lane late into the process.

The zipper merge, which is a form of late merging, has been introduced as a potentially safer and more efficient alternative to traditional merging methods. Drivers continue using both lanes upon the initial notification of a lane closure and then alternately merge at the beginning of the lane taper as they proceed through the work zone. Signs and a taper direct vehicles to take turns merging immediately prior to entering the work zone open lane. Simply put, drivers are encouraged to use both lanes *until the merge point*, rather than merging into the open lane early. In doing so, roadway capacity is more fully realized leading up to the work zone. It also reduces potential interference with entrance and/or exit ramps located prior to the work zone. Several other countries and state DOTs have implemented the zipper merge method for work zones with lane closures, and many have benefited from better flow management, decreased queue length, and safety improvements as a result.

1.2 Objectives

Because KYTC’s goal is to improve work zone efficiency and safety, the Cabinet expressed interest in exploring the use of a zipper merge in Kentucky work zones. The project objective was to evaluate implementation of a zipper merge system for managing traffic at lane closures within work zones.

2 Literature Review

Numerous state DOTs have evaluated various traffic merging systems to determine which one most effectively directs vehicles through highway construction work zones. While the early merge is still popular, state DOTs have recently begun to examine other merging methods to better accommodate congested travel conditions through construction work zones. Late merges and zipper merges are among the popular choices. Additionally, a few DOTs have taken the zipper merge a step further and modified it into the joint merge and/or a signalized control merge system. Each of these merging systems is discussed in detail below.¹

2.1 Michigan DOT Dynamic Late Merge

In 2006, the Michigan Department of Transportation (MDOT) implemented a Dynamic Late Lane Merge System (DLLMS) on three freeways within the state. DLLMS requires drivers to merge at a designated point immediately prior to entering the construction work zone. This type of merge is more commonly referred to as a zipper merge. Signs indicating “Use Both Lanes to the Merge Point” guided drivers through the DLLMS process. Datta et al. (2007) reported on monitoring efforts of the system’s performance, which were carried out on behalf of MDOT. Their study evaluated traffic conditions at these three locations and compared them to a single, designated control site that used the conventional merge.

Researchers collected data to compare the DLLMS merge performance to conventional or early merge work zones. They collected data on traffic volumes, queues, speeds, travel times, merge locations, and crashes. Several methods were employed to collect the data. Digital video cameras placed on overpass locations near the work zones captured traffic volumes, queues, and merge locations. Vehicular speeds at each site were measured using radar guns. Researchers used a floating car to travel and collect real-time data on travel times through the work zone. Floating cars made several passes at select times and on multiple days to calculate average travel times. Finally, researchers reviewed MDOT crash reports to assess crashes occurring at the study sites during the study.

Researchers concluded that the DLLMS increased traffic performance over the conventional merge system. Comparing data between conventional merge and DLLMS, the average travel times for vehicles approaching the work zone decreased from 272 seconds per 10,000 feet per vehicle (sec/10,000ft/veh) with the conventional merge to 167 sec/10,000ft/veh for the DLLMS. This coincided with increases in the average travel speed from 30 mph to 48, respectively. As a result, the average delay decreased from 181 sec/10,000ft/veh to 68 sec/10,000ft/veh, again favoring the DLLMS. These findings were all statistically significant. On the other hand, the number of crashes between the study sites was not statistically different, which may be attributed to the overall small sample size. Ultimately, the DLLMS demonstrated notable improvements in traffic performance over conventional merge and satisfied MDOT’s stated objectives.

2.2 Texas DOT Merge Types

University of Texas researchers Kurker et al. (2014) evaluated the performance of various merging techniques including early merge, zipper merge, and signalized merge. They used VISSIM traffic

¹ The terms *late merge* and *zipper merge* are used synonymously in this chapter and the remainder of the report; likewise, *early merge* and *conventional merge* are treated synonymously.

modeling software to simulate traffic conditions under the different merging techniques. This software analyzes traffic conditions using factors such as the number of lanes, vehicle types, and signalization. Data collected from the field were used to further improve the simulation model. The study demonstrated different merge types performed differently based on the overall traffic conditions surrounding the work zone.

Early merge tended to perform best when existing traffic volumes were less than the roadway capacity. In this scenario, lower traffic volumes provided sufficient spacing or gaps in the prevailing traffic flow and allowed easier merging into the open or through lane. Subsequently, vehicles experienced minimum delays and maximum safety due to the low traffic volume conditions. The study used the established Highway Capacity Manual approximation of 1,800 passenger cars per hour per lane (pcphpl) as the baseline for work zone capacity.

In contrast, the late merge becomes the optimal choice whenever traffic volumes approached or exceeded capacity. Determining whether to use the late merge technique relies heavily on the volume-to-capacity ratio (V/C). The V/C ratio represents the inflection point for actual traffic volumes in relation to the roadway's overall capacity. Heavily congested areas have a V/C ratio nearing or exceeding one. Under these conditions, an increase in queue jumping, lane changing, and crashes, are associated with the early merge technique. The late merge method helps alleviate these unsatisfactory conditions by fully using both lanes of traffic prior to arrival at the work zone.

The signalized merge control technique builds upon the late merge technique by placing signalized control near the entrance of the work zone. Similar to late merge, drivers are required to utilize both lanes of traffic while approaching the work zone. Drivers then either stop or continue through the work zone based on directions from the signalized control found near the entrance. The signalized merge control directs alternate travel lanes to enter the work zone lane one queue at a time. Kurker et al. found this method works best when traffic volume exceeds capacity (over 1,800 vehicles per hour per lane) and the signal cycle time equals or exceeds 40 seconds. The study demonstrated that signalized merge control reduced associated lane changes and more readily incorporated heavy vehicular traffic into optimal flows than other merge types.

2.3 Virginia DOT Late Merge

Beacher et al. (2004) reported on a research consortium from the Virginia DOT and the University of Washington. They studied the zipper merge concept and compared its advantages with the early merge method. The research authors analyzed 2-to-1, 3-to-1, and 3-to-2 lane closures in highway work zones using traffic modeling as well as field data. Various factors were examined including lane configuration, speeds, volumes in vehicles per hour per lane (vphpl), percentage of heavy vehicles (i.e., heavy trucks), and overall throughput. Their traffic model (VISSIM) predicted driver actions related to right-of-way decisions and their impacts on movements through the work zone. Thirty model runs were conducted using unique combinations of traffic variables to predict vehicle merging behaviors. Additionally, researchers collected field data at seven work zone construction sites employing the late merge concept. Field sites were selected based on having the following characteristics: (a) established at least 4 weeks, (b) experienced congestion and queueing, (c) static work zone conditions, (d) straight horizontal alignments, and (e) sufficient shoulders to place research equipment.

Computer simulations were used to analyze the traffic model and field data to determine statistical significance. The 3-to-1 lane closures demonstrated the greatest improvement in overall traffic performance, resulting in increased throughputs across all evaluated conditions. The 2-to-1 and 3-to-2 lane closures produced mixed results on throughput gains. For the field test, the 2-to-1 site did not show a statistical gain in throughput. However, the authors contended that the site's relative lack of heavy vehicle traffic (10 percent of vehicle volume) probably limited the full benefit of the late merge. As a counterpoint, various traffic simulations demonstrated that an increase in the percentage of heavy vehicle traffic corresponded to an increase in throughput. This may be explained by heavy vehicles having slower acceleration times than passenger cars and the late merge being more conducive to filling gaps in front of heavy vehicles. The study indicated throughput gains in 3-to-2 and 2-to-1 lane configurations reach statistical significance on the percentage of heavy vehicles equals or exceeds 20 percent.

2.4 Nebraska Department of Roads and Pennsylvania DOT Late Merge

A research team from the University of Nebraska, McCoy and Pesti (2003), conducted a study on the efficiencies of early versus late merge and concluded that late merge has superior performance at high traffic volumes. Researchers conducted their work on behalf of the Nebraska Department of Roads (NDOR). At the time, NDOR used a traditional merge system with construction zone notification signs placed approximately 1 mile upstream of the work zone as well as a taper that channeled vehicles from the closed lane to the open lane immediately prior to the work zone. Nebraska drivers would normally start merging early in this process. In this context, the NDOR merge would be considered an early merge (Figure 1).

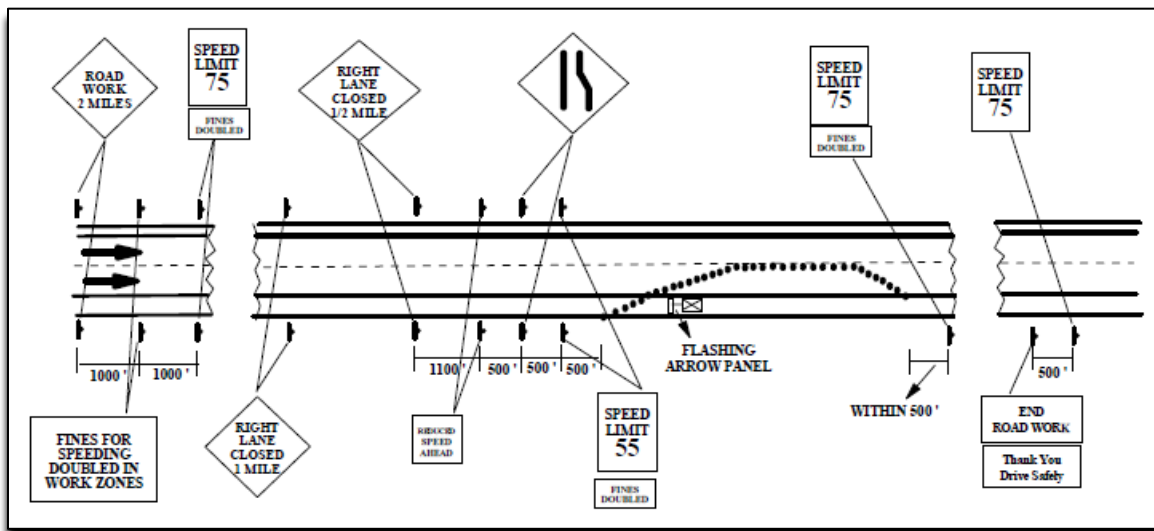


Figure 1 NDOR early merging process.

The research team also coordinated with the Pennsylvania Department of Transportation (PennDOT) to collect and evaluate data related to PennDOT's late merge system, which also required drivers to use both lanes until they alternate merging into the open lane at the taper.

PennDOT's late merge system demonstrated increased performance over the NDOR early merge system. The researchers assessed measures related to safety and traffic operations and determined the following characteristics:

- Late merge decreased forced merges by 75 percent
- Late merge decreased lane straddles by 30 percent
- Late merge increased capacity through the work zone by 20 percent passenger cars per hour per lane (pcph)
- Late merge decreased queues approaching the work zone by approximately 50 percent

McCoy and Pesti concluded that the late merge system outperformed the early merge system during hours of peak congestion. However, they argued that the early merge is preferable and performs better during uncongested or low-volume periods. For construction work zones that experience both conditions, they recommended using dynamic message signs to facilitate the alternation between the early merge and late merge systems based on the prevailing traffic conditions.

2.5 Louisiana DOT Joint Merge

The Louisiana Department of Transportation implemented and analyzed a joint merge concept for traffic entering an interstate work zone (Wolshon et al. 2014). The joint merge concept is similar to the zipper merge concept in that it promotes full use of both travel lanes prior to reaching the work zone transition. Drivers must then alternately merge into the single travel lane without either approach lane having merge priority. However, the joint merge differs from the zipper merge in that it places physical barriers on the road to manually direct the merge. In this case, roadside construction barrels served as the physical barriers. Nevertheless, the joint merge concept is strikingly similar to the zipper merge and the results from this study are useful for evaluating traffic operation results. Figure 2 illustrates the joint merge concept along with the transition zone (segments 1, 2, and 3 in purple).

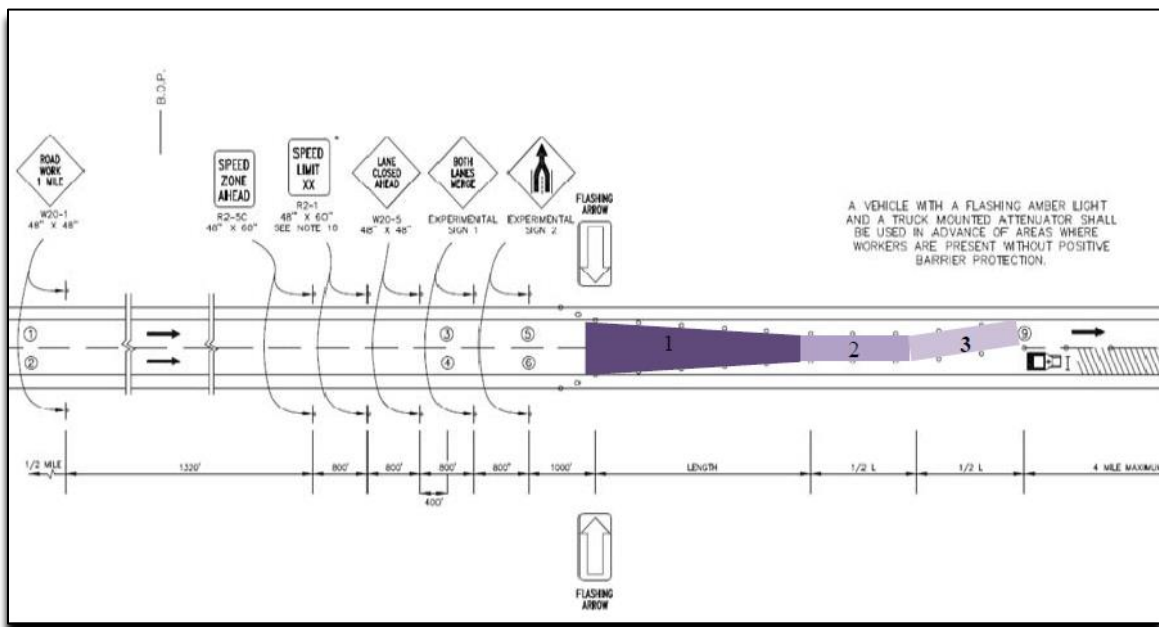


Figure 2 Joint merge, similar to a zipper merge.

Wolshon et al. (2014) evaluated traffic operations and compared the performances of the early merge and joint merge for highway construction work zones. To collect field data, they placed magnetic imaging recorders or VMIRs at select locations leading to the work zone. Placements were located approximately 6,800 feet; 2,200 feet; and 1,000 feet prior to the work zone and just after the work zone exit. Several conditions were monitored including traffic volume, speeds, and vehicle type (i.e., length). The two merge systems exhibited mixed performance. As intended, the joint merge increased traffic volume equitability between the travel lanes since the lane that was closing displayed a higher percentage of vehicles than conventional merge when approaching the work zone. Researchers postulated that this equitable distribution reduced queue lengths leading up to the work zone but did not specifically monitor queue length data. Travel speeds were inconsistent between conventional and joint merge. The conventional merge provided greater consistency in travel speeds for the open lane leading up to the work zone. In other words, the open lane experienced a less severe decline in travel speed. Conversely, the joint merge provided greater consistency in travel speeds for the closing lane. This aligned with researchers' preliminary expectations since more drivers used the closing lane and for greater distances in the joint merge. Use of the joint merge system did not result in a statistically significant increase in traffic flows (or volumes) through the transition zone.

2.6 Summary of Best Practices

Most of these reports included several suggested methods for data collection, such as video cameras, radar guns, traffic modeling software, and in-field floating cars. Crash reports were also used to examine safety. The goal in most of these studies was to determine usability and efficiency and in order to this, certain variables were analyzed. The variables that were most commonly studied included traffic volumes, queues, speeds, travel times, lane configurations, and merge locations.

Overall, implementing alternative merging methods (i.e. the zipper merge) has yielded favorable results. Condensing three lanes down to one benefitted the most from the zipper merge. Most researchers also agree that the late merge is the superior option at high traffic volumes. However, the early merge remains preferable when there is little congestion or during low-volume periods. There seems to be awareness that the zipper merge likely improves safety, since both lanes travel at the same speed and traffic flows more uniformly; however, this claim cannot be verified due to the challenges of quantifying safety improvements. Lastly, public awareness (e.g., clear signage, public education campaigns) was emphasized as an important component of successful zipper merge implementation.

3 KYTC Case Study: Interstate 275 (Carroll Cropper Bridge)

Two case studies involving the use of the zipper merge were performed in Kentucky work zones. A comprehensive examination was performed on the Interstate 275 (I-275) Carroll Cropper Bridge in Boone County, and a less detailed study was done on KY 9 at the Taylor Southgate Bridge in Kenton County. Both case studies considered qualitative and quantitative indicators.

This chapter details the comprehensive I-275 case study, which occurred in fall 2015. I-275 is a four-lane, median-separated interstate that acts as a main commuter route in the Cincinnati area. During the evaluation, its AADT was approximately 35,700. The photos below show lane closures on the bridge (Figure 3) and the location of the zipper merging point (Figure 4). While the Carroll Cropper Bridge spans the Ohio River from Kentucky to Indiana, it is under the jurisdiction of Kentucky and maintained by KYTC. At this location, the project scope included conducting a public awareness campaign, testing traffic control devices, investigating and implementing methods of data collection, and analyzing the data to determine the effect of the zipper merge.



Figure 3 I-275 case study, lane closures.



Figure 4 I-275 case study, merging point. Message board flashes arrow during peak traffic hours.

3.1 Public Awareness Campaign

The public received information about the zipper merge concept and its implementation from a write-up on the KYTC District 6 website. A video highlighting the location of the zipper merge and guidance on how to use it was also posted on the website. Appendix A contains materials used for the public awareness campaign, which included descriptive information on the website, the script of a brief radio announcement as provided to local outlets, and a video offering specific guidance to drivers. The video was taken onsite and explained the zipper merge concept and the importance of using both lanes up to the merge point of closure.

3.2 Traffic Control

A critical part of the zipper merge evaluation was onsite traffic control devices used to advise drivers of the upcoming lane closure and how to utilize the system. The most important aspect was ensuring the use of both lanes to the point of the closure and then alternately merging. The overall layout of advance signing did not vary significantly from a typical lane closure on an interstate. The main exceptions included the use of changeable message boards and fixed signs that read USE BOTH LANES DURING BACKUP as shown in Figure 5. Additionally, a symbol merge sign and a supplemental sign reading TAKE TURNS were used immediately in front of the merge point (Figure 6).



Figure 5 Fixed sign placed in advance of the zipper merge.



Figure 6 Fixed sign placed at the merge point.

3.3 Data Collection

Traffic flow conditions were monitored at the test site to determine vehicle speeds and queue lengths. The early merge was in place from August 1, 2015, through October 18, 2015. Data collected during this period were used as the control. The zipper merge was in place from October 19, 2015, through December 2, 2015. For both types of merges, data were collected twice per week during morning and evening peak travel hours (6-9am and 4-6pm, respectively). The process involved driving through the area several times and collecting quantitative and observational information. A GPS sensor connected to a laptop in the passenger seat created a text file every second with information representative of the vehicle's position. Text files were later converted to Excel files as part of the data analysis. Researchers also took photos, videos, and supplemental notes. Notes typically included observations about traffic flow and driver behavior as well as information that may have affected traffic flow, such as weather and events. Since the project relied heavily on public awareness and cooperation, qualitative observations were arguably as important as the quantitative data. A total of 32 trips were made over this period to collect data.

3.4 Data Processing

Data were processed to determine speed of vehicles through the merges and the queue length, two important parameters with which to analyze the zipper merge's value. Text files were compiled as part of the data collection process and converted to Excel workbooks via comma delineations. Among the data included were latitude, longitude, time, direction, and distance along I-275. These values were used to determine speed by incorporating the coordinates at that second and the second before it according to Equation 1.

$$\text{Speed} = \cos^{-1}(\cos(90 - \text{lat}_p)) * \cos(90 - \text{lat}_c) + \sin(90 - \text{lat}_p) * \sin(90 - \text{lat}_c) * \cos(\text{long}_p - \text{long}_c) * 3958.756 * 3600$$

Equation 1

where lat_p = latitude of previous point
 lat_c = latitude of current point
 long_p = longitude of previous point
 long_c = longitude of current point

Angles are measured in radians; the final two numbers are factors that convert meters per second into miles per hour.

Speed was converted into a simplified scale by grouping values into three categories. Category 1 included speeds above 30 mph; Category 2 encompassed speeds between 15 mph and 30 mph; and Category 3 represented a speed slower than 15 mph. Category values (1, 2, or 3) were put into a column named *Queue* because they represented the speed of vehicles within the merging queue. These surrogate values were useful once the data were entered into GIS.

Through this process, Excel files were created for each of the 32 trips. Each was individually loaded into ArcGIS as a layer file and XY data were displayed. After the layer was created, a basemap was also added to provide location perspective. The surrogate values for queue speed (1, 2, and 3) were then displayed on the map. These values were color-coded: green for Category 1, yellow for Category 2, and red for Category 3. With some trial-and-error manipulation of the size and shape of dots, analysts obtained a completed map.

By this process, researchers developed 32 maps illustrating traffic flow in the work zone. Approximately half of the maps represented conditions with the standard early merge layout of signs, while the other half represented conditions with the zipper merge system in place. The following maps are representative examples of early merge maps (Figure 7) and zipper merge maps (Figure 8).

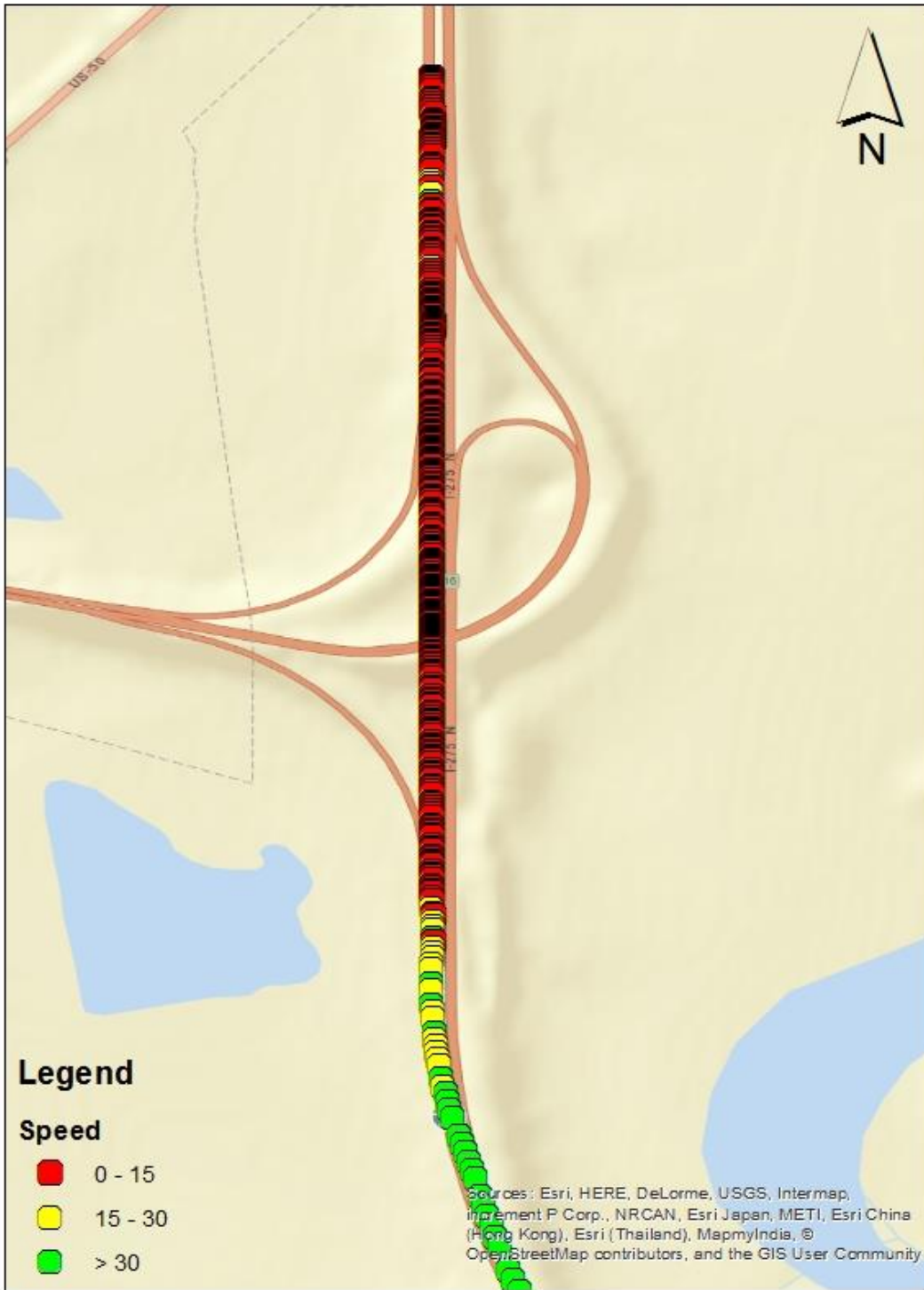


Figure 7 Early merge; speeds color-coded for visual analysis.

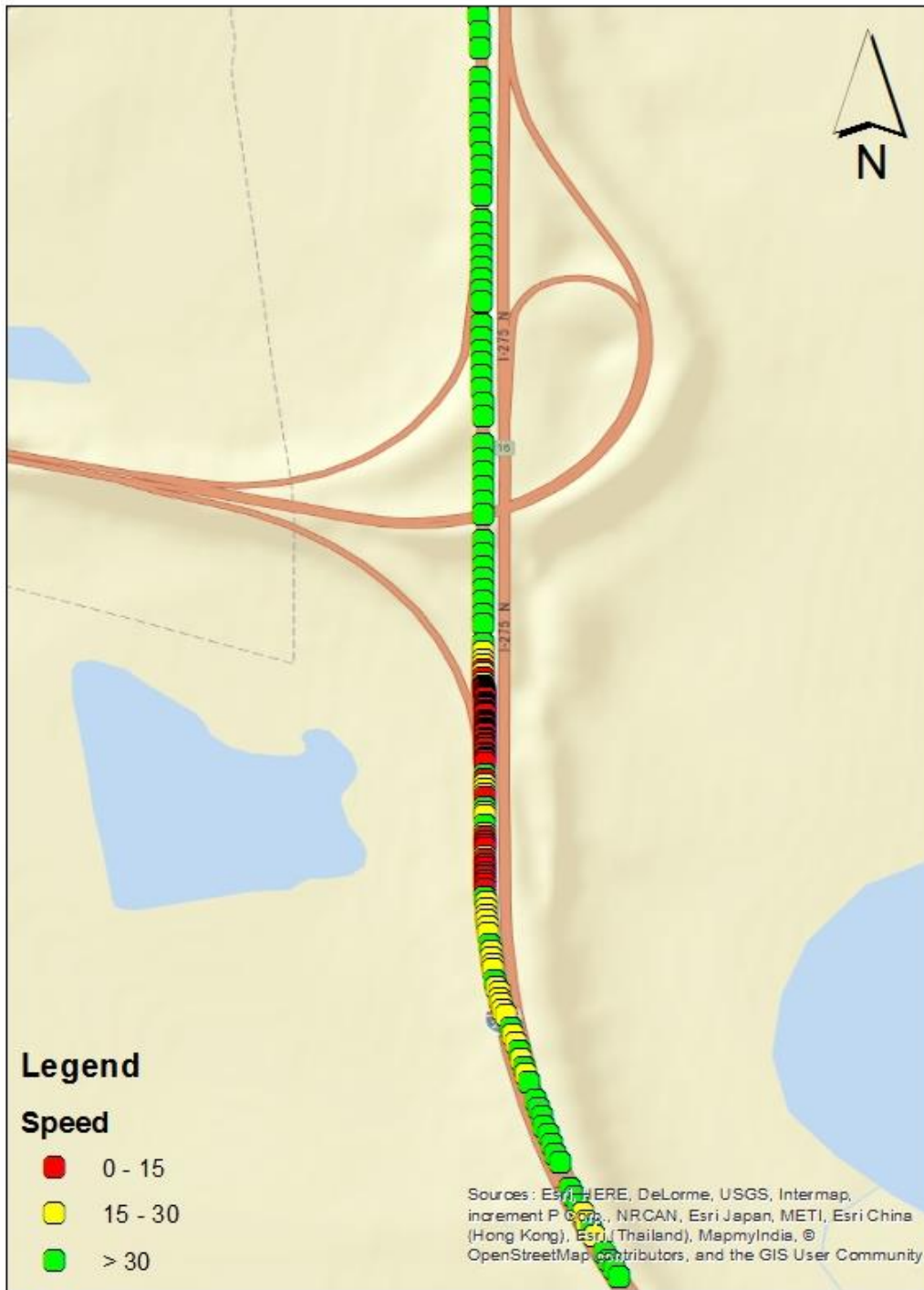


Figure 8 Zipper merge; speeds color-coded for visual analysis.

Figures 7 and 8 demonstrate that in some cases the desired outcome was achieved. On the figures, red points — indicating slower traffic — cover a longer path before implementation of the zipper merge (Figure 7) than after (Figure 8). However, these are relatively extreme examples and not necessarily representative of all days of data collection. In some cases, the early merge appeared to perform better than the zipper merge, and data on both merging methods contained their share

of anomalies that had to be discarded. Because the maps alone were inconclusive, more data analysis was needed. The subsequent steps are detailed in the next section.

3.5 Data Analysis

3.5.1. Traffic Flow Indicators

To more fully analyze the data, maps were combined with quantitative information in the Excel documents. Researchers thoroughly examined several traffic flow indicators, including average time to make a pass, average queue time, average queue length, average speed through a queue, average length of pass, and average speed through a pass.

Based on preliminary analysis, researchers concluded that queue data was most relevant to determining the value of a zipper merge application from the viewpoint perspective of the public and traffic engineers. Queuing (any time speed was below 15 mph) creates longer commutes for drivers and contributes to the economic cost of work zones. Queue length, time spent in queue, and speed through queue are parameters that should be improved to benefit roadway users. Data were also abbreviated to examine only the direction that was more affected. During the morning peak hours, the heaviest traffic flows moved eastbound; conversely, the most significant backups were observed going westbound in the evening. Each queue-defining value was tabulated and then averaged for the two treatment conditions — early merge and zipper merge. Morning data and evening data were analyzed separately, but using the same methods. Below is a summary of data collected during the morning and evening hours.

Table 1 shows the relevant data for morning peak hours. In addition to average values, the table includes standard deviation and sample size, which were used in statistical tests in the next step.

Table 1 Morning Queue Data

		Queue time (minutes)	Queue length (miles)	Queue speed (mph)
Early merge	Average	4.80	0.57	14.14
	Standard deviation	7.07	0.45	14.15
	Sample size	20	20	20
Zipper merge	Average	6.51	0.49	10.93
	Standard deviation	9.93	0.38	26.17
	Sample size	45	45	45

As the table shows, there were differences between the early merge and zipper merge. Queue time increased from 4.8 minutes to 6.51 minutes; queue length decreased from 0.57 mile to 0.49 mile; and queue speed decreased from 14.14 mph to 10.93 mph. The only parameter that showed improvement from the early merge to the zipper merge was queue length. Statistical testing was performed to determine whether these differences were significant.

Researchers calculated the z-score using the following equation:

$$z = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}}$$

Equation 2

where \bar{X}_1 = early merge average
 \bar{X}_2 = zipper average
 σ_1^2 = early merge standard deviation
 σ_2^2 = zipper standard deviation
 n_1 = early merge sample size
 n_2 = zipper sample size

P-values for lower tail and upper tail tests were calculated for each comparison depending on the applicable alternative hypotheses. For this test, the null hypothesis was that the implementation of a zipper merge made no difference in the various metrics. That is, the average values of the measured parameters for the early merge were equal to the averages of the measured parameters after installation of the zipper merge. The alternate hypothesis was that the zipper merge improved the average value of the parameters that were measured. For time and length, this means the average value would have decreased, requiring an upper tail test; for speed, the average value would have increased, meaning a lower tail test is needed. The results of the hypothesis tests are shown in Table 2. Highlighted boxes show the p-values that were of interest in each case.

Table 2 Statistical Tests for Morning Queue Data

	Queue time (minutes)	Queue length (miles)	Queue speed (mph)
z-score	-0.79	0.75	0.64
p-value (lower)	0.21	0.77	0.74
p-value (upper)	0.79	0.23	0.26

Researchers analyzed these data using a 95% confidence interval, meaning p-values must be greater than 0.05 in order for the change in parameter to be considered significant. All p-values

exceeded 0.05, meaning there was no significant difference in queue time, length, or speed between the early merge and zipper merge.

Evening data were analyzed next and the results are presented below in Table 3. Again, values include queue time, queue length, and queue speed, and additional values used in statistical tests.

Table 3 Evening Queue Data

		Queue time (minutes)	Queue length (miles)	Queue speed (mph)
Early merge	Average	6.47	0.76	8.94
	Standard deviation	9.40	1.02	3.65
	Sample size	30	30	19
Zipper merge	Average	7.56	0.86	9.07
	Standard deviation	10.45	0.97	4.91
	Sample size	56	56	42

During the evening peak hours, queue time increased from 6.47 minutes to 7.56 minutes, queue length increased from 0.76 mile to 0.86 mile and queue speed increased from 8.94 mph to 9.07 mph. Thus, only queue speed improved, since traveling faster through the queue is desirable.

To determine whether the changes in parameters were statistically significant, researchers used the same statistical hypothesis tests as were used to analyze morning peak hour performance. The null hypothesis was that implementing a zipper merge did not significantly influence queue time, length, or speed. The alternative hypothesis was that implementing a zipper merge led to significant improvements in these variables. Table 4 summarizes results of the hypothesis tests. Highlighted boxes show the p-values that were of interest in each case.

Table 4 Statistical Tests for Evening Queue Data

	Queue time (minutes)	Queue length (miles)	Queue speed (mph)
z-score	-0.49	-0.42	-0.12
p-value (lower)	0.31	0.34	0.45
p-value (upper)	0.69	0.66	0.55

The results give the same conclusion as the morning data. That is, all p-values are greater than 0.05, meaning there were no statistically significant changes in the performance metrics following

installation of the zipper merge. Therefore, researchers concluded that there was no significant difference in queue time, length, or speed when comparing the early merge and zipper merge.

While none of the comparisons were significant, viewing the original data (Tables 1 and 3) offers additional insights — traffic quality indicators seem to operate independently. Some parameters improved while others did not. Having this knowledge may prove valuable to traffic planners. For example, if the queue length increases but the speed through queue increases, this may be beneficial to travelers who prefer a steadier traffic flows to the stop-and-go traffic of condensed queues. Another possible result is that queue time increases but the length of queue decreases. This scenario may be beneficial in areas where ramp accessibility is of importance.

3.5.2. Safety Indicators

In addition to traffic flow, safety is an important factor to consider when evaluating the applicability of the zipper merge. To assess safety, researchers looked at crash data during the construction period and compared the crashes with the early merge in place to the crashes with the zipper merge in place. Data analysis began on August 1, 2015, when construction began, and ended with the end of the project on December 15, 2015. Table 5 compiles the crash data.

Table 5 Crash Data for Early Merge and Zipper Merge

	File Number	Roadway	Milepoint	Date	Time	Injured	Manner of Collision	Light condition
Pre-zipper	71641721	I275 W	12.8	8/4	1745	0	Rear end	Daylight
	71642626	I275 W	13.6	8/7	1547	3	Rear end	Daylight
	71645502	I275 W	13.6	8/12	1721	0	Rear end	Daylight
	71644878	I275 W	12.0	8/13	908	0	Single vehicle	Daylight
	71652195	I275 W	11.2	8/28	1856	1	Rear end	Daylight
	71653334	I275 E	11.1	8/31	1724	0	Single vehicle	Daylight
	71656819	I275 W	13.6	9/4	1602	0	Rear end	Daylight
	71656818	I275 E	13.8	9/4	1523	0	Rear end	Daylight
	71655035	I275 W	13.0	9/4	1941	0	Rear end	Daylight
	71663573	I275 W	12.4	9/22	1834	0	Rear end	Daylight
	71668701	I275 E	13.8	10/2	1357	0	Rear end	Daylight
	71678675	I275 E	13.8	10/8	1203	0	Rear end	Daylight
	71675562	I275 W	13.6	10/16	1530	3	Rear end	Daylight
	71675770	I275 W	13.5	10/16	1910	0	Sideswipe- same direction	Dusk
71678890	I275 W	12.5	10/20	2204	0	Sideswipe- same direction	Dark- unlit hwy	
Post-zipper	71693054	I275 E	13.6	11/13	809	0	Rear end	Daylight
	71690239	I275 W	13.6	11/13	1342	3	Rear end	Daylight
	71691236	I275 W	13.5	11/13	1825	0	Single vehicle	Dark- unlit hwy
	71692957	I275 E	13.5	11/19	800	0	Rear end	Daylight
	71694279	I275 W	13.5	11/20	1556	0	Sideswipe- same direction	Daylight
	71694099	I275 W	13.6	11/20	1700	0	Rear end	Daylight
	71694278	I275 W	12.7	11/20	1535	0	Sideswipe- same direction	Daylight
	71696412	I275 E	13.7	11/25	1840	0	Rear end	Dusk
	71696413	I275 W	13.3	11/25	1945	0	Rear end	Dark- unlit hwy
	71698860	I275 W	12.2	11/29	1926	0	Rear end	Dark- unlit hwy
	71699631	I275 W	13.6	12/1	1650	0	Rear end	Daylight
	71703041	I275 W	12.5	12/7	1743	0	Sideswipe- same direction	Dusk
71703475	I275 E	13.0	12/9	1805	0	Sideswipe- same direction	Dark- unlit hwy	
Crash report mentions construction								
Crash report mentions zipper merge								

In total, there were 15 crashes before the zipper merge was implemented and 13 crashes after its introduction. Crashes with the early merge were spread over 11 weeks, while the crashes that occurred while the zipper merge was in place took place in the span of eight weeks. Collisions before the zipper merge implementation may be considered less severe: there were seven injuries before compared to three after. In addition, the majority of crashes before installation of the zipper merge was rear ends, but more sideswipes occurred with the zipper merge.

Reading the crash reports offers more insight into each crash's circumstances. Before the zipper merge was used, four of 15 the crash reports mentioned the construction as a contributing factor. Once the zipper merge was in place, construction was mentioned as a contributing factor in five of the 13 crashes. Two additional post-intervention crash reports mentioned the zipper merge. These reports indicated that there was confusion about how to use lanes during the zipper merge process.

Because the length of the project was relatively short, there are limited crash data available. The main conclusion that can be drawn from the safety analysis is that there does not seem to be any quantifiable difference between the early merge and the zipper merge. However, public awareness is an important part of implementing the zipper merge so that the area stays as safe as possible.

3.6 Results for Interstate 275

While the raw data indicated some positive differences after the zipper merge was implemented, none of the changes were statistically significant. The safety analysis was also inconclusive. This case study, while thorough, failed to provide any substantial evidence in favor of the zipper merge or against it. However, it was invaluable in terms of determining a meaningful method of data collection and data analysis. Further studies may expand upon these methodologies in hopes of returning conclusive data. Additionally, this case study highlighted the importance of collecting photos, videos, and subjective evaluations in the future, rather than relying only upon quantitative data.

4 KYTC Case Study: KY 9 (Taylor Southgate Bridge)

To offer a more complete look at the zipper merge, another location was chosen to implement the method. KY 9 crosses the Ohio River from Cincinnati into Covington via Taylor Southgate Bridge, a 0.4-mile passage. The bridge connects Pete Rose Way in Ohio and KY 9 in Kentucky and serves as one of the main routes for commuters between the two states. KY 9 is a four-lane, undivided urban arterial with an AADT of approximately 2,800. The zipper merge was implemented from the project's outset. This was done to facilitate driver understanding, but it prevented researchers from making quantitative comparisons between the zipper merge and traditional early merge. Instead, this case study focused more on qualitative indicators. Qualitative analysis included preparing maps similar to the first case study, recording videos of the zipper merge in use, and obtaining feedback from the community and construction workers.

4.1 Data Collection and Analysis

Data collection efforts focused on driving through the area once the zipper merge had been implemented while collecting GPS/speed data and recording the traffic patterns via a GoPro camera. Maps were built using the same methodology as the I-275 case study. That is, a driver recorded location data as they passed through the zipper merge, converted this data to an Excel format, mapped the data in ArcGIS, and color-coded them based on speed for easy analysis. Figure 9 shows one example of the maps that were created.

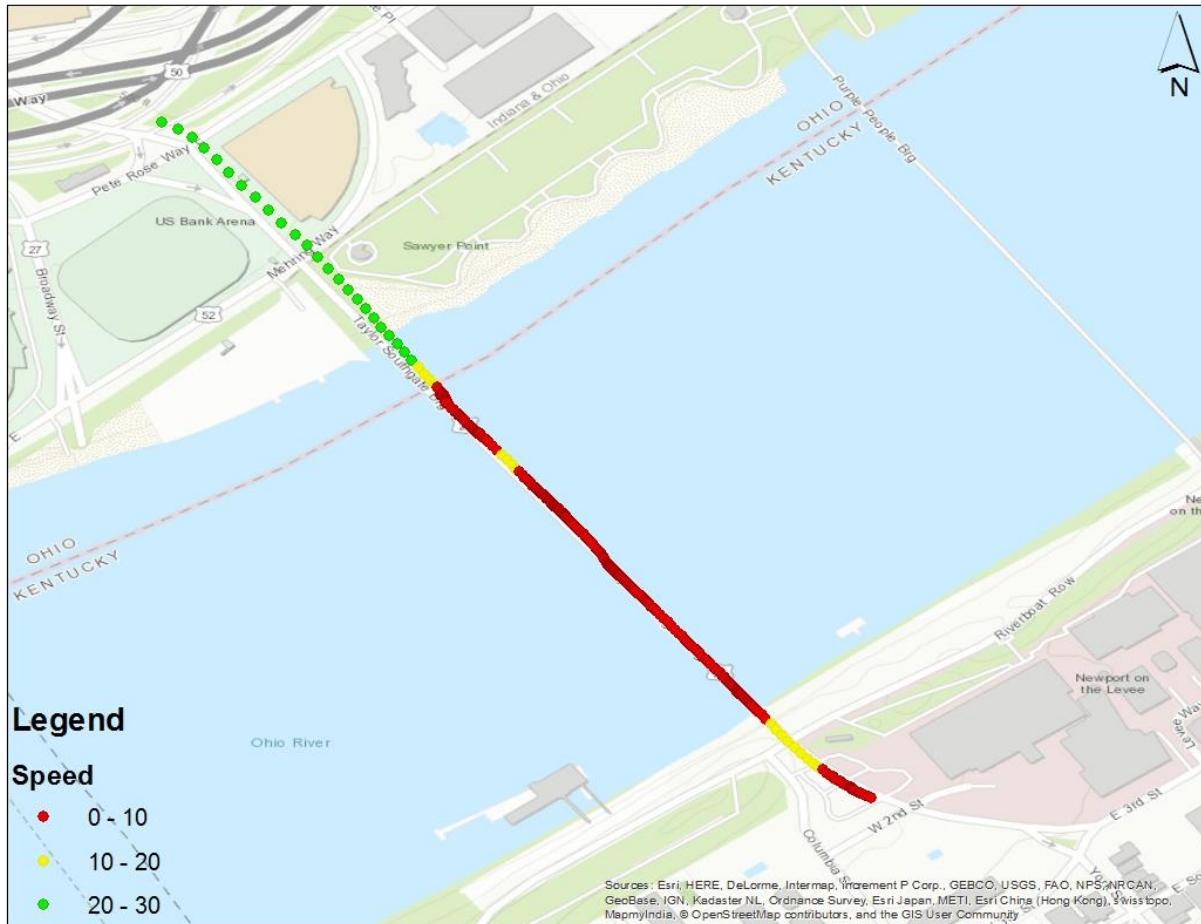


Figure 9 Taylor Southgate Bridge zipper merge; speeds color-coded for visual analysis.

Discussions with KYTC District 6 construction personnel revealed that only southeast-bound traffic during the afternoon rush hour experienced delays; therefore data were collected only during that period. As Figure 9 shows, drivers maintained a steady pace leading up the bridge, but quickly slowed down once they were on it. The zipper merge point was located about halfway across the bridge, and the construction work was on the southeast half of the bridge. However, the effect of the construction was evident across the entire 0.4-mile section of this urban arterial.

In addition to mapping speed through the construction area, videos were taken of the zipper merge in action. After allowing a few days for drivers to grow accustomed to the zipper merge concept, a GoPro camera was secured on a changeable message board where the lane closure occurred. The GoPro recorded use of the zipper merge for several hours during peak travel times. Videos show the zipper merge being utilized by most drivers and creating a uniform flow of traffic at the merge point. Researchers watched all the collected footage and compiled a brief video to show the zipper merge in action. Clips in the video are representative of all the footage collected, but were specifically chosen for their timing and/or clarity. The compilation illustrates the smooth traffic flow that results from implementing the zipper merge.

Readers can find the video at the following link:

https://www.dropbox.com/s/a1mzeps7lczy7cg/zippermerge_KY9.mp4?dl=0

Additionally, some photos from the video compilation are shown in Figures 10 through 12. These snapshots show the zipper merge being effectively used on Taylor Southgate Bridge. Vehicles approach the merge point in two lanes, then merge into one lane by taking turns at the merge point.



Figure 10 Snapshot from video of zipper merge in action on Taylor Southgate Bridge



Figure 11 Snapshot from video of zipper merge in action on Taylor Southgate Bridge



Figure 12 Snapshot from video of zipper merge in action on Taylor Southgate Bridge

4.2 Qualitative Analysis: Researcher Observations and Public Feedback

For this case study, examining qualitative indicators was just as important as analyzing quantitative indicators. This was due in part to its smaller scale, and also due in part to the fact that public perception had been an issue in the previous case study. Researchers focused on feedback from the community, insights from transportation officials and other construction personnel on the work site, and the experience of data collectors who utilized the zipper merge while it was in effect.

The KY 9 zipper merge was implemented based on a suggestion from a Kenton County citizen who commutes to Cincinnati every day. The driver was concerned with the extensive rush hour traffic on the bridge during construction. At the time, the area was relying upon the traditional early merge method. The citizen mentioned the congestion and the fact that traffic backed up far into Cincinnati, blocking other nearby streets. They also expressed concern with the safety of drivers on the bridge, since there had been multiple incidents of drivers leaving their cars during merge-related altercations. They recommended the zipper merge as a solution to the congestion and safety issues. Because KTC researchers were already examining the location as a potential spot for a zipper merge, the input from this driver was valuable for helping finalize the decision because it illustrated community interest. The letter is published in full in Appendix B.

In addition to listening to community concerns, obtaining feedback from transportation and construction personnel was a vital aspect of this project. They noted that, because the traffic on the Taylor Southgate Bridge is mainly commuter traffic to downtown Cincinnati, it took a couple days for drivers to break the habit of staying in one lane. During those first couple days, the backup spanned the entire bridge and extended onto city streets (about 2,500 feet). After a few days, drivers began using both lanes to their full capacity. Once this occurred, backups rarely extended across the entire bridge. On most days the backup would only reach just over half way across the span (approximately 1000 feet). Transportation officials in this area also noted that there were very

few calls or complaints from drivers. They stated that implementing the zipper merge helped move traffic and calm the motorists. Seeing the signs that encouraged the use of both lanes seemed to eliminate the drivers' perceptions of a "good" driver waiting their turn and a "bad" driver racing through traffic. In the officials' opinions, this equalized the drivers and resulted in a better traffic flow.

Because of the qualitative nature of this case study, KTC researchers were also able to draw their own conclusions about the efficacy of the zipper merge. During data collection, researchers noticed a very important detail about traffic at this location: there were very few trucks. On the Carroll Copper Bridge (see Chapter 3), semi-trucks were often a source of traffic issues. They would straddle the centerline leading up to the merge point, preventing other cars from utilizing both lanes, therefore undermining the purpose of the zipper merge. In addition, some trucks stopped in the lane that was closing, forcing cars to merge much earlier than needed. Essentially, they forced drivers to behave as though the early merge system was still in place. Although passenger car drivers occasionally blocked traffic like this as well, they did not have the effect that the large semi-trucks did. Because Taylor Southgate Bridge is not a major route for trucks, this issue was mostly eliminated. According to data collectors, drivers were mostly able to follow the rules of the zipper merge and traffic flowed smoothly.

4.3 Results for KY 9

KY 9's Taylor Southgate Bridge serves as one of the main routes for commuters between Covington and Cincinnati, so closing a lane for construction significantly affected traffic. By utilizing the zipper merge instead of the traditional early merge, the merging area took up less space, facilitating smoother traffic flow. Videos and photos of the area show the performance of the zipper merge and serve as a good illustration of how the system works. Drivers adequately followed the road signs and it seemed to expedite vehicle movement through the area during the construction project. Additionally, the bridge's lack of commercial vehicle activity seemed to facilitate driver cooperation. While it is important to note that this case study was mostly based on qualitative observations rather than quantitative data, researchers concluded that this bridge was a judicious location to implement the zipper merge and that doing so improved the traffic flow.

5 Conclusions and Recommendations

The objective of this project was to determine if application of the zipper merge would provide a more effective merging process compared to the traditional early merge method. Based on tests of the zipper merge at two locations, researchers were able to draw conclusions about its effectiveness and applicability.

The first case study examined a work zone on I-275's Carroll Copper Bridge and provided a thorough comparison between early merge and zipper merge. Researchers collected data about queue time, length, and speed by driving through the merge. Data were then analyzed using ArcGIS mapping techniques and performing statistical tests on the data. While the raw data indicated some positive differences after the zipper merge was implemented, none of the changes were statistically significant. A safety analysis was also performed by examining crash rates; however, this was inconclusive as well. Overall, this case study did not provide any substantive evidence in favor of the zipper merge or against it. Qualitative observations by researchers who drove through the site indicated that drivers generally complied with the zipper merge method, adhering to the signs advising use of both lanes in advance of the lane closure and then alternately merging at the point of closure. In addition, this case study helped researchers establish and validate testing methods that could be applied to other sites, and allowed researchers to consider how to better evaluate the zipper merge.

The second case study focused on KY 9's Taylor Southgate Bridge. Data collection methods mirrored those from the previous case study; researchers drove through the area and monitored speed, queue length, and other relevant data. In addition, they recorded video of driving through the zipper merge and made observational notes about traffic characteristics and driver behavior. Qualitative observations by researchers and construction personnel indicated that utilizing the zipper merge minimized the area affected by construction and enabled traffic to move more smoothly. Specifically, the length of backups on the Taylor Southgate Bridge declined after implementation of the zipper merge.

Both case studies provided thorough examinations of the zipper merge in place at a work zone lane closure. They showed that utilizing a zipper merge yielded some improvements. However, these improvements may sometimes come at the cost of other minor disadvantages. Overall, the conclusions drawn from these case studies are limited and provide minimal support for the application of the zipper merge. However, zipper merges show enough potential that they should continue to be implemented and studied when possible. Further work should identify select characteristics and operational features (number of lanes, AADT, speed limit, and percent trucks) found most suitable for zipper merge applications throughout the state.

A literature review indicated that most agencies agree upon the data that should be collected to properly evaluate the zipper merge. These include traffic volumes, queue information, speeds, travel times, merge locations, and crashes. Additionally, monitoring the area with video cameras and radar guns helps create a complete picture. Evaluating all data is important, as some parameters may show improvement while other do not. Agencies must decide what factors are important to them and choose their merging system accordingly.

Different lane configurations may respond differently to the implementation of a zipper merge. According to Beacher et al. (2004), utilizing a zipper merge when merging three lanes into one is the most beneficial. Most research, including these case studies, agree upon the idea that a late merge is superior at high traffic volumes. However, the early merge remains preferable and performs better during uncongested or low-volume periods.

Public awareness is one of the most important aspects of implementing a zipper merge. This includes the use of clear signage and public education campaigns. All drivers (including truck drivers) must know how a zipper merge operates and understand that it is utilized to benefit them.

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7 Appendix A: Public Awareness Campaign

A. Website information

What is a zipper merge?

In construction zone lane closures, the zipper merge concept directs motorists to use both traffic lanes until reaching the defined merge area, and then alternately merge in "zipper" fashion into the open lane.

Zipper merge vs. early merge

Many drivers react to the first sign indicating "lane closure ahead" by prematurely moving into the traffic lane which will continue through the construction zone. In many instances, the driver's decision to abruptly change lanes may result in the vehicle slowing too quickly. This unexpected behavior can confuse drivers in other following vehicles and result in severe crashes and/or road rage.

Zipper merging, however, benefits individual drivers as well as the public at large.

Research studies show increased safety when motorists use both lanes until reaching the defined merge area and then alternately merge in "zipper" fashion into the open lane. [Watch a brief video of how it works.](#)

So I'm supposed to merge late?

Yes! As you see the "lane closed ahead" sign, stay in your current lane and be on the lookout for traffic backups ahead. Continue driving within your lane until the point of merge. Then take turns with other drivers to safely and smoothly ease into the remaining lane. Each driver should practice zipper merge courtesy by allowing a single vehicle from each traffic lane to alternately proceed through the construction zone open lane. When traffic is

Benefits

- Reduces differences in speeds between two lanes
- Reduces the overall length of traffic backup by as much as 40 percent
- Reduces congestion on freeway interchanges
- Creates a sense of fairness and equity that all lanes are moving at the same rate



heavy and slow, it is much safer for motorists to remain in their current lane until the point where traffic merges in an orderly fashion.

When not to do the zipper merge

When traffic is moving at highway speeds and there are no backups, it makes sense to move sooner to the lane that will remain open through construction. The bottom line is to merge when it is safe to do so.

What does it look like?

A site using a zipper merge looks similar to a site using an early merge. Roadside signs indicate the difference by notifying drivers when to merge. In the zipper merge, signs notify drivers to use both lanes all the way up to the merge point. Ideally, drivers will fully utilize both traffic lanes resulting in nearly identical lengths of backup or congestion. By using both lanes, the length of traffic backups or queues will be reduced and result in improved traffic flow and safety conditions. Drivers should not block or try to prevent other drivers from using both lanes since this interferes with the performance of the zipper merge concept.



SIGNING APPROACHING ZIPPER MERGE

Zipper merge signs instruct drivers where and how to merge. The first sign will notify drivers to “Use Both Lanes During Backup” as indicated in the sign above. At the merge point, a sign will indicate “merge here” by showing two traffic lanes converging into a single lane. Additionally, the sign will instruct drivers to “Take Turns.” Each driver needs to take turns with other drivers when merging to fully employ the zipper merge concept. This will improve traffic flow conditions, prevent confusion, and reduce unnecessary congestion. Drivers not allowing other driver to merge will ultimately cause more delay for everyone.



B. Radio Script

Woman Speaking-- Oh no, lane closed ahead. I just never know when I'm supposed to merge.

Man Speaking-- To make it easier, zipper merges will be used by the Kentucky Transportation Cabinet on select projects. When construction closes traffic lanes, follow the signs. In a zipper merge use both lanes and take turns with other drivers at the merge point. It's the correct, safe, and polite way to merge within construction zones.

Woman Speaking-- That's easy! Use the zipper merge. Got it!

Man Speaking-- Now you know. Use the zipper merge. Look for the signs! And for more information, please visit KYzipper.org. A message from the Kentucky Transportation Cabinet.

C. Instructional Video Script

Beginning on October 26th, the Kentucky Transportation Cabinet will be using a new merging procedure for the lane closures on the Carroll Cropper Bridge on I-275. This procedure, known as the zipper merge, has been developed to address traffic congestion and safety concerns resulting from backups behind interstate construction work zones. In this video, we will show you the correct way to zipper merge and how posted signs assist you in doing so.

Merging should always be done carefully, especially when there's a lane closure caused by road construction or maintenance. So, when do you zipper merge? The simple answer is, do it when it's safe.

Sounds easy. But there's more to know about what you are supposed to do and when to start merging. The zipper merge will save you a lot of confusion when a lane is closed. Naturally, most of us begin merging as soon as we see warning signs indicating a lane is closed ahead. It is our mindset that everyone else not merging immediately is wrong or simply being pushy. That's just not true. You can legally continue in either lane until the lane actually ends. For the zipper merge, drivers should fully use both lanes of traffic as they approach the construction zone and

begin merging at the designated merge point. Roadway signs will clearly indicate the merge point location. Other previously posted signs will provide additional directions as you approach the work zone.



W20-5R

So doing the zipper merge is really simple. Use both lanes and follow the signs.



Obviously, when traffic conditions are light and vehicles are traveling at normal highway speeds, it's best to merge as soon as safely possible and the zipper merge is not needed. However when traffic is congested, it's actually safer and more efficient to use both traffic lanes until the point where traffic can take turns merging, which is indicated by the begin merge sign.



Zipper merge benefits drivers by reducing the difference in speeds between two lanes, reducing the overall length of traffic back up by as much as 40%, reducing congestion on freeway interchanges, creating a sense of fairness and equity that all lanes are moving at the same rate, and reducing incidents of road rage. These benefits allow traffic to move through lane closures safely and efficiently. When there's a lane closed, do the zipper merge. Use both lanes and follow the signs.

To learn more about the zipper merge, please visit KYzipper.org. Thank you for your time.

And as always, please remember to pay attention, wear your seatbelt and never drink and drive.

8 Appendix B: Citizen Letter

Hello [REDACTED],

I don't think we've met – I'm [REDACTED]. I live in Newport, KY with my wife [REDACTED] and son [REDACTED]. We both work in Cincinnati and commute home over the Taylor Southgate Bridge each day. I'm writing with a quick inquiry/request regarding the construction on the bridge. If you can't help, perhaps you can point me in the right direction.

As you know, the traffic circle construction on the Newport side of the bridge has resulted in a south-bound rush hour backup across the bridge each day. Though this is an unavoidable cost of a necessary improvement, the backup on the bridge is becoming an increasingly dangerous situation (and one that could easily be fixed).

As the right lane is closed near the Kentucky side, drivers waiting to cross the bridge line up in the left lane. At rush hour, that line stretches all the way to the Ohio side of the bridge. However, a number of drivers (including trucks and buses) will speed up the empty right lane all the way to the merge point and then attempt to merge in. Though using both lanes like this, all the way to the merge point, is actually the safest, most efficient traffic pattern, it naturally angers everyone in the left lane who has been patiently inching across the bridge. Left lane cars will often attempt to block right lane cars, or refuse to let them in. Right lane cars will accelerate suddenly, swerving in to the narrow berm to pass. While trapped in the left lane with my infant son in the car I have now, on three separate occasions, witnessed drivers actually get out of their vehicles to confront each other in stopped traffic. It is only a matter of time until one of those drivers pulls a firearm on the other.

The solution is simple: Near the Ohio side of the bridge erect a couple signs reading "Use both lanes. Merge at end." This would encourage all drivers to use both lanes and eliminate the passing and jockeying for position in the right lane. It would also eliminate the routine problem of left lane traffic backing all the way in to Pete Rose Way and further congesting traffic on that side of the river.

Is there anything you can do to help implement that simple solution? Is there anyone else I can appeal to for help with this?

Thanks for your time,
[REDACTED]