ASSESSING THE BENEFITS OF SMART WORK ZONE SYSTEMS

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ABSTRACT

Smart work zones (SWZs) are being deployed around the United States as a way to inform drivers dynamically about traffic conditions within a work zone. SWZs use sensors to detect traffic flow conditions on the work zone approaches. These data are then used to alert drivers of congestion or speed differentials in an effort to improve operations or safety.

Agencies that are considering deploying SWZs are often faced with the challenge of trying to justify the cost of an SWZ system to decision makers who may be more inclined to use the funds for more traditional maintenance purposes. Although a number of states have evaluated SWZ systems, there has not been much effort to identify trends across multiple tests or extend those findings to predict likely impacts of proposed deployments. This paper synthesizes the results of a number of deployments of SWZ technology and identifies some common trends in performance. The data are then used to develop benefit-to-cost (B/C) ratios for a variety of traffic and diversion alternatives. The B/C ratios are then used to identify some project duration thresholds at which an SWZ would be beneficial based on user delay savings for a two-lane directional segment.

INTRODUCTION

A number of transportation agencies have deployed intelligent transportation systems (ITS) in work zones in an attempt to mitigate traffic congestion and safety problems. These systems, commonly called smart work zone (SWZs), generally consist of three major functional components: speed detectors and surveillance equipment, a central control system, and information dissemination devices. The interaction among these systems is shown in Figure 1. The speed detectors and surveillance equipment collect real-time data on traffic flow approaching and within the work zone. These data are then sent to an automated central control system that processes the data and uses preset rules to determine the current conditions in the work zone. Based on the conditions present, the system automatically informs drivers of conditions using predefined messages delivered through portable changeable message signs (PCMSs), highway advisory radio (HAR), an Internet web site, or other methods such as fax or e-mail alerts. Typically, information on travel speeds or travel time is presented. The purpose of the system is to provide drivers with sufficient information to allow them to make informed choices on their route, speed, or departure time. The components of SWZs are automated, with little or no human intervention.

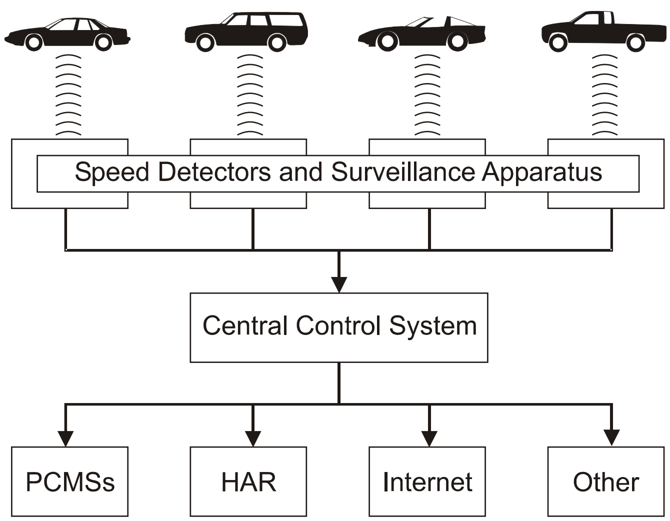

FIGURE 1 Smart work zone information flow. PCMSs = portable changeable message signs, HAR = highway advisory radio.

Agencies wishing to deploy SWZs must often compete for funding with more traditional uses of maintenance and construction money. Many decision makers do not fully understand the potential benefits of ITS and must be shown quantitative data that indicate an SWZ would be a good investment of limited agency funds. Agencies need data on the anticipated benefits of SWZ systems on traffic operations and safety to justify the additional expense required to deploy them. Initial deployments of SWZs were often more focused on evaluating whether the systems tested could work from a technical perspective and did not measure whether they had an impact on mobility or safety. Recent work has begun to examine operations and safety and provides an opportunity to define some expected impacts of SWZs. These impacts can then be used by an agency to make a decision about whether the expense of installing an SWZ is justified for a specific location.

PURPOSE AND SCOPE

The purpose of this paper is to report trends in the impact of SWZ systems on traffic operations and safety. Typical impacts seen in field deployments were reviewed, and conditions that impact the effectiveness of these systems were summarized. In this paper, the term *smart work zone* is narrowly construed to mean an automated system that provides real-time information on work zone traffic conditions. Only systems that operate with minimal human intervention are discussed. The discussion focuses on two commonly used functions of these types of SWZs:

1. *Speed advisory messages,* where approaching traffic is alerted to slower speeds in the work zone. The purpose of these messages is to improve safety by encouraging drivers to slow down approaching the work zone. The information on lower speeds is typically conveyed via PCMS.

2. *Travel time or delay messages,* where approaching traffic is informed of the approximate travel time or delay to travel through the work zone. This may also include a suggested alternate route, at the discretion of the agency. The purpose of these messages is to provide traveler information so that drivers can make alternate route decisions or at least be informed of congestion.

The expected operational and safety impacts presented were developed from a review of *successful* implementations of SWZ systems. There are additional cases where SWZ systems were not able to produce tangible improvements, usually because of technology difficulties or because the specific work zone was not well-suited to the application of these systems. Specifically, SWZ deployments that were not successful often lacked significant congestion or a viable alternate route for traffic diversion. This paper focuses on the effects that can be expected from a successful deployment, while other research provides guidance on fundamental prerequisites for when an SWZ should be considered at a site (*1*). Other specialized SWZ systems such as variable speed limit systems and demand-responsive late merge systems are not included in this synthesis.

Guidelines for when an SWZ may be justified were developed using microscopic traffic simulation. The expected operational impact of an SWZ is modeled on a simple network to help quantify the potential benefits of an SWZ system under a variety of traffic conditions. These data are used to provide a baseline estimate of the benefits of SWZs that could be used to help justify their installation.

SUCCESSFUL DEPLOYMENTS

A total of 15 successful tests in eight states were identified and reviewed. They all deployed systems that provided either a congestion warning, a travel time message, or a speed advisory message. The purpose of the deployment, site characteristics, and methodologies used to evaluate the systems sometimes varied considerably among the tests. Because of this, the results of the evaluations are grouped into three categories:

1. Driver response. These evaluations conducted surveys that asked drivers to self-report how they reacted to an SWZ.

2. Effect on operations. These tests attempted to measure how the SWZ impacted traffic operations, e.g., by measuring diversion from the mainline to alternate routes.

3. Effect on safety. These deployments assessed the impact of the SWZ on crash statistics or surrogate safety measures, such as speed.

Driver Response

One study examined an SWZ that was used to provide travel time information on I-75 near Dayton, Ohio, for approximately 4 months (*2*). Although no formal operational analysis of the effect of the system on traffic was performed, the researchers performed a survey where 3,177 drivers through the work zone were asked how frequently they changed their route in response to the travel time information. The 660 survey responses received showed a difference in how drivers reported using the travel time information based on how frequently they traversed the work zone. Drivers who reported traveling through the work zone “almost every day” or “several times a day” reported changing their path in response to the travel time information “quite often” 19.7 percent of the time and “a few times” about 51.9 percent of the time. Drivers who traveled the work zone less frequently reported values of 6.8 and 42.6 percent for these two categories, respectively. Since no alternate route was specified and an alternate route was not readily apparent, it is probably not surprising that the more occasional drivers were less apt to change path.

Researchers also used a survey to try to determine how motorists responded to an SWZ on I-95 in North Carolina (*3*). This stretch of I-95 had an ADT between 35,000 and 40,000 vehicles per day. The deployment provided both delay and alternate route information on PCMSs when the site became congested. A survey was mailed to 1,486 local residents, and 333 people responded. Of those respondents who remembered the PCMSs, there was significant variation in how the drivers used the information based on how frequently they traveled the corridor. Frequent drivers of the corridor indicated that they were more likely to use the delay data to change their route either “sometimes” or “often,” with 86.4 percent of drivers in this category selecting these responses. This is in contrast to the occasional and infrequent drivers who selected these responses 70.3 and 60.2 percent of the time, respectively.

Effect on Operations

A number of studies have attempted to assess SWZ impacts on traffic operations. In most cases, the researchers sought to determine how many people leave the mainline freeway in response to the SWZ information, although there have been limited attempts to determine delay on alternate routes as well. There is a consensus among the studies that the SWZ can effectively divert traffic from the mainline, producing improvements in overall operations. The level of diversion varies but generally appears to range from 4 to 20 percent.

A speed advisory system was also deployed on U.S. 41 in Green Bay, Wisconsin, and its impact on diversion and travel time was measured (*4*). Warning messages reporting actual speeds ahead were reported when speeds fell below 50 mph. Congestion was generally light and related to recreational traffic. The operational analysis of this site was limited, but the data collected implied that minimal diversion impacts were achieved. This was likely due in part to the large amount of traffic diversion that was already achieved through an extensive outreach campaign that occurred prior to the installation of the SWZ. A roadside survey was performed downstream of the site, and drivers were asked about their travel times. Drivers who elected to divert in response to the PCMS messages reported delays that were no worse than those reported by drivers who did not divert.

An SWZ deployment along I-80 in Nebraska was used to provide the message "CONSIDER ALTERNATE ROUTE" on PCMSs to travelers when there were large delays (*5*). The researchers found that the percentage of traffic exiting the highway onto an alternate route increased from 8 to 11 percent when this message was displayed. Another system tested on another section of I-80 displayed the PCMS message "DELAYS—USE ALTERNATE ROUTE" during congestion (*6*). This study revealed that this message increased diversion by about 4 percent.

A study on I-680 in Nebraska evaluated a speed advisory system at a work zone where the number of lanes dropped from three to two *(7).* The site carried 88,000 vehicles per day, and a major interchange reconstruction project was occurring within the work zone. The SWZ displayed the mean speed within the work zone on PCMSs, rounded to the nearest 10 mph. When speeds within the work zone dropped to below 15 mph, the PCMSs displayed the message "I-680 MAJOR DELAYS." There was no statistically significant change in diversion as a result of implementing the SWZ, but traffic volumes were not large enough to generate recurring congestion consistently.

In an evaluation of a work zone on I-94 in the Milwaukee area (*8*), travel time information was provided to drivers approaching a work zone who experienced delays because of recreational traffic. Peak delays were usually around 30 minutes, and PCMSs were installed to provide travel time information prior to potential diversion points. Although no alternate route information was explicitly provided on the PCMSs, alternate routes were fairly obvious, with a parallel frontage road and several other parallel routes present. Static guide signs were provided on the alternate routes for any motorists who elected to divert. Data collected over a 2-month period revealed that approximately 7 to 10 percent of mainline traffic used an alternate route when the drivers were provided with travel time information. The researchers could not relate travel times to the amount of traffic that would divert in part because the diversion of traffic caused mainline travel times to decline.

Another SWZ deployment on I-94 in Milwaukee, different from the one discussed previously, was used to provide delay and travel time information (*9*). This particular deployment had three potential alternate routes available, including a signed, designated alternate route. The researchers found that an additional 5 to 10 percent of mainline traffic diverted to the alternate route when the SWZ was active as compared to when it was not active. Travel times were not explicitly measured in this test.

An SWZ was tested on I-40 in Arkansas. It was used to provide queue length information and a "SLOW TRAFFIC AHEAD—BE PREPARED TO STOP" PCMS message (*10*). Traffic volumes on an alternate route were measured to determine the impact of the message on traffic diversion. The researchers found that an additional 75 to 200 vehicles per hour (vph) traveled on the alternate route when a 5-mile queue or the slow traffic message was displayed. This represented an approximate doubling of the traffic the alternate route typically carried. The reaction from the truck drivers was more dramatic, ranging from an additional 30 to 100 trucks per hour using the alternate route. The increased response of the trucks was thought to be due to truck drivers confirming the accuracy of the messages over citizens band (CB) radio, causing other truckers to divert to the alternate route.

A deployment along I-5 in Santa Clarita, California, used a delay advisory system that also provided alternate route information on PCMSs if congestion was severe (*11*). The researchers found that extensive diversion did occur, ranging from 5.3 to 8.7 percent diversion of traffic off I-5. Up to 20 percent of traffic whose drivers were informed of congested conditions prior to merging onto the highway diverted. A good alternate route was available that had travel times that were consistently lower than travel times on the highway during congested conditions. The travel time savings was usually around 3 to 4 minutes, although reductions of up to 10 minutes were observed during some periods.

Effect on Safety

Safety effects of SWZs have been evaluated in several studies, but these evaluations often rely on limited crash data. Evaluations that look at speed surrogate measures of safety can draw more statistically meaningful conclusions, but translating those effects into reductions in crashes is a problem. As a result, there does not appear to be a consensus on the effect of SWZ systems on safety.

Researchers from the University of Nebraska evaluated the safety impacts of an SWZ with a speed advisory message on I-80 (*12*). The site evaluated carried 38,000 vehicles per day, and speed limits were reduced from 75 to 55 mph within the work zone. PCMSs displaying the speed advisory information were located approximately 1, 3, and 7 miles from the work zone lane closure. Data collected on the work zone approaches showed that the speed advisory messages produced little or no reduction in mean or 85th percentile speeds during uncongested conditions. During congested conditions, speeds seemed to be closer to the advisory speeds but this was due to the combined impact of the congestion and the speed advisory signs. They could not isolate the impact of the signs from the congested flow, however. Crashes were also analyzed for this deployment (*5*). The researchers found that the crashes during the SWZ test increased from an average of 30.7 per year for the prior 3 years to 45 during the SWZ deployment. This change was probably attributable to the introduction of the new long-term work zone, so it is difficult to ascertain whether the SWZ had any impact on the number of crashes. Another system tested on I-80 provided alternate route guidance (*6*). This particular deployment did not provide any statistically significant reduction in speeds, although this is probably not surprising since its purpose was to encourage drivers to divert from the highway.

Researchers from the University of Wisconsin–Milwaukee looked at crash experience at an SWZ deployment on I-94 in Milwaukee (*9*). Travel time information was provided, and the researchers compared crash data using 2 months of before data where the work zone was present but the SWZ was not active to 2 months of after data when the SWZ was active. The researchers found that the number of crashes in the work zone increased from 70 to 89 from the before to the after period. This change was not found to be statistically significant, in part due to an increase in the traffic volumes between the before and after period. This means that the increase in crashes cannot be attributed to the installation of the SWZ.

Arkansas evaluated the safety impact of an SWZ located on I-40 (*10*). The system was intended to provide speed advisory and delay messages. During testing, however, the specified estimates of delay time were replaced with more generic "EXPECT DELAYS" or "EXPECT LONG DELAYS" based on driver complaints about the accuracy of the delay estimates. Crashes at one site were compared with crashes at two similar work zones that did not have an SWZ installed. The results show that the fatal crash rate at the SWZ site was approximately 50 percent lower than at the comparison sites (2.2 fatal crashes per 100 million vehicle miles of travel [VMT] vs. an average of 3.3 fatal crashes per 100 million VMT at the comparison sites). These results were based on limited data, however, with only 1 year of data available at the test site and 6 and 15 months of data available at the two comparison sites. The rear-end crash rate at the site was essentially the same as at the two comparison sites.

An SWZ was used to provide speed advisory messages at a work zone along I-70 in Missouri. In this study, drivers were alerted to slower speeds ahead when speeds dropped below 45 mph (*13*). The researchers found that 66.3 percent of drivers slowed down, with an overall speed reduction of 7 mph near the work zone activity area. Speed variance was also reduced by a statistically significant margin, but changes in speed were more pronounced during congestion.

A test of an SWZ on I-55 in Springfield, Illinois, provided travel time information to drivers (*14*). No recurring congestion occurred at this site, but some potential safety benefits occurred. Only two crashes occurred within the work zone over 16 months, and the number of citations written for moving violations declined.

Another evaluation examined an SWZ that provided delay and alternate route information on I-95 in North Carolina (*15*). This evaluation examined approximately 5 months of crash data at the 15 km work zone site. There were 22 crashes during the 92 days the SWZ was in operation. This is in contrast to 2 crashes during 13 days when it was not in operation. The limited size of this dataset makes it difficult to draw any conclusions about the impact of the SWZ on safety at this site.

Summary of Deployments

Although conditions often vary among deployments, common trends in SWZ impact do begin to emerge when the deployments are looked at collectively. Generally, the potential diversion impacts of SWZs have been documented the best. Safety and speed impacts show more variation, attributable in part to the lack of high-quality data in many of the studies. The following impacts appear in at least two SWZ deployments:

- Both studies of driver attitudes showed that drivers who traveled the corridor with the SWZ frequently were more likely to change their path in response to delay or travel time information than those who drove the corridor infrequently (*2*,*3*). Frequent drivers are probably more likely to realize that real-time operational data are being presented and probably have a greater overall level of familiarity with the area.

- Between 4 and 20 percent of mainline traffic diverted in response to travel time or delay information during congested conditions (*5, 8, 9, 11*). Minimal diversion was observed in response to speed advisory information (*4, 7*). Diversion percentages were usually greater when specific alternate routes were specified or the alternate route could be obviously seen from the mainline highway.

- Speed advisory systems appeared to be effective at getting drivers to reduce speeds approaching work zones, but benefits appeared to be most pronounced during congested operation (*12, 13*). It is unclear, however, whether this effect is due to the congestion or greater credibility of the speed advisory message during congested flow.

- The impacts of SWZs on safety appear to be inconclusive at this time, primarily because of limited data. Studies that have attempted to evaluate crash frequency or rate have shown conflicting results. Crashes increased in some cases, although this was likely attributable to other work zone features. No systematic trends in crash performance were apparent.

SIMULATION OF OPERATIONAL BENEFITS

Many transportation agencies that are considering deploying SWZ systems want to know when the potential benefits of installing a system justify the installation costs. Guidance on the potential benefits of these systems is needed so that SWZ systems can be compared side-by-side with more traditional uses of maintenance funds. As shown from the reviews of deployments, it is often difficult to assess the safety impacts of SWZ systems. The diversion impacts of SWZs have been assessed in enough studies that it is possible to develop generic guidance as to when an SWZ may be justified based purely on the operational benefits created by diverting traffic to alternate routes.

A series of microscopic traffic simulations were developed using VISSIM to identify the potential breakpoints at which it was justified to install an SWZ from an operational perspective. A simulation of a simple freeway network with a single diversion route was developed to identify situations where an SWZ may provide improvements in overall system delay.

This is not the first attempt to define potential B/C ratios for SWZ systems. Bushman and Berthelot (*16*) attempted to quantify operational, safety, and emissions benefits using data based on a site on I-95 in North Carolina. QuickZone was used to perform the operational evaluation, supplemented with safety prediction models that estimated possible safety impacts of the SWZ. Although the evaluation did provide an initial indication of the positive benefits of SWZs, it contained several assumptions that could be questioned, including:

- capacities between 1,200 and 1,400 vph, which appears to be on the low end of reported capacities for single lane closures.

- an average travel speed on the 10-mile alternate route of 55 mph, which is likely too high, especially for urban applications.

- a static 17-month analysis period.

The economic benefits of safety impacts calculated could be argued, given the lack of consistent safety data from SWZ deployments. Using these assumptions, the authors estimated that the B/C ratio was between 15.1 and 42.8, depending on traffic demand conditions. This indicates that SWZs can produce a positive benefit, but it raises a number of additional questions. It is unclear if the SWZ would produce benefits that are as large if the analysis period was shorter or the alternate route had performance characteristics that were much worse than those of the freeway. In some respects, the earlier analysis represents a best case scenario where benefits could accrue over a long period of time and there was a very attractive alternate route. Agencies need additional information as to whether these systems should be used on projects of shorter duration or in cases where drivers would be diverted to congested roads or arterial streets.

Experimental Design of Simulation

Figure 2 is a schematic of the roadway network used for testing. The network represented a simple case where there is one alternative route to a freeway with a lane closure. The alternate route around the lane closure is 8.2 miles in total length, in contrast to an 8-mile mainline route. The alternate route is a single lane with no traffic control of any sort on the link. There was no background traffic on the diversion route. Only traffic diverting from the mainline used the road. This simulation is intended to represent a rural case, where drivers would not have detailed knowledge of alternate routes. Many past deployments of SWZs have occurred in these areas. In urban locations with recurrent congestion, many drivers would likely be able to determine alternate routes, even without input from the SWZ.

A two-lane directional freeway segment with a single lane closure was examined. The right lane was closed, and traffic was diverted approximately 5 miles in advance of the lane closure and merged back on to the mainline approximately 1 mile after the lane closure. Desired speeds on the mainline route were normally distributed with a mean of 65 mph and a standard deviation of 5 mph.

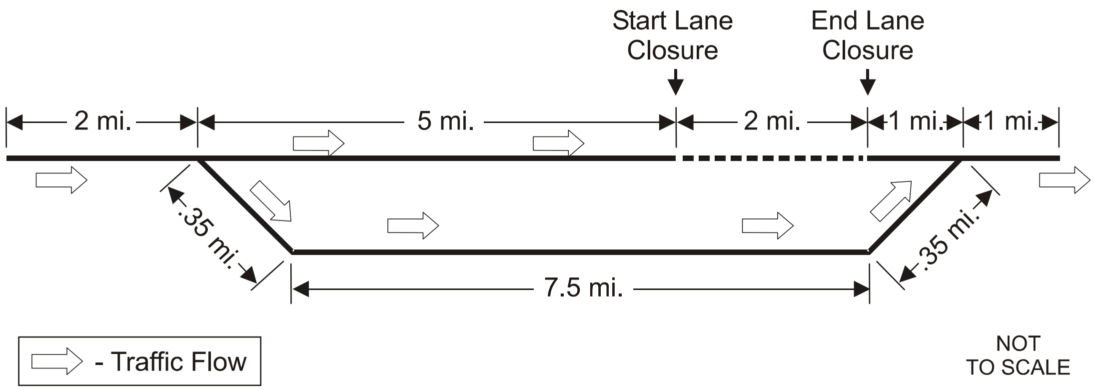

FIGURE 2 Simulation network schematic.

The roadway network was calibrated to the average capacity values listed in the *Highway Capacity Manual* (*17*). The average capacity of the two-to-one lane closure was 1,420 vph, which is consistent with the capacities reported by Dudek and Richards in a study of urban work zone capacities (*18*). Lane direction decisions and driver behavior values in the VISSIM model were modified to ensure that capacity values appropriate for the simulation were consistently reached.

Three factors were examined to determine their role in system performance: diversion rate, traffic volumes, and alternate route speed.

1. Diversion rate. Three different diversion scenarios were tested: (1) a no diversion case, (2) a 5 percent diversion case, and (3) a 15 percent diversion case. These levels were derived from the observed diversion percentages found in prior tests of SWZs. These are intended to represent situations where (1) no SWZ is in place, (2) where travel time information is provided but (a) no specific diversion information is presented or (b) the diversion route is not apparent, and (3) a best case scenario where a diversion route is obvious or specific route information is provided.

2. Traffic volumes. The daily traffic distributions from major freeway facilities in the Northern Virginia suburbs of Washington, D.C., were examined to determine an average distribution of annual average daily traffic (AADT) by hour throughout the day. These data were derived from permanent count stations in place on these freeway facilities. This was done so that a realistic hourly distribution of traffic volumes for an urban area could be applied to look at the potential performance of an SWZ over the course of a day. This synthesis of traffic volumes produced the distribution shown in Figure 3.

Different AADT values were examined so that the performance of the SWZ could be observed under different demand conditions. These AADTs were then multiplied by the volume distribution to determine the vehicle demand per hour. The network was simulated for an entire 24-hour period so that the total impact of the queue building and dissipating could be captured. Only those time periods when the demand for the no diversion case was over capacity were examined when deriving B/C estimates, since the SWZ would not provide any operational benefit during uncongested periods. In other words, if the no diversion case was congested between 5 and 7 PM, only the corresponding periods were examined in the diversion cases. In all cases, 5 percent of the traffic was assumed to be large trucks, which is consistent with many urban freeways. Table 1 summarizes the conditions examined.

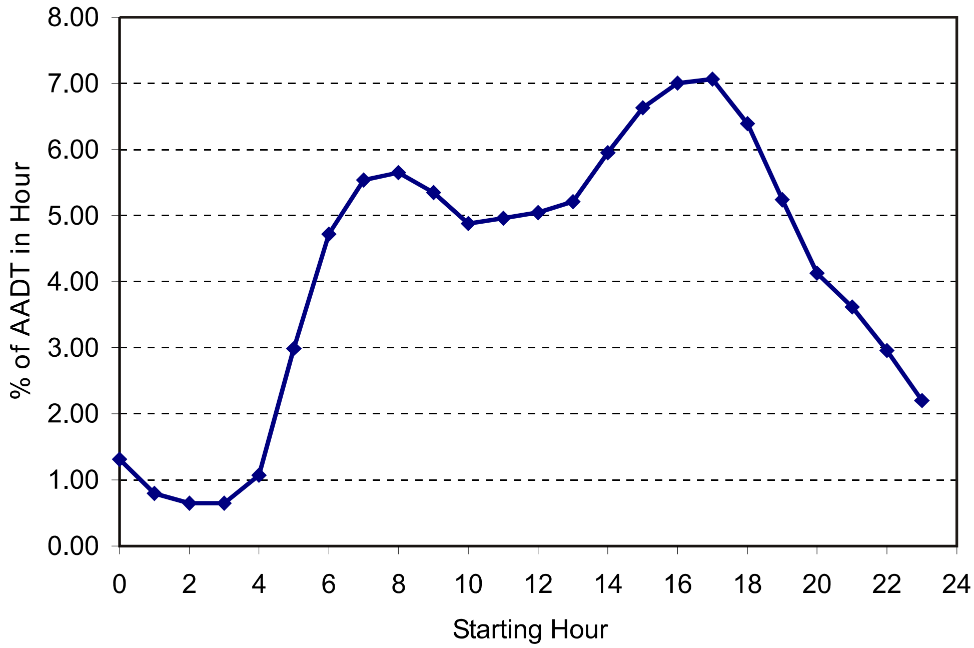

FIGURE 3 Assumed daily distribution of traffic.

TABLE 1 Traffic Demand Volume Scenarios Examined

AADT	**No. of Hours Where Demand > Capacity**	**Peak Hour Volume (vph)**	**Peak Hour Volume to Capacity Ratio**
21,225	2	1500	1.06
22,650	4	1600	1.13
24,050	5	1700	1.20
25,450	6	1800	1.27

3. Alternate route speed. Two alternate route speeds were evaluated: a mean speed of 25 mph and a mean speed of 35 mph. Obviously, there are infinite combinations of potential traffic control, lane geometry, and traffic volumes on the alternate route. By using a homogenous route with a single desired speed, it should be possible to extend the results of this simulation to other situations where mean speeds are similar, regardless of the actual traffic control.

Each discrete combination of variables was simulated using 5 random number seeds. This produced a total of 120 simulation runs (3 diversion rates × 4 traffic volumes × 2 alternate route speeds × 5 random seeds). The results from each random number seed were averaged to produce an average result for each of the 24 combinations of variables.

Measures of Effectiveness

The simulations were used to capture the total system travel time in the network, which is the sum of travel times of all vehicles in the network (including both, vehicles that stayed on the mainline and those that diverted to the alternate route). The potential benefits of the SWZ system were assessed by calculating the system wide travel time savings that were produced by the SWZ system during periods where there was a standing queue in the no diversion case. Thus, the total system travel time during the congested periods for the no diversion case was compared to the total system travel time in the corresponding periods for the various diversion scenarios. This provided an indication of the net travel time savings for each scenario.

The next step was to take these travel time savings and assess the potential benefit/cost (B/C) ratio of deploying an SWZ under various scenarios. A value of time of $15.14 per hour was used, which was based on the value used in the Texas Transportation Institute's *2005 Urban Mobility Report* adjusted for inflation to 2006 dollars (*19)*. Costs for SWZ systems recently deployed in North Carolina varied between $150,000 and $300,000 in initial capital costs (*20*). Using these data, it should be possible to determine combinations of project durations, traffic conditions, and system costs to develop some guidelines for situations where SWZ systems provide a B/C > 1.0.

Guidelines for Deploying SWZ

The results of the simulations were processed to determine the approximate number of days that an SWZ would need to be in operation before the accrued delay savings would justify the initial cost of the system. Table 2 summarizes the results of the analysis for the different combinations of traffic variables and potential system costs. Several interesting trends emerge from the data. For cases where the peak hour volume just surpasses the capacity of the lane closure, a 5 percent diversion rate actually provides the best performance in terms of improvements in overall system delay. This lower level of diversion causes just enough drivers to seek the alternate route to cause mainline demand to fall below the lance closure capacity. The higher 15 percent level of diversion diverts so much traffic to the alternate route that the lower travel speeds on the alternate route actually lead to worse overall performance on the network. At a peak hour flow of 1,600 vph and above, delay savings are maximized by diverting more traffic, although the alternate route remained under capacity in all cases.

Table 2 provides an indication of the potential duration of deployment that would be required to justify the installation of an SWZ. For the case with a 1,500 vph peak flow, the SWZ would need to be in place during congested conditions between 30 and 120 days for the B/C to at least equal 1.0. For the higher volume cases, the potential breakeven point occurs much sooner. It should be noted that the days listed in Table 2 represented days of operation during congested conditions. If a site is not congested during the weekends, the actual duration of the work zone would need to be adjusted upward.

TABLE 2 SWZ B/C Breakeven Duration

Peak Hour Volume (vph)	Diversion %	Alternate Route Speed (mph)	Daily Travel Time Savings (veh-hr)	Days in Operation Until B/C > 1.0			
				$150,000*	$200,000	$250,000	$300,000
1,500	5	25	164.4	61	81	101	121
	5	35	272.1	37	49	61	73
	15	25	No travel time savings				
	15	35	196.1	51	68	85	102
1,600	5	25	738.0	14	18	23	27
	5	35	836.2	12	16	20	24
	15	25	786.6	13	17	21	26
	15	35	1206.3	9	11	14	17
1,700	5	25	1502.4	7	9	11	14
	5	35	1661.9	6	8	10	12
	15	25	2467.8	5	6	7	9
	15	35	3054.4	4	5	6	7
1,800	5	25	2262.5	5	6	8	9
	5	35	2517.9	4	5	7	8
	15	25	4362.6	3	4	4	5
	15	35	5221.4	2	3	4	4

[a]Capital costs for SWZ

An alternative way of looking at the potential B/C ratios for SWZs is to examine the ultimate B/C achieved for a fixed project duration and cost assumptions. A short 30-day timeframe and a longer term 150-day duration were examined. SWZ cost figures of $150,000 and $300,000 were used. Table 3 shows that SWZs cannot be justified based on operational improvements for projects of short duration where the peak volume is just over the capacity of the work zone. B/C ratios increase substantially as the level of congestion increases.

TABLE 3 B/C Ratios for 30- and 150-Day Project Durations

Peak Hour Volume (vph)	Diversion %	Alternate Route Speed (mph)	$150,000 Initial Cost		$300,000 Initial Cost	
			30 Day B/C	150 Day B/C	30 Day B/C	150 Day B/C
1,500	5	25	0.5	2.5	0.2	1.2
	5	35	0.8	4.1	0.4	2.1
	15	25	No travel time savings			
	15	35	0.6	3.0	0.3	1.5
1,600	5	25	2.2	11.2	1.1	5.6
	5	35	2.5	12.7	1.3	6.3
	15	25	2.4	11.9	1.2	6.0
	15	35	3.7	18.3	1.8	9.1
1,700	5	25	4.5	22.7	2.3	11.4
	5	35	5.0	25.2	2.5	12.6
	15	25	7.5	37.4	3.7	18.7
	15	35	9.2	46.2	4.6	23.1
1,800	5	25	6.9	34.3	3.4	17.1
	5	35	7.6	38.1	3.8	19.1
	15	25	13.2	66.0	6.6	33.0
	15	35	15.8	79.1	7.9	39.5

The preceding data give an indication of the levels of benefits that could be achieved by using an SWZ. The results are network specific but could be used to help educate decision makers on the potential benefits of deploying SWZ technology. Before a final deployment decision is made, it is recommended that the agency perform a study of the specific site being considered using appropriate diversion assumptions.

CONCLUSIONS

Some systematic trends in the performance of SWZ systems are apparent from deployments, allowing for general guidelines to be developed. The operational impacts of SWZ systems appear to be reasonably consistent although the potential safety impacts have not been defined so well. There appears to be a need to develop some systematic methodologies for how SWZ systems should be evaluated so that the results can be transferred to other situations.

From a purely operational standpoint, the potential savings in delay that can be created by using an SWZ system can create a situation where the B/C ratio exceeds 1.0 in a short period of time. Although the results presented in this paper provide an indication of likely benefits, agencies considering deploying a system should conduct their own, site-specific analysis using reasonable assumptions of diversion. Agencies should also recognize that although it is likely that these systems will produce safety benefits, there are insufficient data available to quantify any trends in safety improvement.

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