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Evaluation of New Simplified Dynamic Lane Merging Systems (SDLMS) for Short-Term Work Zone Lane Closure Configuration

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ABSTRACT

To improve traffic safety and mobility in work zone areas, the Dynamic Lane Merge (DLM) systems, intelligent work zone traffic control systems, have been explored by several states of the U.S.A. The DLM can take two forms; dynamic early merge and dynamic late merge. The DLM systems were designed to advise drivers on definite merging locations. Up to date, there are no studies that contrast both merging schemes in the field under matching work zone settings. This study suggests two Simplified Dynamic Lane Merging Systems (SDLMS) (early merge and late merge) to supplement the current Florida Maintenance Of Traffic (MOT) plans for a three-to-two- work zone lane closure configuration. Data was collected in work zones on I-95, Florida for three different maintenance of traffic plan treatments. The first maintenance of traffic plan treatment was the standard MOT plan employed by FDOT. The second MOT was the early SDLMS and the third MOT was the late SDLMS. Results showed that dynamic early merging (early SDLMS) outperforms late SDLMS and the conventional Florida MOT plans under lower demand volumes. However, results also showed that late SDLMS outperforms early SDLMS and MAS under higher demand volumes.

KEYWORDS: Dynamic early merge, Dynamic late merge, Work zone, Intelligent transportation system, Lane management.

INTRODUCTION

Traffic safety and efficiency of roadway work zones have been considered among the major concerns in highway traffic operations in Florida. Due to the capacity diminution resulting from lane closures, congestion will occur in the midst of high traffic demand. Furthermore, the binding merging to the open lane(s) augments the number and possibly the severity of traffic conflicts. Consequently, work zones became a challenge for traffic safety and operation engineers.

To improve traffic safety and mobility in work zone areas, the Dynamic Lane Merge (DLM) systems, intelligent work zone traffic control systems, have been explored by several states of the U.S.A. The DLM can take two forms; dynamic early merge and dynamic late merge (See Figure 1). The dynamic aspect of DLM systems allows them to respond to real-time traffic changes *via* traffic sensors.

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Dynamic Early Merging

The idea behind the dynamic early merge is to create a dynamic no-passing zone to encourage drivers to merge into the open lane before reaching the end of a queue and to prohibit them from using the closed lane to pass vehicles in the queue and merge into the open lane ahead of them (Tarko et al., 2001). As shown in Figure 1, a typical early merge DLM system consists of queue detectors and “DO NOT PASS WHEN FLASHING” signs that would be triggered by the queue detectors. When a queue is detected next to a sign, the next closest sign’s flashing strobes, upstream, are activated creating the no-passing zone (Tarko et al., 1998).

The early DLM, identified initially as the Indiana Lane Merge System (ILMS), was tested in the 1997 construction season by the Indiana Department of Transportation. Results showed that the system smoothes the merging operations in advance of the lane closures. Drivers merged when they were supposed to merge, the flow in the open lane was uniform and rear-end accident rates decreased. However, this system did not increase the throughput. The results of a simulation study conducted by Purdue University indicated that travel times through work zones with ILMS are longer than travel times with the traditional system (Tarko et al., 1998).

The ILMS was also studied by Purdue University on I-65 near West Lafayette, Indiana. This project entailed extensive data collection under both congested and uncongested conditions for a duration of four months in 1999. The results of the analysis showed that the ILMS decreases the capacity by 5%. The authors mentioned that the decline in the capacity may be due to the unfamiliarity of the drivers with the system (Tarko et al., 2001).

The Wayne State University conducted a study to assess the ILMS, commonly referred to as Michigan Lane Merge Traffic Control System (LMTCS). According to their results, the ILMS (or LMTCS) increased the average operating speed, decreased the delays (49 vehicle hours of delay per hour) and decreased the number of aggressive driving maneuvers during peak hours (from 73 to 33) (Wayne State University, 2001) when compared to the traditional work zone traffic control system.

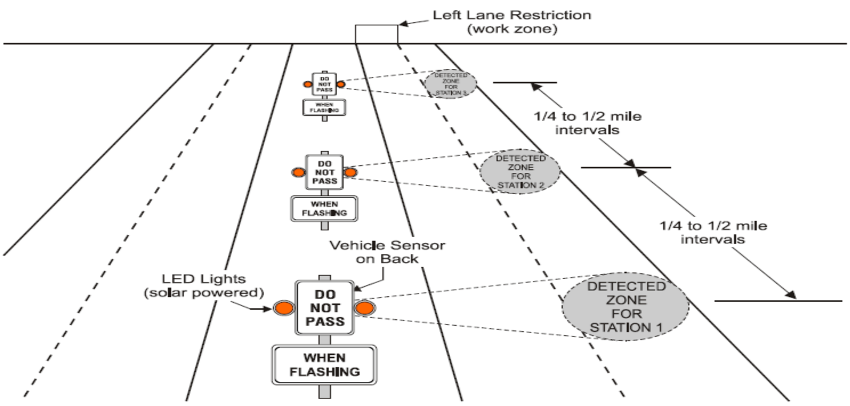
Dynamic Late Merging

The concept behind late merging is to make more efficient use of roadway storage space by allowing drivers to use all available traffic lanes to the merge point. Once the merge point is reached, the drivers in each lane take turns proceeding through the work-zone (Beacher et al., 2004). As shown in Figure 1, a typical dynamic late merge system consists of several Portable Changeable Message Signs (PCMSs) that would be activated under certain traffic conditions to display “USE BOTH LANES TO MERGE POINT” and a PCMS at the taper advising drivers to “TAKE TURNS/ MERGE HERE”.

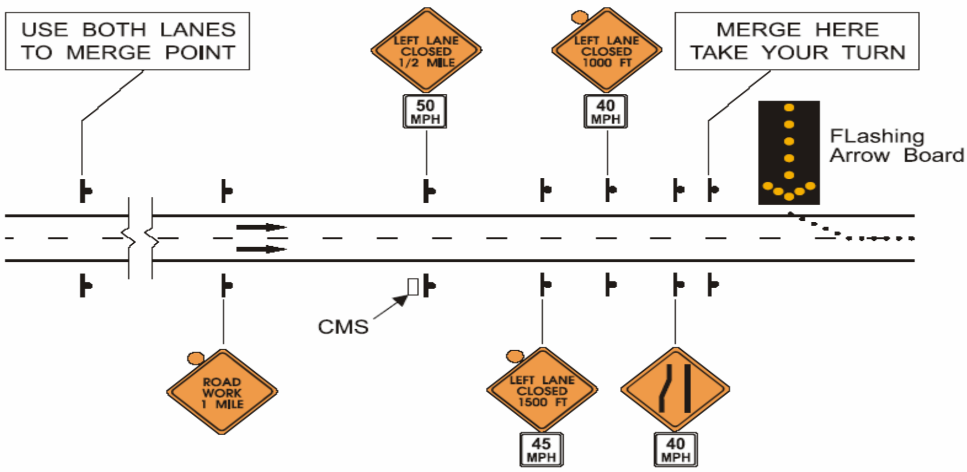
The late merge form of the DLM was also subject of various studies. McCoy and Pesti (2001) proposed a dynamic late merge in an effort to reduce congestions and delays (Beacher et al., 2004). Beacher et al. (2004) applied the dynamic late merge system in Tappahannock, Virginia and conducted a before and an after study to explore the benefits of the system. According to their results, the throughput volumes showed no statistical differences between the MUTCD treatment and the dynamic late merge treatment which was related to the low percentages of heavy vehicles (McCoy et al., 2001).

The University of Kansas, in cooperation with the Kansas Department of Transportation and the Scientex Corporation, deployed the Construction Area Late Merge (CALM) system in Kansas (Meyer, 2004). The results showed that the average volume through the work zone was enhanced after the drivers were accustomed with the system. However, the net change in volume did not show a significant improvement over baseline values.

The University of Maryland, College Park also compared the late merge DLM system to the standard static traffic control signs. The results showed that queue lengths were reduced and throughputs were increased (An Applied Technology, 2006).



Dynamic Early Merge (Source: Grillo et al., 2008)



PennDOT's Late Merge Concept (Beacher et al., 2004)

Figure 1: Dynamic early merge and dynamic late merge systems

The Minnesota Department of Transportation (MnDOT) tested the dynamic late merge system and showed that typical queue lengths and throughputs decreased compared with the regular traffic control. The MnDOT recommended the late merge DLM for volumes exceeding 1,500vph (URS, 2003; URS, 2004).

Grillo et al. (2008) deployed the dynamic late merge system, referred to as Dynamic Late Lane Merge System (DLLMS), on I-94 in the state of Michigan. Their results indicated that compared to the conventional work zone system, the DLLMS improved the flow of travel and that the monetary benefits of DLLMS outweighed the cost of the system (Grillo et al., 2008). Table 1 summarizes the advantages and disadvantages of the dynamic early merging and dynamic late merging shown in the literature review.

Table 1. Literature summary

Dynamic Late Merge		Dynamic Early Merge	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Work-zone throughputs increased (*An applied technology,2006*)	No difference in time in queue when truck percentage is lower than 20% (*Beacher et al., 2004*)	Smoothes the merging operations in advance of a lane closure (*Tarko et al., 1998*)	Travel times through work-zones are larger (*Tarko, 1998*)
Queue length decreased by 8% to 33% (*An applied technology,2006*)	No difference in the throughput volume when truck percentage is lower than 20% (*Beacher et al., 2004*)	Rear-end Accident rates decreased (*Tarko et al.,1998*)	Decrease capacity by 5% (*Tarko and Venugopal, 2001*)
Reduced queue length (*URS, 2003; URS,2004*)	No signinicant improvement in net volume (Meyer et al., 2004)	Decrease delays (*Wayne State University, 2001*)	Unfamiliarity and confusion of the drivers with the systems (*Tarko and Venugopal, 2001*)
Enhance the overall driving condition upstream of the lane closure (*URS, 2003; URS,2004*)	Increased stop and go at the taper point (*An applied technology, 2006*)	Decrease in number of forced merges (*Wayne State University, 2001*)	
Improvement in the flow of travel (*Grillo et al., 2008*)			

Study Motivations and Objectives

The Florida Department of Transportation (FDOT) addressed their interest in incorporating and testing an ITS-based lane management system into their existing Maintenance Of Traffic (MOT) plans for short-term movable wok zones (e.g. milling and resurfacing jobs). Previous dynamic lane merging systems, as shown in the literature review section of this study, comprise several Portable Changeable Message Signs (or other forms of dynamic message signs) and traffic sensors. The addition of multiple PCMSs to the current FDOT MOT plans may encumber the latter. Moreover, previously deployed DLM systems (dynamic early merge systems and dynamic late merge systems) may require relatively extensive equipment installation and relocation which could be inefficient for short-term movable work zones (moving on average every 7 to 10 hours). Furthermore, up to date, literature lacks comparison amongst the dynamic lane merging schemes in the field under the same work zone settings. Therefore, two forms of dynamic lane merging; namely two Simplified Dynamic Lane Merging Systems (SDLMS), are suggested for deployment and testing on short-term work zones. The first SDLMS is a simplified dynamic early merge system (early SDLMS) and the second SDLMS is a simplified dynamic late merge system (late SDLMS). The following sections elaborate further on the two suggested forms of SDLMS. This study aims at comparing the effectiveness of both forms of SDLMS to the conventional MOT plans deployed by FDOT.

Simplified Dynamic Lane Merging Systems

Florida Maintenance of Traffic Plan: Motorist Awareness System (MAS)

Currently, the Florida Department of Transportation deploys an MOT plan known as the Motorist Awareness System (MAS). According to the Florida Plans Preparation Manual (PPM), the Motorist Awareness System (MAS) aims at increasing the motorist awareness of the presence of active work and at

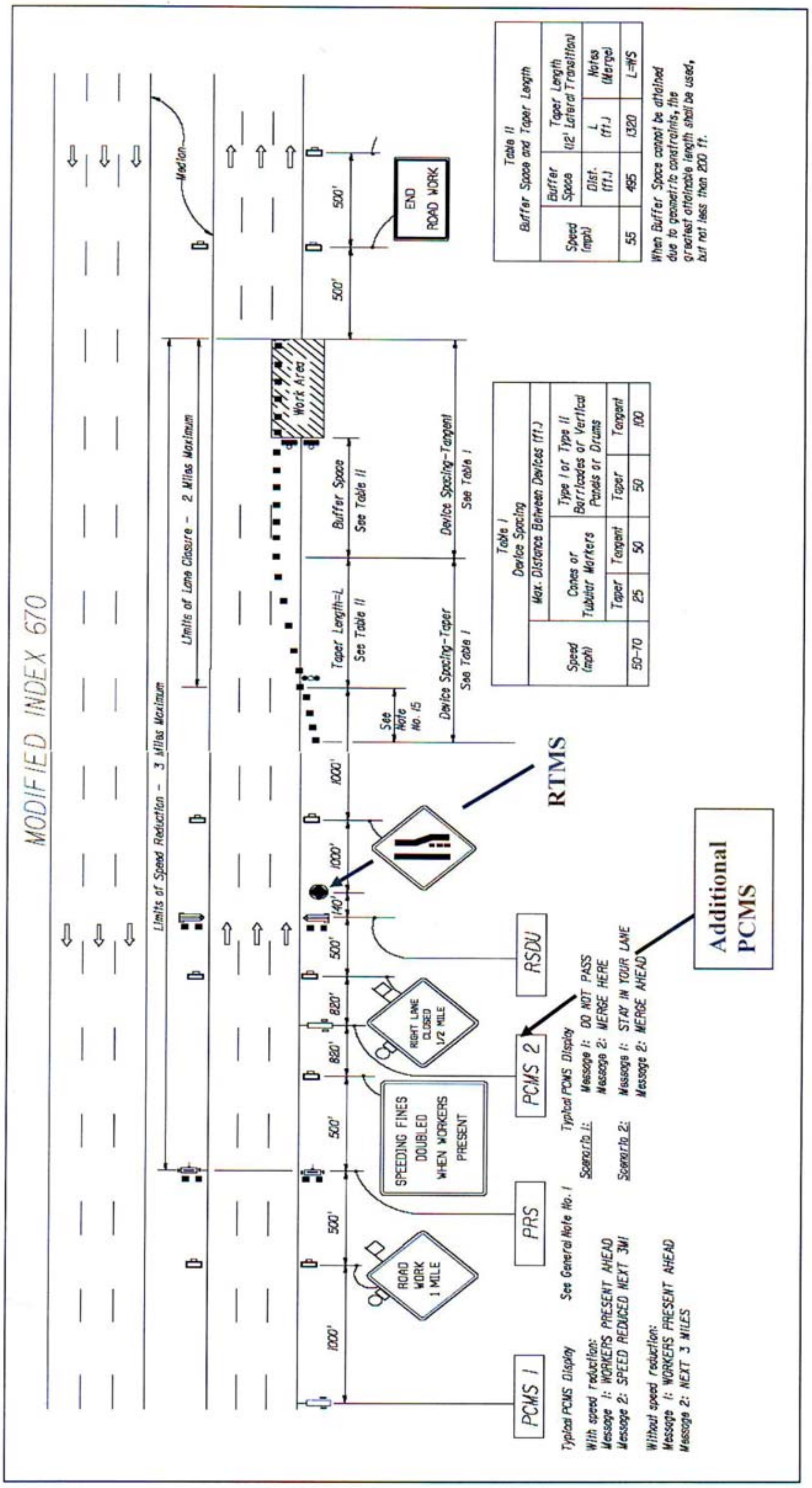


Figure 2: Motorist awareness system (MAS) in Florida and modifications

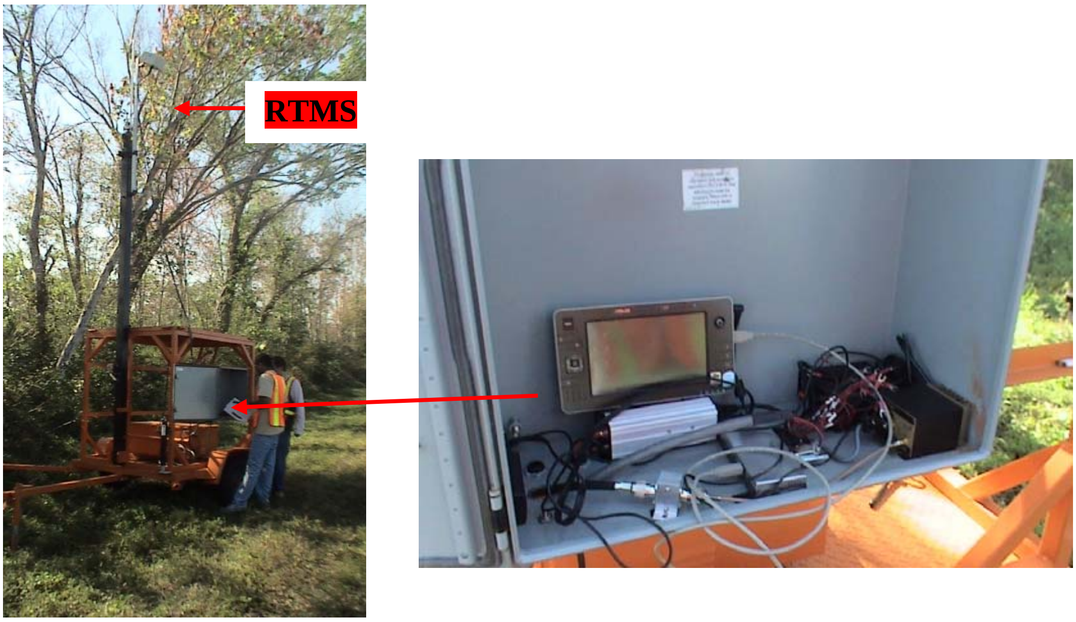


Figure 3: Traffic detection station

providing emphasis on reduced speed limits in the active work area. The Florida PPM states that the MAS shall be used on multilane facilities, where the posted speed limit is 55mph or greater and where work activity requires a lane closure for more than five days only when workers are present. The MAS, as shown in Figure 2 (excluding the additional PCMS and the RTMS), consists of Portable Regulatory Signs (PRS) highlighting the regulatory speed for the work zone and a Radar Speed Display Unit (RSDU) displaying the motorist's work zone speed. The MAS also comprises a Portable Changeable Message Sign (PCMS), a lane drop warning sign, a speeding fines doubled warning sign, in addition to road work ahead warning signs (FDOT, 2008).

Modified MOT/MAS Plans

The modified MAS plans, as mentioned earlier, consists of the addition of an ITS-based lane management system to the conventional MAS. Two modified MAS plans (early SDLMS and late SDLMS) are suggested. The first modified MAS plan is a simplified dynamic early merge system and the second modified MAS plan is a simplified dynamic late merge system. Therefore, the conventional MAS plans are supplemented with one Portable Changeable Message Sign (PCMS) and a non-intrusive sensor (Remote Traffic Microwave Sensor, RTMS) trailer as shown in Figure 2. The modified MAS plan is referred to in this paper as Simplified Dynamic Lane Merge System (SDLMS). The additional PCMS and sensor trailer are placed at the same location in both modified MAS plans. The messages displayed by the PCMS will differ as elaborated on in the next section. The modified MOT plans were signed and sealed by a Florida licensed consultant.

SDLMS Operation

The SDLMS operation is based on real-time speed data acquired from the traffic detection zones with each data sample (time-stamped over 2 minutes) to indicate currency of the message displayed. The RTMS collects the average speed of the vehicles passing through the detection zones over 2-minute time intervals. The SDLMS operates under two modes; the passive mode and the active mode. Under the passive mode, the additional PCMS is set to display a flashing "CAUTION/CAUTION" message for both the early and the late SDLMS. Under the active mode, the PCMS displays "DO NOT PASS" followed by "MERGE HERE" alternately for the early SDLMS and "STAY IN YOUR LANE' followed by "MERGE AHEAD" alternately for the late SDLMS. The early and late SDLMS are activated once the average speed over any 2-minute time interval drops below 50mph. The SDLMS will be deactivated (passive mode) once the average speed over the next time stamp goes over 50 mph. It should also be noted that the minimum activation time of the PCMS was set at 5 minutes.

Figure 4: Data collection site

SDLMS equipment

The Simplified Dynamic Lane Merge System (SDLMS) consists of supplementing the Motorist Awareness System (MAS) with a traffic sensor trailer and a Portable Changeable Message Sign (PCMS). International Road Dynamics (IRD, Inc.) provided the components of the proposed SDLMS comprising the following:

- **One traffic detection station** (See Figure 3), namely the sensor trailer, wirelessly linked to central computer base station. The traffic sensor is an RTMS (Remote Traffic Microwave Sensor) sensor. Remote Traffic Microwave Sensors are radar-based, non-intrusive advanced sensors. RTMS can collect the per-lane presence, volume, vehicle classification, occupancy and speed in up to 8 user-defined detection zones.
- **Central computer base station** environmentally hardened and equipped with appropriate software and dedicated wireless communications to "link" with the traffic sensor station and the PCMS. The computer base station is housed in a standard weather proof traffic-signal control cabinet.
- **Wireless communication links** consisting of Road-

side Remote Stations (RRS), duly equipped with radio modems (for transmitting and receiving licensed UHF radio frequencies), micro- processors and antennae.

The additional Portable Changeable Message Sign (PCMS), provided by FDOT, is remotely controlled *via* a central computer base station or Central System Controller (CSC). The SDLMS communications system incorporates an error detection/correction mechanism to ensure the integrity of all traffic conditions data and motorist information messages.

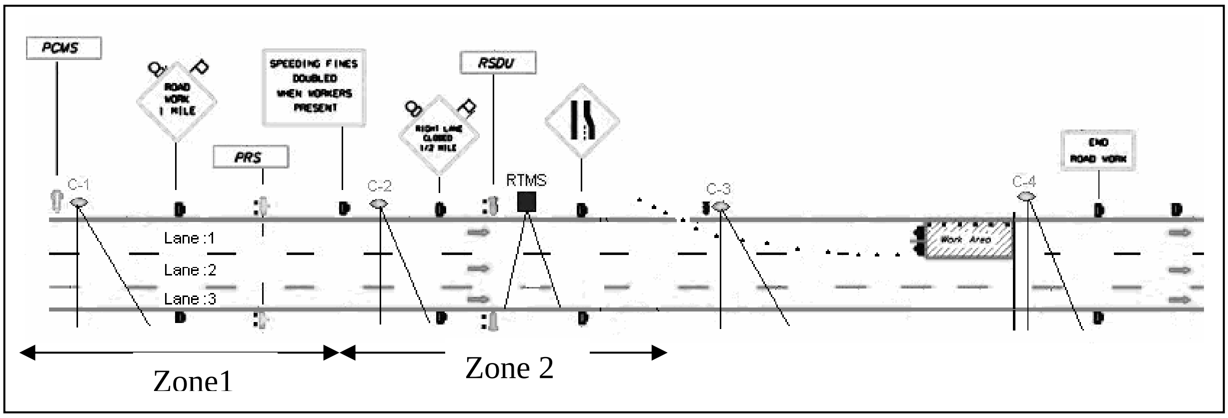


Figure 5: Data collection equipment location

Data Collection

Data Collection Site

The selected site was located on Interstate-95 in Palm Beach, Florida as shown in Figure 4. At that location, I-95 consisted of three -lane per direction urban freeway with 60mph speed limit (reduced to 50 mph during the work). The work zone consisted of a resurfacing and milling job on the south bound of I-95 on an 18 mile stretch. A three-to-two lane closure configuration was adopted and the work zone was moved on a daily basis covering a length of approximately three miles per day. Data was collected on homogenous basic freeway segment of I-95 with no on/off ramps.

Data Collection and Extraction

Four digital camcorders were set in the field labeled C-1, C-2, C-3 and C-4 as shown in Figure 5. To synchronize the camcorders spatially (i.e. upon daily relocation), C-1 was always located behind the first PCMS, C-2 was always located behind the lane drop static signs, C-3 was always located behind the arrow panel and C-4 was always located at the end of the lane closure. All 4 camcorders were started at the same time to synchronize the temporal events and flow of vehicles. Data was collected on the same site for the MAS, early SDLMS and late SDLMS for two days each. From C-1, C-2, C-3 and C-4, per-lane vehicle counts including vehicle classification were extracted in 5 minute intervals in the laboratory. The zone between C-1 and C-2 is identified as zone 1 and the zone between C-2 and C-3 is identified as zone 2. The difference between the vehicle counts (including vehicle classification) in the closed lane between C-1 and C-2 is the number of lane changes made in zone 1. The remaining vehicle counts (including vehicle classification) remaining in the closed lane at C-2 are the number of lane changes in zone 2.

The RTMS was temporally synchronized with C-1, C-2, C-3 and C-4 and the PCMS activation time (recorded by the RTMS) was extracted and concatenated temporally to the vehicle count data. From

Table 2. Data summary statistics

MOT Type	Variable	Unit	Minimum	Maximum	Mean	Std. Deviation
Conventional MAS	Demand Volume	Veh/hr	270	2730.00	1064.87	488.58
	Throughput	Veh/hr	120	2580.00	911.92	467.40
	Truck %	N/A	0	50.00	11.30	10.78
	% Car Lane Change Z1	N/A	0	100.00	52.08	28.39
	% TRK Lane Change Z1	N/A	0	100.00	60.68	41.59
	Ratio (Throughput/Demand)	N/A	0	1.00	0.86	0.20
Early SDLMS	Demand Volume	Veh/hr	230	1890.00	763.96	377.49
	Throughput	Veh/hr	120	1530.00	713.17	406.63
	Truck %	N/A	0	74.00	17.84	19.09
	% Car Lane Change Z1	N/A	0	100.00	59.55	30.98
	% TRK Lane Change Z1	N/A	0	100.00	66.34	35.43
	Ratio (Throughput/Demand)	N/A	0	1.00	0.87	0.21
Late SDLMS	Demand Volume	Veh/hr	180	3120.00	1209.06	577.11
	Throughput	Veh/hr	60	2940.00	1152.81	596.01
	Truck %	N/A	0	54.00	13.84	11.29
	% Car Lane Change Z1	N/A	0	100.00	46.35	34.24
	% TRK Lane Change Z1	N/A	0	100.00	38.21	37.38
	Ratio (Throughput/Demand)	N/A	0.15	1.00	0.86	0.18

C-1, the demand volume for the work zone was determined. From C-4, the throughput of the work zone was determined. Under the standard MAS configuration, data was collected from July 24th 2008 through July 29th 2008 (29 data hours). Under the early SDLMS, data was collected from July 30th 2008 through August 8th 2008 (30 data hours). Under the late SDLMS, data was collected from August 12th 2008 through August 15th 2008 (32 data hours). There were several difficulties engaged in the data collection process. In fact, for short-term moving work zones, there exist inherent logistic and operational difficulties. For instance, the work, hence data collection was cancelled and/or interrupted unexpectedly multiple times due to adverse weather conditions that are crucial for resurfacing and milling jobs. Work was also unexpectedly cancelled on several occasions without prior notice due to contractor-related logistic issues. Moreover, the freeway shoulders were narrower at some locations which made the installation of the SDLMS equipment almost impossible. It is recommended that a good communication/planning be established between the researcher team and the work zone crew (construction manager) for future data collection on short-term moving work zones.

Table 3. Parameter estimates under different demand volumes (dependent variable ratio of throughput over demand volume)

<table>
<tr><td rowspan="10">0-500 veh/hr (N=130)</td><td colspan="4">ANOVA AND PARAMETER ESTIMATES</td></tr>
<tr><td>Parameter</td><td>Estimate</td><td>Standard Error</td><td>Pr > |t|</td></tr>
<tr><td>Intercept</td><td>0.880</td><td>0.083</td><td><.0001</td></tr>
<tr><td>% Trucks</td><td>-0.088</td><td>0.149</td><td>0.558</td></tr>
<tr><td>% PC Lane Changing in Zone 1</td><td>-0.008</td><td>0.089</td><td>0.925</td></tr>
<tr><td>%TRK Lane Changing in Zone 1</td><td>0.032</td><td>0.070</td><td>0.653</td></tr>
<tr><td>Dynamic Late Merge</td><td>-0.234</td><td>0.083</td><td>0.006</td></tr>
<tr><td>Dynamic Early Merge</td><td>0.058</td><td>0.055</td><td>0.291</td></tr>
<tr><td>MAS</td><td>0</td><td>.</td><td>.</td></tr>
<tr><td colspan="4">R-Square=0.19</td></tr>
<tr><td rowspan="10">501-1000 veh/hr (N=150)</td><td colspan="4">ANOVA AND PARAMETER ESTIMATES</td></tr>
<tr><td>Parameter</td><td>Estimate</td><td>Standard Error</td><td>Pr > |t|</td></tr>
<tr><td>Intercept</td><td>0.627</td><td>0.056</td><td><.0001</td></tr>
<tr><td>% Trucks</td><td>-0.222</td><td>0.161</td><td>0.170</td></tr>
<tr><td>% PC Lane Changing in Zone 1</td><td>0.071</td><td>0.064</td><td>0.269</td></tr>
<tr><td>%TRK Lane Changing in Zone 1</td><td>0.187</td><td>0.048</td><td>0.0001</td></tr>
<tr><td>Dynamic Late Merge</td><td>0.082</td><td>0.050</td><td>0.102</td></tr>
<tr><td>Dynamic Early Merge</td><td>0.133</td><td>0.054</td><td>0.014</td></tr>
<tr><td>MAS</td><td>0</td><td>.</td><td>.</td></tr>
<tr><td colspan="4">R-Square=0.22</td></tr>
<tr><td rowspan="10">1001-1500 veh/hr (N=235)</td><td colspan="4">ANOVA AND PARAMETER ESTIMATES</td></tr>
<tr><td>Parameter</td><td>Estimate</td><td>Standard Error</td><td>Pr > |t|</td></tr>
<tr><td>Intercept</td><td>0.652</td><td>0.054</td><td><.0001</td></tr>
<tr><td>% Trucks</td><td>-0.288</td><td>0.168</td><td>0.090</td></tr>
<tr><td>% PC Lane Changing in Zone 1</td><td>0.141</td><td>0.067</td><td>0.038</td></tr>
<tr><td>%TRK Lane Changing in Zone 1</td><td>0.104</td><td>0.044</td><td>0.018</td></tr>
<tr><td>Dynamic Late Merge</td><td>0.099</td><td>0.042</td><td>0.187</td></tr>
<tr><td>Dynamic Early Merge</td><td>0.029</td><td>0.053</td><td>0.059</td></tr>
<tr><td>MAS</td><td>0.000</td><td>.</td><td>.</td></tr>
<tr><td colspan="4">R-Square=0.203</td></tr>
<tr><td rowspan="10">1501-2000 veh/hr (N=250)</td><td colspan="4">ANOVA AND PARAMETER ESTIMATES</td></tr>
<tr><td>Parameter</td><td>Estimate</td><td>Standard Error</td><td>Pr > |t|</td></tr>
<tr><td>Intercept</td><td>0.523</td><td>0.074</td><td><.0001</td></tr>
<tr><td>% Trucks</td><td>0.004</td><td>0.292</td><td>0.988</td></tr>
<tr><td>% PC Lane Changing in Zone 1</td><td>0.166</td><td>0.081</td><td>0.044</td></tr>
<tr><td>%TRK Lane Changing in Zone 1</td><td>0.122</td><td>0.072</td><td>0.097</td></tr>
<tr><td>Dynamic Late Merge</td><td>0.204</td><td>0.063</td><td>0.002</td></tr>
<tr><td>Dynamic Early Merge</td><td>0.156</td><td>0.152</td><td>0.031</td></tr>
<tr><td>MAS</td><td>0.000</td><td>.</td><td>.</td></tr>
<tr><td colspan="4">R-Square=0.19</td></tr>
<tr><td rowspan="10">>2000 veh/hr (N=80)</td><td colspan="4">ANOVA AND PARAMETER ESTIMATES</td></tr>
<tr><td>Parameter</td><td>Estimate</td><td>Standard Error</td><td>Pr > |t|</td></tr>
<tr><td>Intercept</td><td>0.760</td><td>0.176</td><td>0.001</td></tr>
<tr><td>% Trucks</td><td>-3.068</td><td>1.020</td><td>0.010</td></tr>
<tr><td>% PC Lane Changing in Zone 1</td><td>0.043</td><td>0.152</td><td>0.782</td></tr>
<tr><td>%TRK Lane Changing in Zone 1</td><td>0.569</td><td>0.315</td><td>0.094</td></tr>
<tr><td>Dynamic Late Merge</td><td>0.203</td><td>0.176</td><td>0.271</td></tr>
<tr><td>Dynamic Early Merge</td><td>0.000</td><td>.</td><td>.</td></tr>
<tr><td>MAS</td><td>0.000</td><td>.</td><td>.</td></tr>
<tr><td colspan="4">R-Square=0.23</td></tr>
</table>

Data Analysis

Measure of Effectiveness

Roadway capacity in which a work zone is located is lower than the normal operating conditions. The impact of the early and late SDLMS on the work zone capacity is studied by comparing the capacity of the work zone under the MAS traffic (control) to the capacity of the work zone under the early SDLMS (test1) and late SDLMS (test 2). It should be noted that different researchers, as mentioned by Heaslip et al. (2007), have different definitions of work zone capacity. “Some researchers measured the mean queue discharge flow rate as work zone capacity when the upstream of work zones was in sustained congested traffic flow (Maze et al., 2000; Kermode et al., 1970; Dudek et al., 1981), while other researchers (Jiang, 1999; Dixon et al, 1999) defined the work zone capacity as the traffic flow at the onset of congested traffic conditions” (Ping et al., 2006). In this study, measure of effectiveness under the three different scenarios is determined as the queue discharge flow rate or throughput volume over the demand volume, whereas this ratio of these two entities consists the measure of effectiveness.

Extracted Data

Table 2 summarizes the variables taken into account to analyze the operational aspects of the work zone under three different regimes (MAS, early and late SDLMS). Extracted data resulted in 280, 260 and 305 observations for the MAS, early SDLMS and late SDLMS in that order. The maximum observed throughput for the work zone under the MAS system is 2,580 veh/hr. The maximum observed throughput under the dynamic early merge is 1530 veh/hr and the maximum observed throughput under the late merge is 2940 veh/hr. The mean throughputs were 911.92 veh/hr, 713.17 veh/hr and 1152.81 veh/hr for the MAS, early SDLMS and late SDLMS, respectively. It should be noted here that the demand volumes for the MAS and late SDLMS were higher than the demand volumes under the early SDLMS (See Table 2).

Five linear regression models (one for each demand volume level) were estimated to determine the effect of the truck percentages in the traffic composition, percent trucks lane changing in zone1, percent cars lane changing in zone 1 and MOT type on the throughput over demand volume of the work zone. Table 3 summarizes the parameter estimates and their significance on the ration of throughputs over demand volume under each demand volume level. Looking at the first estimated model in Table 3, where the demand volume ranges between 1 and 500 veh/hr, it was found that the dynamic late merge displays a significant (*p*-value=0.006) negative effect (parameter estimate= -0.234) compared to the MAS system. This indicates that under this range of demand volume (1-500 veh/hr), the MAS resulted in higher ratio of throughput over demand volume compared to the dynamic late merge system.

Looking at the second estimated model for demand volumes ranging between 501 and 1000 veh/hr, results showed that the percentage of trucks changing lanes in zone one has a significant positive effect on the ratios (parameter estimate = 0.187; *p*-value=0.0001). This indicates that the higher the percentage of trucks changing lane in zone 1 the higher the ratio (i.e. the throughput of the work zone). The same model shows that the dynamic early merge resulted in a significantly higher ratio of throughput over demand volume (parameter estimate = 0.133; *p*-value=0.014) compared to the MAS system.

For demand volume ranging between 1001 and 1500 veh/hr, the third estimated main effect model showed that the percentage of trucks changing lanes in zone 1 (parameter estimate = 0.104; *p*-value=0.018) and the percentage of passenger cars changing lanes in zone 1 (parameter estimate = 0.141; *p*-value=0.038) have a significant positive effect on throughputs. This means that when trucks and passenger cars changing lane in zone 1 increased, the ratio of throughputs over demand volume increased. The same model shows that the dynamic early merge resulted in significantly higher ratios (throughputs over demand volume) compared to the MAS system (parameter estimate = 0.029; *p*-value=0.059). The truck percentage in the traffic composition displays a marginal significance with the ration. In fact, the model shows that the lower the truck percentage in the traffic composition, the higher the ratios of throughputs over demand volume (parameter estimate = -.288; *p*-value=0.09).

For demand volume ranging between 1501 and 2000 veh/hr, the fourth estimated main effect model (see Table 2) showed that the percentage of passenger cars changing lanes in zone 1 (parameter estimate = 0.166; *p*-value=0.044) has a significant positive effect on throughputs. This means that when the passenger cars changing lane in zone 1 increased, the throughput increased. The same model shows that the dynamic early merge (parameter estimate =0.156; *p*-value=0.031) as well as the dynamic late merge (parameter estimate = 0.204; *p*-value=0.002) resulted in significantly higher ratios compared to the MAS system. This means that the dynamic early merge and the dynamic late merge resulted in higher ratios of throughput over demand volume compared to the MAS system under demand volumes ranging between 1501 and 2000 veh/hr.

CONCLUSIONS AND RECOMMENDATIONS

The Florida Department of Transportation expressed their interest in adding a lane management strategy to their existing Maintenance of Traffic MOT plans, known as the Motorist Awareness System (MAS), for short-term movable work zones. Since previous dynamic lane merging systems may be inefficient for short-term work zones when supplemented to the MAS system, and since the literature lacks a cross-comparison between dynamic early and dynamic late merging in the field, this study suggests two Simplified Dynamic Lane Merging Systems; early SDLMS and late SDLMS, for deployment and testing in the field.

The early and late forms of SDLMS consist of adding one sensor trailer and one PCMS to the existing MAS plans. The PCMS displays early merging advisory messages for the early SDLMS and late merge advisory messages for the late SDLMS. The locations of the sensor trailer and the additional PCMS remain the same for the early and the late SDLMS. The modified MOT plans were signed and sealed by a licensed Florida professional engineer. The SDLMS equipment was leased from International Road Dynamics (IRD, Inc.).

Data was collected on a work zone consisting of a resurfacing job on a thirteen mile stretch of I-95 Malabar, Florida. This section of I-95 is a rural limited access freeway. Data was collected on geometrically and environmentally homogenous segments of I-95 for the control (MAS) and test (early and late SDLMS) scenarios.

Work zone throughput under the control and test MOT plans was used as a measure of effectiveness to explore the impact of the early and late SDLMS on work zones. Five regression models were estimated to expose the effect of different MOT types on work zone throughputs under five demand volume levels.

Results showed that under lower volumes (lower than 500 veh/hr), the late SDLMS has the lowest performance in terms of throughput compared to the early SDLMS and the MAS. Under demand volumes ranging between 501 and 1500 veh/hr, the early SDLMS outperformed the MAS and the late SDLMS. Under volumes higher than 1500 veh/hr and lower than 2000 veh/hr, the late SDLMS outperformed the early SDLMS and the MAS. For volumes higher than 2000 veh/hr, the limited data size restricted our conclusions.

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