TWO SIMPLIFIED DYNAMIC LANE MERGING SYSTEM (SDLMS) FOR SHORT TERM WORK ZONES

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ABSTRACT

ITS-based lane management technologies were introduced to work zones in an attempt to reduce congestions and diminish queue lengths. Two forms of lane merging namely the early merge and the late merge were designed to advise drivers on definite merging locations. 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. 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 the maximum queue discharge rate (or capacity) of the work zone was significantly higher for the early SDLMS compared to the conventional FDOT MOT plans. The late SDLMS increased the work zone capacity; however, this increase was not statistically significant. Moreover, results showed that early merging rate was the highest for the early SDLMS and the lowest for the late SDLMS which suggests that some drivers are complying to the messages displayed by the system.

KEYWORDS

Dynamic Early Merge, Dynamic Late Merge, Work Zone, Intelligent Transportation System, Lane Management

INTRODUCTION

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

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 (*1*). 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 (*2*).

The concept behind late merge 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 (*3*). 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”.

In contrast to the static lane merging, the dynamic lane merging systems respond to real-time traffic changes via traffic sensors. The real-time traffic data acquired by the sensors is communicated to a central controller in a time-stamped manner. Then, appropriate algorithms determine whether to activate real-time lane merging messages to drivers based on preset traffic characteristics thresholds.

BACKGROUND

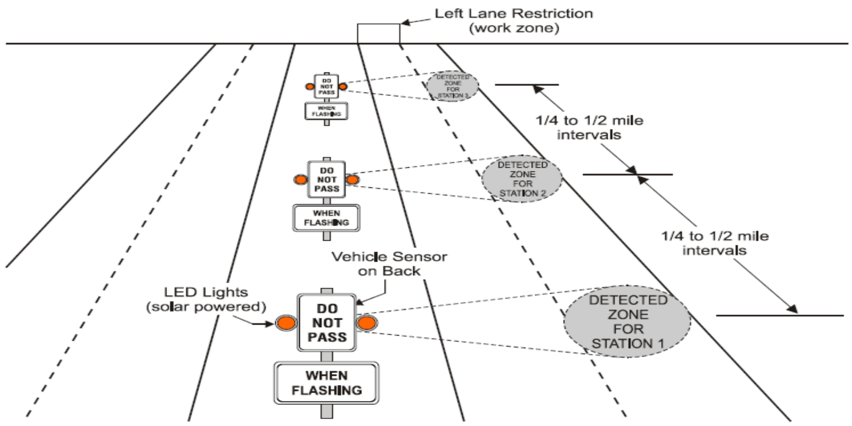
Dynamic Early Merging

The early merge form of the DLM system 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 larger than travel times with the traditional system (*2*).

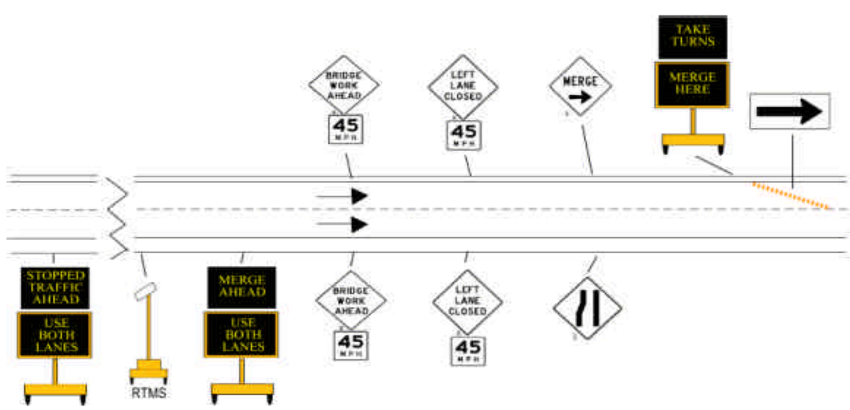
In 1999, the University of Nebraska conducted a study of the Indiana Lane Merge System (ILMS) on I-65 in the vicinity of Remington, Indiana. Comparing the ILMS with the standard MUTCD merge control, the results showed that the ILMS increased the capacity to from 1,460 vphpl to 1,540 vphpl (*4*).

The ILMS was also studied by Purdue University on I-65 near West Lafayette, Indiana. This project entailed extensive data collection under both congestion and uncongested conditions for a duration of four months in 1999. The results of the analyses 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 (*1*).

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) (*5*) when compared to the traditional work zone traffic control system.



Dynamic Early Merge **(Source: *6*)**



Dynamic Late Merge **(Minnesota DLM)**

Figure1: Dynamic early merge and dynamic late merge systems

Dynamic late Merging

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 (*3*). Beacher et al. (2004) applied the dynamic late merge system in Tappahannock, Virginia and conducted a before and after study to explore the benefits of the system. According to their results, the throughput volumes showed no statistical difference between the MUTCD treatment and the dynamic late merge treatment which was related to the low percentages of heavy vehicles (*6*).

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 (*7*). 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 increased (*8*).

The Minnesota Department of Transportation (MnDOT) tested the dynamic late merge system and showed that typical queue length and throughputs decreased compared with the regular traffic control. The MnDOT recommended the late merge DLM for volumes exceeding 1,500vph (*9, 10*).

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 outweigh the cost of the system (*11*).

STUDY MOTIVATION 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). Therefore, 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 the 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 SYSTEM

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 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, 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 (*12*).

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 3. 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 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 for 5 minutes.

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**, 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 for the detection and measurement of traffic on roadways. The 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.

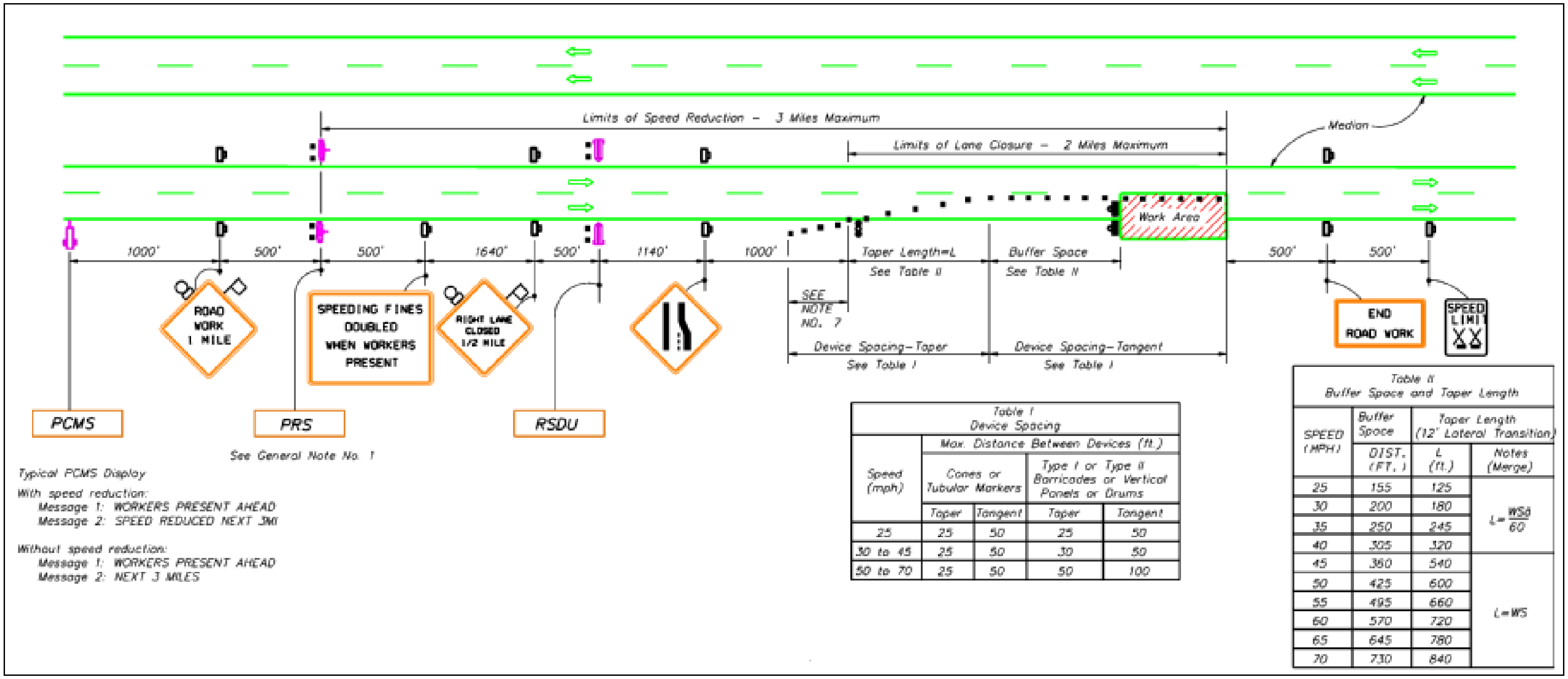


Table I
Device Spacing

Speed (mph)	Max. Distance Between Devices (ft.)			
	Cones or Tubular Markers		Type I or Type II Barricades or Vertical Panels or Drums	
	Taper	Tangent	Taper	Tangent
25	25	50	25	50
30 to 45	25	50	30	50
50 to 70	25	50	50	100

Table II
Buffer Space and Taper Length

SPEED (MPH)	Buffer Space	Taper Length (12' Lateral Transition)	
	DIST. (FT.)	L (ft.)	Notes (Merge)
25	155	125	$L = \frac{WS^2}{60}$
30	200	180	
35	250	245	
40	305	320	
45	360	540	L = WS
50	425	600	
55	495	660	
60	570	720	
65	645	780	
70	730	840	

Figure 2: Motorist Awareness System (MAS) in Florida (Index 670 FDOT-standards, *12*)

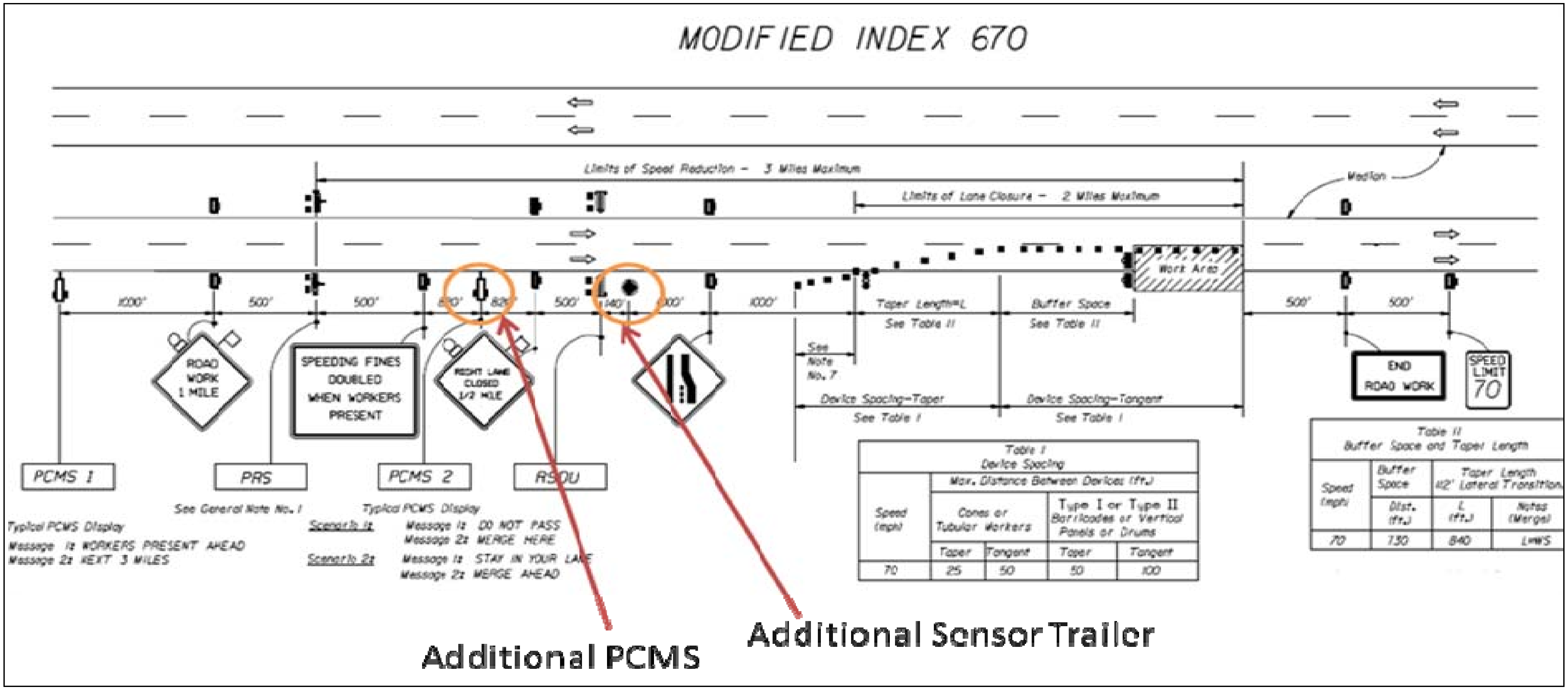


Figure 3: Modified Motorist Awareness System (MAS) in Florida

DATA COLLECTION

Data collection site

The selected site was located on Interstate-95 in Malabar, Florida as shown in Figure 4. I-95 is 2-lane per direction limited access rural freeway with 70mph speed limit (reduced to 60mph during work). The work zone consisted of a resurfacing and milling job on the south bound of I-95 on a 13 mile stretch. A 2 to 1 lane closure configuration was adopted and the work zone moved on a daily basis covering a length of approximately 3 miles per day. Data was collected on homogenous basic freeway segment of I-95 with no on/off ramps.

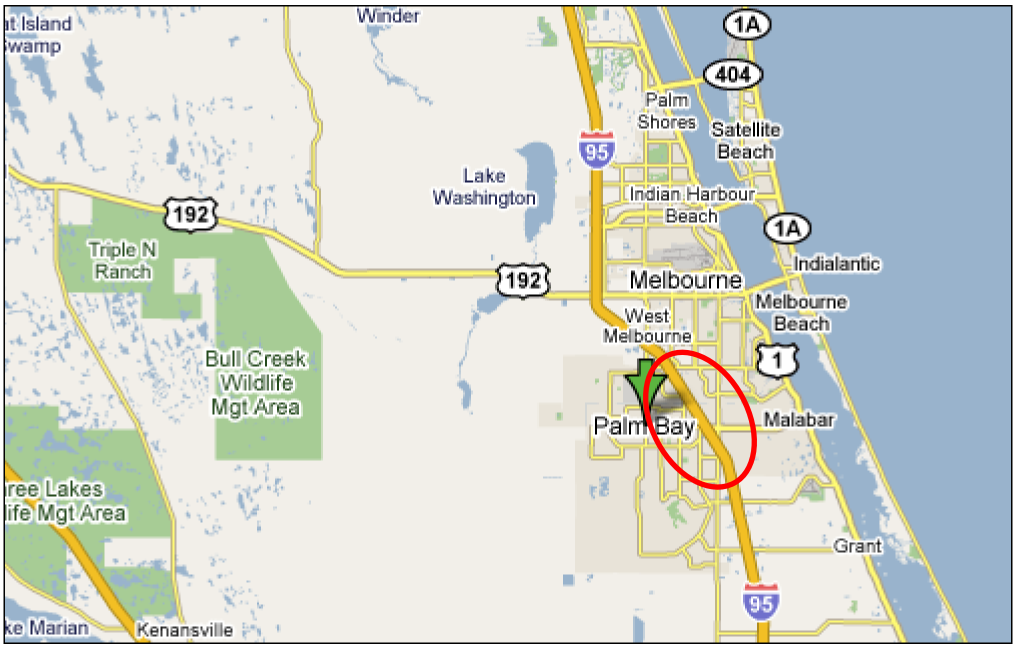


Figure 4: Data collection site

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 minutes 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 is the number of lane changes in zone 2.

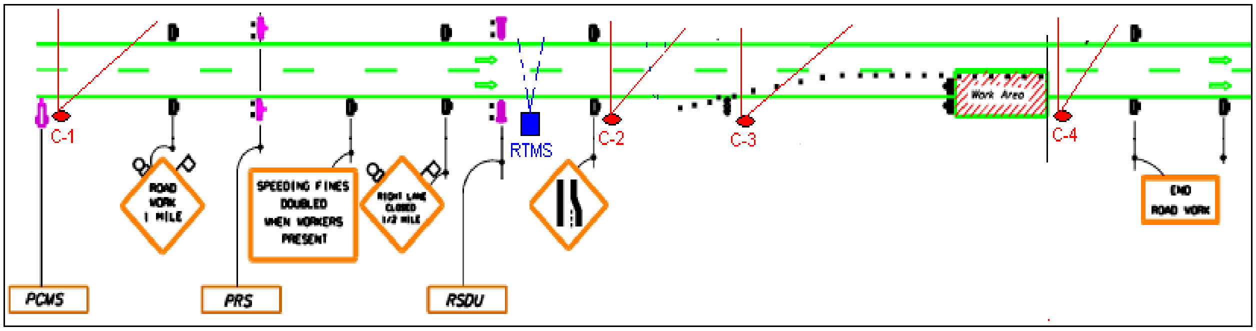


Figure 5: Data collection equipment location

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 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 on February 11th and 12th 2008, under the early SDLMS data was collected on March 17th and 18th 2008, and under the late SDLMS data was collected on March 27th and 28th, 2008. 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.

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 (test2). 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 (*14*, *15*, *16*), while other researchers (*17*, *18*) defined the work zone capacity as the traffic flow at the onset of congested traffic conditions" (*19*). In this study, the work zone capacity under the three different scenarios is determined as the queue discharge flow rate or throughput volume under queuing/congested conditions. The onset of congestion is determined by C-3 shown in Figure 5.

DATA ANALYSES

Table 1 summarizes the data extracted from C-1, C-2, C-3, and C-4. As shown by Table 1, the mean and maximum capacities of the early SDLMS are the highest among the three

MOT treatments. The mean and maximum capacities of the conventional MAS system are 881 veh/hr and 1092 veh/hr respectively. The mean and maximum capacities of the early SDLMS are 970 veh/hr and 1272 veh/hr correspondingly. The mean and maximum capacities of the late SDLMS are 896veh/hr and 1093 veh/hr in that order.

Table 1: Data summary statistics

MOT TYPE	Variable	Unit	Mean	Standard Deviation	Min.	Max.
Conventional MAS	Capacity	Veh/hr	881	120	624	1092
	Car Lane changes in Zone1	Pc/hr	143	118	84	324
	Truck Lane changes in Zone1	Trk/hr	57	46	84	120
	Car Lane changes in Zone2	Pc/hr	51	53	48	168
	Truck Lane changes in Zone2	Trk/hr	16.8	30	12	132
	% Trucks	N / A	0.151	0.060	0.024	0.258
	% Car Lane Changes in Zone 1	N / A	0.663	0.247	0.125	0.957
	% Truck Lane Changes in Zone 1	N / A	0.796	0.192	0.389	1.000
Early SDLMS	Capacity	Veh/hr	970	135	696	1272
	Car Lane changes in Zone1	Pc/hr	293	102	96	516
	Truck Lane changes in Zone1	Trk/hr	92	81	24	312
	Car Lane changes in Zone2	Pc/hr	108	62	12	312
	Truck Lane changes in Zone2	Trk/hr	23	26	24	96
	% Trucks	N / A	0.055	0.136	0.136	0.357
	% Car Lane Changes in Zone 1	N / A	0.675	0.071	0.071	1.000
	% Truck Lane Changes in Zone 1	N / A	0.769	0.000	0.000	1.000
Late SDLMS	Capacity	Veh/hr	896	111	696	1092
	Car Lane changes in Zone1	Pc/hr	274	95	60	516
	Truck Lane changes in Zone1	Trk/hr	33	24	24	84
	Car Lane changes in Zone2	Pc/hr	100	51	12	192
	Truck Lane changes in Zone2	Trk/hr	12	13	0	48
	% Trucks	N / A	0.246	0.054	0.136	0.357
	% Car Lane Changes in Zone 1	N / A	0.519	0.157	0.250	1.000
	% Truck Lane Changes in Zone 1	N / A	0.741	0.289	0.000	1.000

Also from the above table, the mean number and mean percentage of lane changes in zone 1 for cars and trucks are the highest for the early SDLMS and the lowest for the late SDLMS. These average numbers of lane changes are taken for all times including when the additional PCMS is not activated for the early and late SDLMS. The mean number and percentage of passenger cars changing lanes in zone 1 for the early SDLMS are 293pc/hr and 67.5% respectively (92Trk/hr, 76.9% for trucks). The mean and percentage of passenger cars changing lanes in zone 1 for the late SDLMS are 274 pc/hr and 51.9% respectively (33 Trk/hr, 74.1% for trucks). The mean and percentage of passenger cars changing lanes in zone 1 for the conventional MAS are 143 pc/hr and 66.3% in that order (57Trk/hr, 79.6% for trucks). These results indicate that some drivers are complying with the messages displayed by the additional PCMS in the early and late SDLMS.

During the early and late SDLMS, the additional PCMS may not be activated when the average detected speed does not fall below the preset threshold speed (50mph). Therefore, one should compare the capacities of the early and late SDLMS with the conventional MAS only when the additional PCMS is activated, hence displaying the lane merging advisory messages. Therefore, a new variable (labeled ACT) is derived to reflect this issue. This variable (ACT) consists of four levels; early and late SDLMS not activated, early SDLMS activated, late SDLMS activated, and conventional MAS. A multiple linear regression model is conducted to explore the effect of the MOT plan type and other collected variables on the work zone capacity. Table 2 shows the results of the regression model.

Table 2: Multiple linear regression results

ANOVA and Parameter Estimates

Parameter	Categories	Estimate	Standard Error	t Value	Pr > |t|
Intercept	N/A	78.447	6.173	12.710	<.0001
% PC lane changing in zone1		-9.514	5.546	-1.720	0.089
%TRK lane changing in zone1		1.965	4.037	0.490	0.628
%TRK		-2.010	19.303	-0.100	0.917
ACT	Late SDLMS	4.507	4.890	0.920	0.359
	Early SDLMS	10.312	3.520	2.930	0.004
	NOT ACTIVATED	4.300	3.406	1.260	0.209
	CONVENTIONAL MAS	0.000	.	.	.

Overall ANOVA

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1656.106	276.0177	2.45	0.0291
Error	109	12268.4	112.5542		
Corrected Total	115	13924.51			

From Table 2 the ACT shows significant effect on the capacity (queue discharge) of the work zone. In particular, the early SDLMS treatment affects positively (parameter estimate= 10.312) and significantly the capacity of the work zone compared to the conventional MAS maintenance of traffic plan. The other variables included in the model do not have a statistical significant effect on the work zone capacity at 0.05 significance level.

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 system may be inefficient for short term work zones when supplemented to the MAS system, and since the literature lacks of a cross-comparison between dynamic early and dynamic late merging in the field, this study suggests two Simplified Dynamic Lane Merging System; early SDLMS and late SDLMS, for deployment and testing in the field.

The early and late forms of the 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 location of the sensor trailer and the additional PCMS remain the same for the early and 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.

The capacity of the work zone 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. The regression model showed that the early SDLMS enhance work zone capacity significantly from 881 veh/hr to 970veh/hr. The late form of SDLMS increased the mean capacity from 881 veh/hr to 896 veh/hr, however this increase was not statistically significant.

The number and percentage of lane changes in zone 1 were the highest for the early SDLMS and the lowest for the late SDLMS. This indicates that drivers are complying with the messages displayed by the additional PCMS.

It was noted during data collection, for the early SDLMS, that drivers usually comply with the messages displayed by the PCMS. However, it was also observed that when a vehicle uses the closed lane to pass vehicles in the queue and merge into the open lane ahead of them, a platoon of vehicles follows this vehicle which defeats the purpose of the early SDLMS.

Future research may include the application of the early and late SDLMS on different sites with different geometric and environmental characteristics to explore the impact of the SDLMS on work zones with different attributes.

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