EVALUATION OF WORK ZONE DESIGN STRATEGIES: QUANTIFYING THE IMPACT OF DRIVER BEHAVIOR ON TRAFFIC FLOW AND SAFETY

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ABSTRACT
This paper presents an algorithm that considers the influence of driver behavior on traffic flow and safety when drivers encounter and respond to changing roadway conditions found in work zones. The conditions modeled by the algorithm in this research effort are lane drops and the forced merges that are caused by the lane drop. Central to the algorithm is the integration of two concepts: *driver familiarity and driver adaptability* to the changing road conditions. The use of these concepts incorporates two notions: 1) drivers must manage interaction with both the roadway and other drivers; and 2) drivers exhibit varying preferences for early or late merges based on their willingness to respond to upcoming lane restrictions and their inclination to be passive or aggressive in forced merge situations. The algorithm assesses driver behavior at an agent-based level and was developed with the aid of a field study. The paper proposes that the algorithm be considered for use as a microscopic evaluation tool to quantify the impacts of different work zone strategies on traffic flow and safety.

INTRODUCTION

This paper presents an algorithm that considers the influence of driver behavior on traffic flow and safety when drivers encounter and respond to changing roadway conditions found in work zones. The conditions modeled by the algorithm are lane drops and the forced merges that are caused by the lane drop. The development of this algorithm is a product of several years of field-based research conducted by the authors and others. The researchers noted that drivers must manage interaction with both the roadway and other drivers. Drivers exhibit varying preferences for early or late merges based on their willingness to respond to upcoming lane restrictions and their inclination to be passive or aggressive in forced merge situations. This knowledge can be used as a basis for simulation of work zone conditions and as an evaluative tool to quantify the impacts of different work zone strategies on traffic flow and safety.

The overall principle governing the algorithm is the tendency for drivers to adjust to changing roadway conditions while interacting with other drivers on the roadway. Interaction with the roadway is controlled by driver's ability to cope with changing roadway conditions and preference for early or late merges. Interaction with other drivers is controlled by a merge aggressiveness index of the driver attempting the merge as compared with the merge accommodation index of the driver in the adjacent lane.

Within the algorithm, the impact on traffic flow and crash potential is examined by evaluating two dimensions of the problem. The first dimension is roadway interaction, which is assessed by calculating the degree of match between the coping skills of drivers and the opportunity to merge in a preferred zone. The second dimension is the driver-to-driver interaction, which is assessed by evaluating the outcome of interactions using strategic game theory to resolve the interaction and to assess the success or failure of a merge attempt. The output of the model is an estimate of the speed shift that occurs when merges are attempted. The algorithm responds to variation in traffic density levels representing the difference between peak and off-peak periods.

The algorithm presented in this paper provides a basis for development of new models and employs an alternative approach of evaluating work zones at the microscopic level by accounting for driver behavior as opposed to the traditional approach which is based on reduction in lane capacity caused by construction activity. This alternative approach will allow transportation professionals to assess the impact of alternative work zone delineation strategies and Intelligent Transportation Systems (ITS) based work zone solutions that encourage more efficient and safer merge patterns based on prevailing traffic conditions in ways not possible today.

PROBLEM STATEMENT

The design of temporary traffic control plans are based upon typical applications in the *Manual on Uniform Traffic Control Devices (MUTCD)* and the *Highway Design Handbook for Older Drivers and Pedestrians*. MUTCD provides basic guidelines given the roadway configuration, the expected encroachment, and the expected duration of the construction activity. The *Highway Design Book for Older Drivers and Pedestrians* recommends adjustments to accommodate the needs of special roadway user groups. The development of "smart work zones" and other ITS applications in work zones provide additional configuration options to the engineer which will further modify the "typical application" given the local roadway, traffic flow patterns, and alternate route options. Modifications of typical applications give the engineer flexibility to customize the traffic control plan appropriate for their work zone but, there is currently no means available to evaluate a proposed configuration in order to determine the traffic flow performance difference between the options available - thus it is difficult to know what the "best" strategy is for the work zone.

The aim of this paper is to assist transportation professionals in addressing the question: "How do work zone delineation strategies, ITS based work zone solutions, and driver behavior impact traffic flow and crash potential in and around work zones given the local driver population makeup, including driver age, attitudes, abilities, and other factors?" Key to the answer of this question is the drivers' ability to react to an individual component of a work zone strategy such as cones, barrels, variable message signs, and barriers. Important to answering the question is also the ability for the driver to adapt over repeated exposures to the work zone strategy. Once the questions of how the strategy affects traffic flow and how drivers adapt to the strategy in the short and long term are answered, it becomes necessary to quantitatively assess the impact of driver behavior on delay and identify the occurrence of high crash potential situations. The ability to make these assessments may improve the ability for transportation professionals to address the significant non-recurring freeway travel delay and crashes associated with highway work zones. Quantifiable information will be useful in developing the right configuration for the work zone given the uniqueness of each situation.

At present, a problem for those interested in assessing work zones is that current micro-simulation tools are not capable of addressing the dynamics that take place within work zones because traditional car following and lane changing algorithms are based on normal or near-normal traffic flow conditions and were developed for use in continuous flow models such as CORSIM and VISSIM. To make microscopic models useful in specialized situations such as work zones, transportation professionals need a model that can address driver–to-roadway interaction and driver-to-driver interaction at an individual vehicle level. One potential solution to the problem is the use of an agent-based model that is computationally efficient enough to be employed on commonly available desktop and notebook computers.

DESIGN OF TRAFFIC CONTROL PLANS IN THE MUTCD

The *MUTCD* is the most comprehensive source for work zone design covering fundamental principles, temporary traffic control elements, pedestrian and worker safety, flagger control, temporary traffic control zone devices, and 46 typical work zone applications. The *MUTCD* emphasizes the issues of road user and worker safety as well as accessibility in work zones. The *MUTCD* (*1*) states that safety and accessibility "should be an integral and high-priority element of every project from planning through design and construction." Safety is most important for freeway work zones because of the high speeds in the work zone and the nature of freeways to be inaccessible to pedestrians.

Temporary Traffic Control Zones

Work zones are areas of a highway with construction, maintenance, or utility work activities typically marked by signs, channelizing devices, barriers, pavement markings, and/or work vehicles. These traffic control devices (Figure 1) are placed into four areas: the advance warning area, the transition area, the activity area, and the termination area.

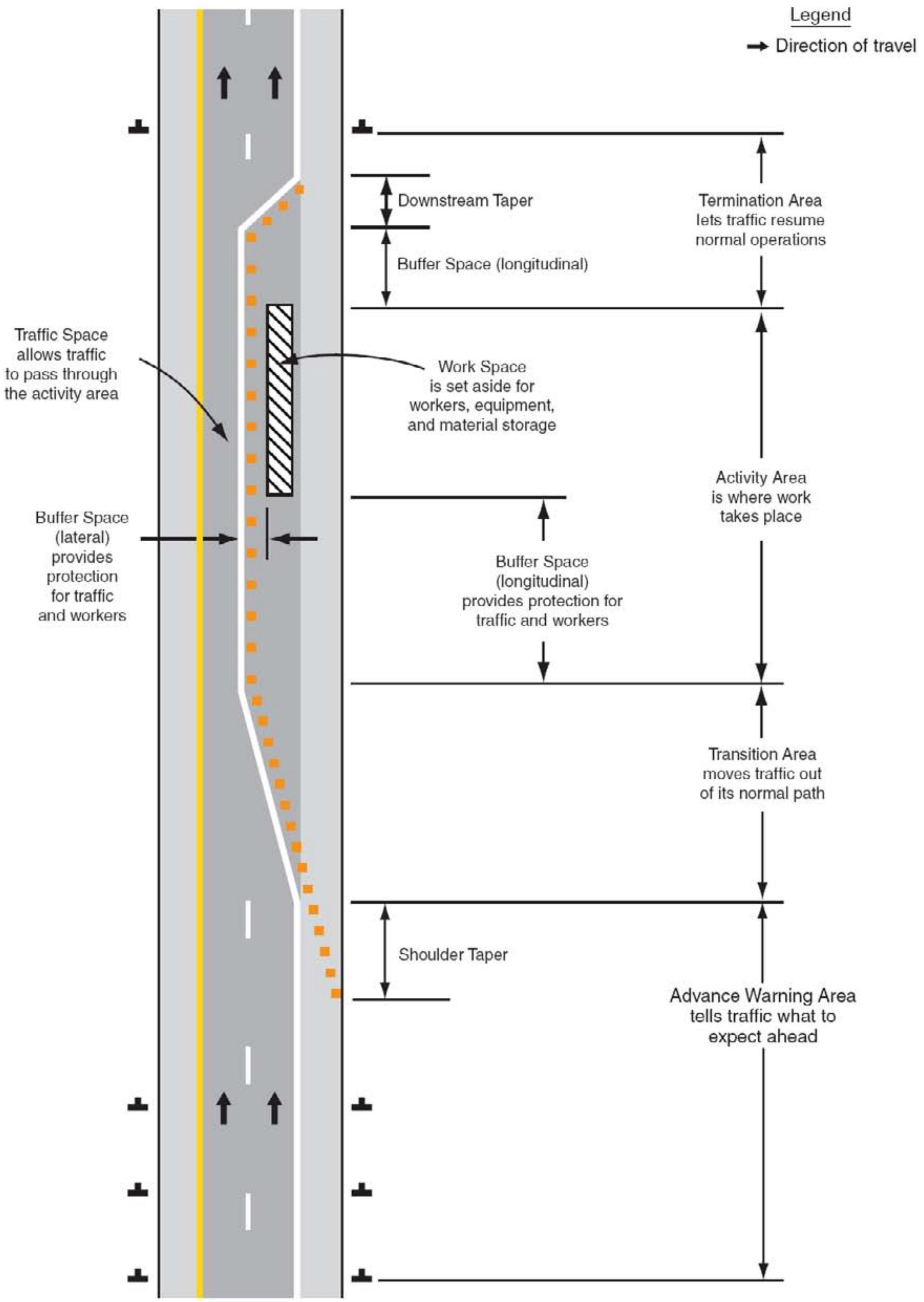

FIGURE 1 Component parts of a temporary traffic control zone. (*1*)

HIGHWAY DESIGN HANDBOOK FOR OLDER DRIVERS AND PEDESTRIANS

The *Highway Design Handbook for Older Drivers and Pedestrians* included highway construction and maintenance zones because of their potential to violate ***driver expectancy. The handbook*** attempts to mitigate the increased risk associated with work zones with the use of traffic control devices. The guidelines also state that driver expectancy is "a key factor affecting the safety and efficiency of all aspects of the driving task." (*2, 3*)

The guidelines stress repeated and simple notice of the upcoming work zone. The guidelines state that the implementation of the *MUTCD* recommendations concerning signing and other work-zone safety features, "provide more than adequate warning for a *vigilant* driver, but may be inadequate for an inattentive or otherwise impaired driver." (*4*)

In the research leading to the formation of the guidelines, the most frequent contributing factor to crashes were driver ***attention errors and failure to yield right-of-way*** (*5*). Driver attention errors may be caused by impairments as well as distractions that are commonplace in the driving task. Failure to yield right-of-way may be caused by aggressive driver behavior or by failure to comprehend and react to a complex situation.

CURRENT EVALUATION METHODS

Many difficult questions have to be answered in order to have an accurate simulation of work zone traffic conditions. The calculation of demand and capacity are two calculations that are the most difficult in the evaluation of work zones. Demand calculations are difficult due to the diversions caused by drivers delaying, canceling, or diverting trips to other routes. The capacity of open lanes in work zones is documented in the Highway Capacity Manual and has been studied extensively.

One difficulty in finding a true capacity is that different researchers have different definitions of how work zone capacity is defined. "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 (*6, 7, 8*), while some other researchers (*9, 10*) defined work zone capacity as the traffic flow rate on the onset of congested traffic conditions." (*11*)

One broadly employed method for evaluating the impacts of work zones is based on the FHWA developed software, QuickZone (*12*). QuickZone is a sketch level tool that supports assessment of work zone mitigation strategies and estimates the costs, traffic delays, and potential backups associated with these impacts. QuickZone can be used to evaluate traffic delays associated with work zone schedules in relation to peak and off-peak traffic periods and/or with the employment of diversion routes. The program displays the amount of delay in vehicle hours and the maximum length of the projected traffic queue associated with the work activity.

The advantage of QuickZone is that it runs in Microsoft Excel and provides quick estimates for use in planning. The disadvantage is that it does not provide insight into the actual traffic flow conditions that are a product of driver behaviors that vary among different demographic groups according to population composition and/or local tendencies concerning aggressive driving. Also, there is no measure of the occurrence of driver-to-driver conflicts that constitute low, moderate, or severe crash potential levels.

REQUIREMENTS FOR MODELING WORK ZONE MERGE TRAFFIC FLOW

Table 1 presents four variables identified by Maze, Burchett, and Hochstein as important variables in modeling work zone capacity. One variable that listed in Table 1 was driver characteristics, which prove important because the reactions of the drivers that move through the work zone will affect the capacity of the roadway. Maze, Burchett, and Hochstein stated, "drivers that have experience with the work zone are likely to select shorter headway and capacity will increase." (*13*) In the field research conducted in the development of the algorithm, researchers observed a five mile an hour increase in speeds during commuting peak hours as opposed to the adjacent off peak hours. The four variables that the algorithm attempts to address are the work zone lane closure configuration, driver characteristics, duration of work, and location of merge point and enforcement. The ability to model this interaction is the foundation for improving the simulation models that are available today.

TABLE 1 Selected Variables Known to Impact Work Zone Capacity (*13*)

Variable impacting capacity	Attributes associated with variable	Known characteristics
Work zone lane closure configuration	The capacity of a lane closure is dependent on the number of lanes left open and closed and the location of the lane or lanes closed.	When one or more lanes are closed, the remaining open lane(s) have less capacity than normal through lanes. Right lane closures have lower capacity than left lane closures because the right lane generally carries more traffic, resulting in more vehicles merging into the open lane.
Driver characteristics	Drivers that have experience with the work zone are likely to select shorter headway and capacity will increase.	Commuters making routine trips are familiar with the work zone and are more likely to reduce headways through the work zone. Al-Kaisy and Hall found that during off-peak hours capacity reduced by around 7% and during the weekends by 16% (*14*).
Duration of work	As the work zone increases in time, drivers are more likely to be familiar with the work zone and reduce their headways, thus increasing the capacity of the work zone with time.	The comments here are similar to those with regard to the driver characteristics.
Location of merge point and enforcement	Merging upstream from the taper point of a lane closure increases capacity more than late merging. However, drivers not following expected merge discipline skip to the head of the queue and force themselves into it, creating a crash risk and turbulence and diminishing any efficiency gained through an early merge.	Very little is known about the benefits of enforcement, and most studies of enforcement focus on safety benefits as opposed to traffic flow efficiency benefits (*15*). It is believed that using enforcement personnel to support smooth behavior improves traffic flow.

THE WORK ZONE ALGORITHM MODULES, TERMS, AND VARIABLES

Within the work zone algorithm developed in the research supporting this paper, three modules are employed to address the requirements to account for: driver-to-roadway interactions, driver-to driver interactions, and traffic stream impacts that govern vehicle progression into and through a work zone lane drop. In this section, each module is described by function and the key terms and variables associated with each are defined and highlighted in bold, italics.

Module I (Driver-to-Roadway Interaction): Drivers enter the work zone with a certain amount of familiarity before the first warning of the work zone. The drivers will react to the first warning of the work zone by adjusting their speed in accordance to their knowledge of the conditions ahead and their driving preferences. Their degree of reaction will be governed by their familiarity with the work zone and their ability to adapt to the changing conditions that work zone present. When drivers are given repeated warning of the work zone ahead, the drivers tend to choose to merge and adjust their speed further. Drivers approaching work zones have differing preferences on whether to begin to attempt to merge well prior to the merge taper, just prior to the merge taper, or within the merge taper. To address this, the merge zone is divided into three zones (early merge, middle merge, and late merge) as depicted in Figure 2.

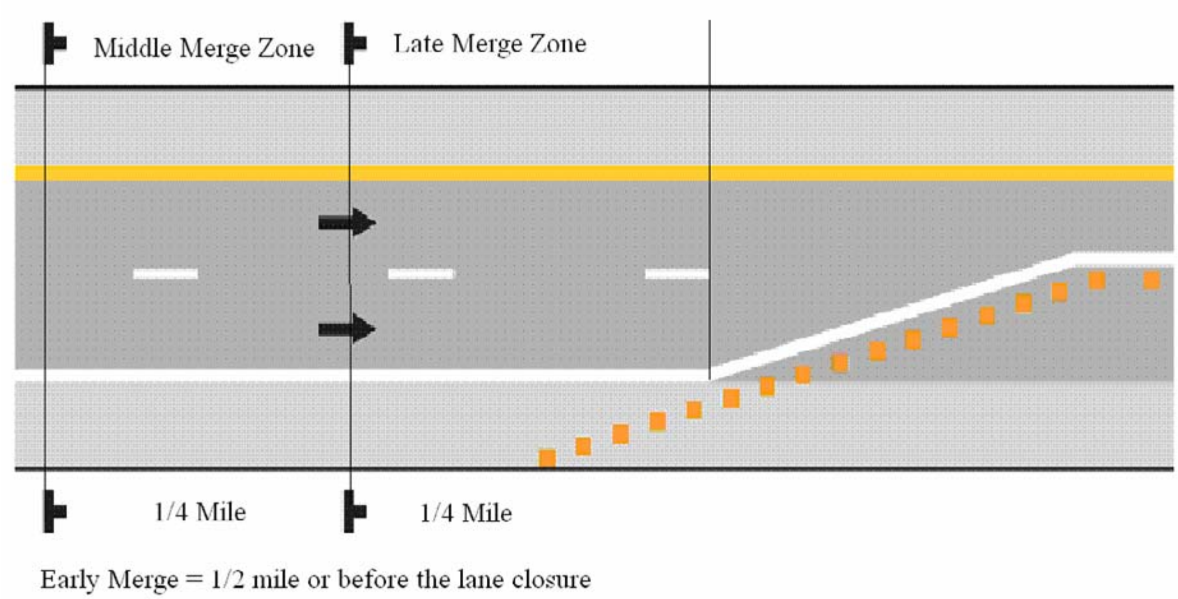

FIGURE 2 Merge zone definitions.

In the area before warnings are given, drivers are assigned knowledge of the upcoming work zone through the use of a fuzzy system that rates the driver on their familiarity and adaptability to the work zone which will be used to determine the merging behavior of the driver. This knowledge will be used to assign the driver a preferred speed as they enter the taper and into a possible queue. Then, drivers within the module are stochastically assigned a preference for an ***early*** merge, stimulated by a lane drop warning sign positioned well prior to the beginning of the merge taper, an ***intermediate*** merge stimulated by a position halfway between the lane drop warning sign and the beginning of the merge taper, or a ***late*** merge stimulated by a position corresponding with the beginning of the merge taper.

Module II (Driver-to-Driver Interaction): Drivers attempt to merge when stimulated by arrival in their preferred merge zone. If the ***occupancy condition*** does not present an acceptable gap, the ***merging driver*** will attempt a forced merge. The outcome of this attempt will be determined by comparing the driver's ***merge aggressiveness index*** with the ***merge accommodation index*** of the ***accommodating driver*** in the adjacent lane. In effect, the merging driver and the accommodating driver engage in a single-shot strategic game (*16, 17*) that determines a ***merge-yes*** or ***merge-no*** outcome. As a driver progresses towards and into the work zone taper, they may exhibit a change in merge aggressiveness as they are forced beyond their preferred merge zone. This is represented within the algorithm through the use of a fuzzy inference system that assigns the driver a different aggressiveness based upon the deviation from the preferences of the merging driver. In the case when a driver cannot make a merge in the late merge zone, the merging will continue to attempt a merge with the newly assigned realized merge aggressiveness index until a driver pairing occurs that generates a merge-yes.

Module III (Traffic Stream Impacts): Speed fluctuation in the traffic stream in both the continuing and dropping lane are a function of prevailing traffic density and merge dynamics. Under densities associated with LOS A through C, the speed impacts of merges are generally low and are considered to be negligible in the algorithm. As densities increase, merges produce micro-shockwaves that are a function of the merge dynamics as indicated by the realized merge aggressiveness index and the merge accommodation index of the respective drivers at the point of time that the merge occurs. Merges in which the accommodating driver has a ***high*** merge accommodation, merges will generate lesser speed shifts by both the accommodating and merging drivers and will generate less intense micro-shockwaves that do not propagate very far back in the traffic stream. In cases where the accommodating driver has a ***low*** merge accommodation index, forced merges will result in greater speed shifts by both the accommodating and merging drivers and will cause more intense micro-shockwaves that propagate further back into the traffic stream.

A Simplified Representation of the Computational and Comparative Processes

<u>Step 1 (Inputs)</u>*:* The user will input the following parameters: Driver familiarity with the work zone, driver adaptability to the work zone traffic control, and proportion of merges that take place in each merging zone. The user will then input the proportions of drivers that display low, medium, and high aggressiveness and accommodation as well as the driver's preferred merge zone. Table 2(a) is an example of input for the base familiarity and adaptability of the drivers in the work zone. Changes in the values in Table 2(a) model the differences in peak and off peak drivers. The inputs in Table 2(b) provide the analyst the opportunity to compensate for the regional differences in drivers by changing the characteristics of the different driver groups. This step will provide engineers the ability to change the characteristics of the driving population based on the work zone strategy that is employed on the roadway, enabling comparisons of different driver populations and work zone strategies.

TABLE 2(a) Inputs of Driver Familiarity, Adaptability and Actual Merge Zone

Driver Attributes				**Merge Attribute**	
Familiarity		***Adaptability***		***Actual Merge Zone***	
Low	0.1	Low	0.05	Early	0.2
Medium	*0.45*	Medium	*0.45*	Middle	0.35
High	0.45	High	0.5	Late	0.45

<u>Input Values</u>:
Low - Low familiarity with the work zone
Medium - Limited familiarity with the work zone
High - High familiarity with the work zone

TABLE 2(b) Inputs of Driver Aggressiveness, Accommodation, and Preferred Merge Zone by the Five Driver Groups

Driver Attributes									
Driver Group	***Aggressiveness***			***Accommodation***			***Preferred Merge Zone***		
	Low	*Med*	*High*	*Low*	*Med*	*High*	*Early*	*Middle*	*Late*
Very Low	0.3	0.25	0.45	0.3	0.35	0.35	0.3	0.4	0.3
Low	0.3	0.2	0.5	0.3	0.3	0.4	0.2	0.5	0.3
Medium	0.2	0.4	*0.4*	*0.2*	0.2	0.6	*0.35*	0.35	*0.3*
High	0.2	0.2	0.6	0.4	0.3	0.3	0.2	0.3	0.5
Very High	0.1	0.1	0.8	0.5	0.2	0.3	0.1	0.3	0.6

<u>Step 2</u>: Five random numbers are assigned to each driver entering the work zone. The two random numbers generated for *familiarity and adaptability* are then compared to Table 2(a) and the drivers are then assigned values of low, medium, or high for familiarity and adaptability. In addition a random number will be assigned for each merge and compared to the values in Table 2(a).

Example:
If RN (random number) <= .1 then Familiarity = None
If .1 < RN < .55 then Familiarity = Medium
If RN >= .55 then Familiarity = High

Random Numbers Assigned to a Driver and Result According to Table 2 (a):

	<u>Familiarity</u>	<u>Adaptability</u>	
Random Number	.5	.35	
Result	Medium	Medium	* shown in italics in Table 2 (a)

Step 3: The values for familiarity and adaptability are then fed into a fuzzy inference system and that assigns all drivers to one of the five driver groups. The driver groups are Very High, High, Medium, Low, and Very Low. The outputs from the fuzzy inference system are shown in Table 3.

Table 3 Fuzzy Inference System Outputs for Driver Group

Familiarity	**Adaptability**		
	Low	*Medium*	*High*
Low	Very Low	Low	Medium
Medium	Low	Medium	High
High	Medium	High	Very High

Step 4: As in Step 2, the driver *aggressiveness, accommodation, and preferred merge zone for each driver* based upon the random number generation from Step 2 and the driver group selected in Step 3 are determined comparing the values to Table 2 (b).

Random Numbers Assigned to a Medium Group Driver and Result According to Table 2 (b):

	Aggressiveness	Accommodation	Preferred Merge Zone
Random Number	.75	.15	.89
Result	High	Low	Late Merge Zone

Step 5: The algorithm assigns the *Actual Merge Zone* for the merge using the random number generated in Step 2 and the process detailed in Step 2.

Step 6: The algorithm inputs the work zone *base aggressiveness, base accommodation, preferred merge zone* and the *actual merge zone* assigned in Step 1 as inputs to a fuzzy inference system. The system outputs the *realized merge aggressiveness and accommodation* according to Table 4.

Table 4 Outputs of the Fuzzy Inference System for Merge Aggressiveness and Accommodation

Early Merge Realized Aggressiveness			
Base Aggressiveness	***Merge Zone Preferences***		
	Early	Middle	Late
Low	High	Medium	Low
Medium	High	Medium	Medium
High	High	High	Medium
Middle Merge Realized Aggressiveness			
Base Aggressiveness	***Merge Zone Preferences***		
	Early	Middle	Late
Low	High	Medium	Low
Medium	High	Medium	Low
High	High	High	Medium
Late Merge Realized Aggressiveness			
Base Aggressiveness	***Merge Zone Preferences***		
	Early	Middle	Late
Low	High	Medium	Low
Medium	High	High	Medium
High	High	High	High

Early Merge Realized Accommodation			
Base Accommodation	***Merge Zone Preferences***		
	Early	Middle	Late
Low	Low	Low	Low
Medium	Medium	Medium	Medium
High	High	High	Medium
Middle Merge Realized Accommodation			
Base Accommodation	***Merge Zone Preferences***		
	Early	Middle	Late
Low	Low	Low	Low
Medium	High	Medium	Medium
High	Medium	High	Medium
Late Merge Realized Accommodation			
Base Accommodation	***Merge Zone Preferences***		
	Early	Middle	Late
Low	Low	Low	Low
Medium	Low	Low	Medium
High	Medium	High	High

<u>Step 7</u>: The algorithm inputs the work zone *realized merge aggressiveness, realized merge accommodation*, and the *actual merge zone* assigned in Step 1 as inputs to a <u>fuzzy inference system.</u> The system outputs the *success of the merge* as shown in Table 5(a). The *impact to the traffic stream* is a function of the merge zone and the merge compatibility, which outputs *the speed shift, and the length of the micro-shockwave* caused by the merge and is shown in Table 5(b).

Table 5(a) Merge Success and Compatibility Outputs

Merge Aggressiveness	**Merge Accommodation**		
	High	*Medium*	*Low*
High	Low	Medium	No Merge
Medium	Medium	Medium	No Merge
Low	High	No Merge	No Merge

Table 5(b) The Traffic Impact from Successful Merges

Speed Shift in MPH		**Impact to the Traffic Stream**		
		Low	*Medium*	*High*
Merge Zone	*Early*	2	4	6
	Middle	4	8	12
	Late	10	20	30
Length of the Micro-shockwave in Vehicles		**Impact to the Traffic Stream**		
		Low	*Medium*	*High*
Merge Zone	*Early*	2	4	6
	Middle	4	8	12
	Late	10	20	30

AN ILLUSTRATIVE EXAMPLE

In order to further develop an understanding of how the work zone algorithm works and to illustrate its capability to emulate the merge and traffic stream impact, the following example is presented. The first part of the example illustrates the merge dynamics of one vehicle and the second part shows a simulation of 1000 repeated merges.

<u>Part 1/Merge Dynamics</u>: Figure 3 provides a sequential illustration of a merge attempt by Vehicle 101. The scenario is set just prior to the transition point between the intermediate and late merge zones. Vehicle 101, whose driver behavior attributes are recorded in Figure 3, attempts to merge with Vehicle 202. The pairing results in merge-no result. Driver 101 continues at a speed advantage and attempts a merge with Vehicle 201. At this point, Vehicle 101 has transited into the late merge zone that has triggered an increase in realized merge aggressiveness. The pairing of Vehicle 101 to 201 results in a merge-yes result. The speed impact on the traffic stream due to Vehicle 201's realized merge accommodation index is a reduction in speed from 25 ft/sec to 16 ft/sec generating a micro-shockwave that is five vehicles deep.

	Time = 0 sec	Time = 2.0 sec
Merging Driver	Vehicle ID 101	Vehicle ID 101
Merge Zone Preference	Intermediate	Intermediate
Actual Merge Zone	Intermediate	Late
Base Merge Aggressiveness	Medium	Medium
Merge Aggressiveness Change	Yes	Yes
Realized Merge Aggressiveness	Medium	High
Car Following Tendency	Moderate	Moderate
Speed at the beginning of Timestep	25 ft/sec	25 ft/sec
Speed at the end of Timestep	25 ft/sec	25 ft/sec
Adjacent Driver	Vehicle ID 202	Vehicle ID 201
Base Merge Accomodation	Low	Medium
Merge Accomodation Change	No	No
Realized Merge Accomodation	Low	Medium
Speed at the beginning of Timestep	16 ft/sec	16 ft/sec
Speed at the end of Timestep	16 ft/sec	9 ft/sec
Outcomes		
Probability of Merge	Merge-No	Merge-Yes
Wave Propagation	None	5 Vehicles

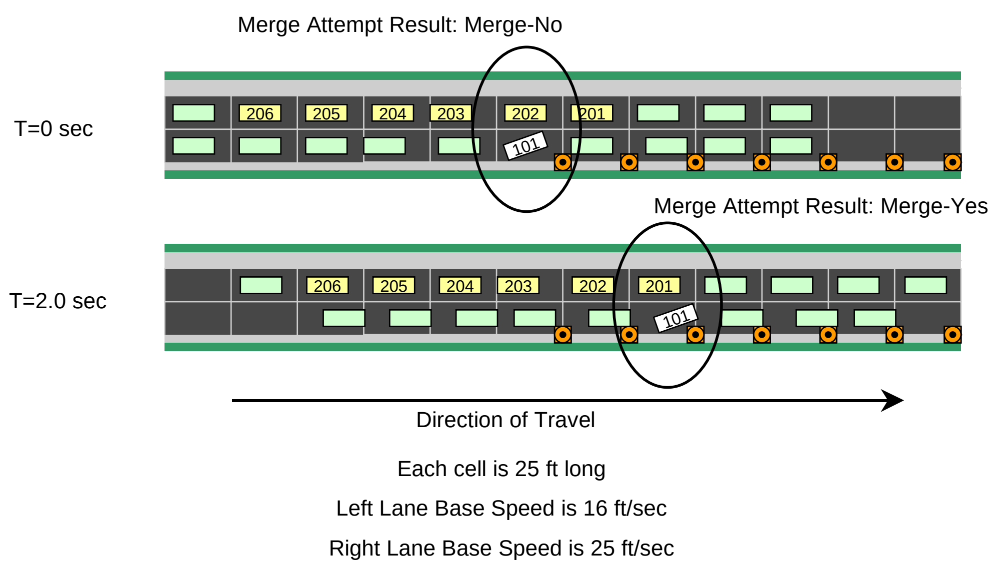

Figure 3 Merge dynamics example.

Part 2/ Simulation of 1000 Repeated Vehicles: To further demonstrate the merge dynamics example, a simulation of 1000 peak merges and 1000 off peak merges were simulated using code programmed into Microsoft Excel. The inputs used to conduct these simulations are presented in Table 6.

TABLE 6 Algorithm Inputs

Part (a) Off Peak Drivers				**Actual Merge Zone**	
Familiarity		*Adaptability*		*Zone*	*%*
Low	0.4	Low	0.3	Early	0.15
Medium	0.4	Medium	0.5	Middle	0.15
High	0.2	High	0.2	Late	0.7
Part (b) Peak Period Drivers				**Actual Merge Zone**	
Familiarity		*Adaptability*		*Zone*	*%*
Low	0.1	Low	0.05	Early	0.2
Medium	0.45	Medium	0.45	Middle	0.35
High	0.45	High	0.5	Late	0.45

As observed in Table 6 Part (b), major differences in the inputs for the two time periods include greater proportions of drivers with higher work zone familiarity (45%) and adaptability (50%) in the peak period as compared to the proportion of such drivers in the off peak period, shown in Table 6 Part (a). The higher proportion of peak hour drivers with high familiarity levels is due in part to the fact that many drivers during the peak period use the roadway on a regular basis for commuting purposes as compared to the infrequent use by off peak drivers. It should also be noted that the higher percentage of late merges (70%, Table 6 Part (a)) during the off peak is due to the lack of familiarity of off peak drivers as compared to the peak hour drivers who tend to merge earlier because of their knowledge of the work zone.

The outputs from both periods reflect the difference in the composition of the driver populations which are primarily defined by differences in: familiarity with the work zone, adaptability to changing conditions, merge zone preference. The peak period drivers are more familiar, are more adaptable, and are less likely to be forced into late merges. In addition, in a late merge situation, the peak period drivers tend to demonstrate a higher merge success rate. The off-peak drivers, on the other hand, are not generally familiar with the work zone, are less adaptable, and are more likely to be forced into late merges where they have difficulty in executing successful merges. Analysis of the simulated merges is provided in detail in Table 7 Part a-c. Major findings are summarized below and presented in Table 8.

- 758 of 1000 off-peak drivers were in the medium (314) or high aggressiveness (444) in the off peak compared with 868 of 1000 in the peak period.
- The more merges that occurred in the early (71% success rate) and middle (64% success rate) zones helped the peak have a higher merge success rate overall (61% to 55%).
- The off peak merges were typically forced into the late merge zone that had a success rate of 51% as opposed to the peak period during which merges were more spread out within the zones. The resulting speed shift was another major difference between the two groups.
- The successful merges in the peak period had an average speed shift of 10.4 mph while the off peak merges had a speed shift of 12.9 mph per merge.

Other detailed output from the simulation analysis is provided in Table 7 and output associated with summary statements above is highlighted.

TABLE 7 Algorithm Outputs

Part (a)

Off Peak Merging Drivers			Peak Period Merging Drivers			Diff.
Group	*Count*	*%*	*Group*	*Count*	*%*	*#*
1	114	11%	1	5	0.5%	109
2	324	32%	2	72	7%	252
3	346	35%	3	289	29%	57
4	175	18%	4	386	39%	-211
5	41	4%	5	248	25%	-207
Base Aggressiveness		*%*	*Base Aggressiveness*		*%*	*#*
Low	242	24%	Low	152	15%	90
Med.	314	31%	Med.	446	45%	-132
High	444	44%	High	402	40%	42
Preferred Merge Zone		*%*	*Preferred Merge Zone*		*%*	*#*
Early	253	25%	Early	211	21%	42
Middle	391	39%	Middle	315	32%	76
Late	356	36%	Late	474	47%	-118
Realized Aggression		*%*	*Realized Aggression*		*%*	*#*
Low	100	10%	Low	142	14%	-42
Med.	266	27%	Med.	372	37%	-106
High	634	63%	High	486	49%	148

Part (b)

Off Peak Accepting Drivers			Peak Period Accepting Drivers			Diff.
Group	*Count*	*%*	*Group*	*Count*	*%*	*#*
1	114	11%	1	10	1%	104
2	321	32%	2	63	6%	258
3	357	36%	3	287	29%	70
4	165	17%	4	399	40%	-234
5	43	4%	5	241	24%	-198
Base Accommodation		*%*	*Base Accommodation*		*%*	*#*
Low	272	27%	Low	229	23%	43
Med.	307	31%	Med.	456	46%	-149
High	421	42%	High	315	32%	106
Preferred Merge Zone		*%*	*Preferred Merge Zone*		*%*	*#*
Early	248	25%	Early	218	22%	30
Middle	391	39%	Middle	315	32%	76
Late	356	36%	Late	474	47%	-118
Realized Accommodation		*%*	*Realized Accommodation*		*%*	*#*
Low	409	41%	Low	325	33	84
Med.	336	33%	Med.	359	36%	-23
High	255	26%	High	316	32%	-61

Part (c)

Off Peak Merges			Peak Merges			Diff.
Actual Merge Zone		*%*	*Actual Merge Zone*		*%*	*#*
Early	135	14%	Early	208	21%	-73
Middle	142	14%	Middle	334	33%	-192
Late	723	72%	Late	458	46%	265
Merge Successful		*%*	*Merge Successful*		*%*	#
No	445	45%	No	389	39%	56
Yes	555	55%	Yes	611	61%	-56
Speed Shift (mph)		*%*	*Speed Shift (mph)*		*%*	#
N/A	445	45%	N/A	389	39%	56
2	18	2%	2	19	2%	-1
4	86	9%	4	157	16%	-71
6	2	0.2%	6	4	0.4%	-2
8	73	7%	8	149	15%	-76
10	147	15%	10	100	10%	47
12	6	0.6%	12	31	3%	-25
20	207	21%	20	140	14%	67
30	16	2%	30	11	1%	5

Off Peak Merges			Peak Merges			Diff.
Yes- Early	97	10%	Yes- Early	147	15%	-50
No - Early	38	4%	No - Early	61	6%	-23
Yes - Middle	88	9%	Yes - Middle	213	21%	-125
No - Middle	54	5%	No - Middle	121	12%	-67
Yes - Late	369	37%	Yes - Late	251	25%	118
No - Late	351	35%	No - Late	205	21%	146
Early Merge Success		72%	Early Merge Success		71%	1%
Middle Merge Success		62%	Middle Merge Success		64%	-2%
Late Merge Success		51%	Late Merge Success		55%	-4%

Average Off Peak Speed Shift	12.9 mph	Average Peak Speed Shift	10.4 mph

TABLE 8: Major Findings from the Example Simulation

Measure	Peak	Off-Peak	Off-Peak Difference
Aggressiveness	High	Moderate	Approx 12 % Less Aggressive
Predominant Realized Merge Zone	Early and Middle	Middle and Late	Approx 10% Shift to Late
Merge Success Rate in the Late Zone	55% of 456 merges	51% of 720 merges	Approx 170% increase failed merges in late zone
Speed Shift in Receiving Lane	10.4 mph	12.9 mph	Approximately 30% Increase

These results correspond with the observations taken in the field in the form of videotape. Individual merges were assessed using a set of discrete measures revealing that off-peak drivers, due to lower aggressiveness, tend to get forced into the late merge zone. Once in this zone, the lower aggressiveness causes a higher number of failed merge attempts leading to more pronounced impact on traffic flow quality as indicated by the field and simulation results. Small changes in the magnitude of the speed shift in the receiving lane were found to generate increased queue length at the end of the taper, lower capacity through the taper, and more complex merge maneuvers.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

This paper presents an algorithm, which has the potential for use in the FHWA sponsored micro-simulation and driver behavior modeling approaches. A unique aspect of this algorithm relates to the integration of the driver's familiarity and adaptability to the work zone. These two concepts were developed based on a field study that showed that drivers in peak hours had significantly different driver behavior then the off peak drivers. Another strength of the algorithm lies in its ability to simulate large amounts of merges instantly. The algorithm also provides the modeler a simple way to adjust the population of drivers that will be entering the work zone. This is especially helpful in rural areas that experience a vastly different driver population in the off peak periods, particularly on weekends. The ability to customize the model based upon a small number of inputs will give the modeler the flexibility to evaluate the work zone in many different configurations. It should be noted that this algorithm provides functionality that is based upon benchmarks that were determined from the field study. This functionality affords the opportunity to develop a more comprehensive model that models the car following of vehicles and takes into consideration more detailed information about the work zone strategy.

To further explore the application of the algorithm and the concepts of driver familiarity and adaptability, software will be developed through a lay-friendly interface to provide batch level inputs and outputs allowing analysis on a large scale. In addition, the algorithm will be linked to a visualization mechanism to support a broader utility in communicating the advantages of driver education, work zone delineation, and ITS based work zone solutions.

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