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Evaluation of Work Zone Strategies at Signalized Intersections

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***Abstract*—Reducing congestion in work zones and improving mobility has become more crucial than ever especially with the increased number of road projects. Work zones at street intersections are costly due to the delay experienced by both contractors and motorists. Work zones at signalized intersections are needed in the case of new construction, re-building the signal, or maintaining an existing traffic. This type of work can significantly affect traffic operations at intersections. Any lane reduction due to the construction zones will result in significant congestion. Another alternative is to reduce the existing lanes width and the speed limit instead of closing lanes. Although the literature shows statistics on work zone operations especially on freeways, there is a lack of information about signalized intersections. The purpose of this paper is to compare the amount of motorist delay that would accrue along the work zone from two strategies. Alternative 1 is based on reducing the number of lanes at the intersection and Alternative 2 is based on reducing lanes' width and maintaining the number of lanes at the intersection. The conducted methods showed that Alternative 2 provided better system operational performance than Alternative 1 for the cases tested.**

***Index Terms*—Work zones, traffic signal, intersections**

I. Introduction

Work zones operation is a vital concern when it comes to maintaining safety and mobility at signalized intersections. According to the NHTSA, 154 work zone fatalities occur every year from 2003 to 2007 at intersections from a total of 1,011 work zone fatalities that occur every year during the same time period. At work zones, drivers deal with new conditions they are not familiar with, which can be potentially dangerous due to the surprise factor. Dealing with the new conditions adds burdens to travel time and increases the delay. Finding the best way to handle the work zone will provide safer conditions for workers and drivers in an intersection work zone. The design of an intersection work zone should focus on providing the drivers with enough time and distance to make decisions to stop or to reduce the speed as needed. Traffic delay at intersections should be reduced to the greatest extent possible, which will lead to an improvement in the operation and safety of the intersection work zone [1].

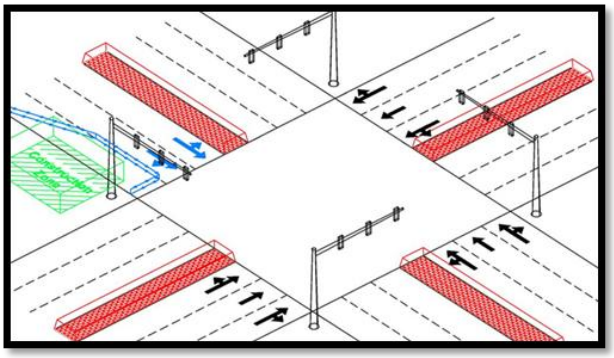

Figure 1. Alternative 1 – Reducing the Number of Lanes

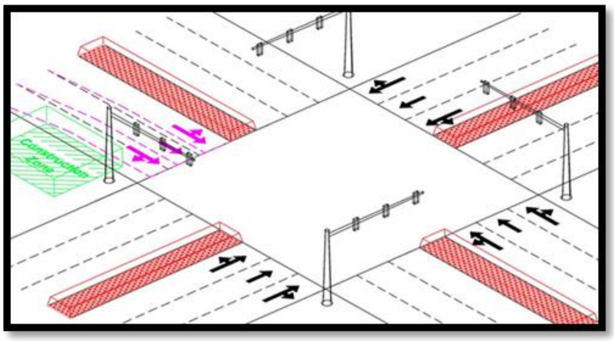

Figure 2. Alternative 2 – Reducing Lanes Width

II. Literature Review

Traffic simulation modeling is a crucial analytical tool that enables the simulation and analysis of the real-world traffic conditions in a safe and cost-effective manner. Different studies used simulation to study work zones. Kang and Chang used micro simulation to study three work zone merge control strategies; (i.e., static early merge, static late merge, and dynamic late merge) and investigated their merging features under the various

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traffic conditions at the same work zone environment. Their study employed CORSIM-RTE (CORridor SIMulation – Run Time Extension) to conduct extensive simulation experiments. The evaluation results have revealed their relative and distinctive properties, depending on traffic volumes and their fluctuations. Those outputs may be useful as guidelines in planning a proper merge control strategy for the highway work zone operations [2].

Collura et al. investigated different simulation tools for studying work zones. In this research, different cases were studied to evaluate these different tools in terms of traffic simulation of different work zones strategies. The study also provided information about the accuracy, ease of use, and data requirements for each model. This research compared simulation results to actual work zones conditions in eight locations across New England. The study showed that some of the models tested such as QUEWZ and QuickZone provided reasonable values when compared to observations collection in the field [3].

Rayaprolu et al. evaluated the operational efficiency of a newly proposed configuration, joint lane merge, and compares its performance with the conventional lane merge configuration. A simulation model (VISSIM) was calibrated with real-world data from an existing work zone on I-55 and used to simulate a work zone area with both configurations. A total of 25 different scenarios were generated from five different levels of demand and five truck percentages. Performance measures in terms of total throughput and average delay time were compared, and statistical analysis was conducted to determine if the differences in operational performance between both configurations were significant. The results showed that the new proposed configuration outperformed the conventional lane merge by a maximum of 12.6% improvement in throughput and 94.83% reduction in average delay time at high levels of demand. The results also indicated that the conventional lane merge configurations are more suitable for sites with relatively high percentage of trucks, while joint lane merge configurations are more suitable for sites with low percentage of trucks [4].

Harb et al. studied different forms of dynamic lane merging (DLM) systems, which is an ITS based lane management technology that was introduced by several states in an attempt to enhance both safety and mobility of roadway work zones. Two forms of lane merging namely the “early merge” and the “late merge” were designed to advise drivers on definite merging locations. This study simulated a two-to-one work zone lane closure configuration in VISSIM under three different maintenance of traffic (MOT) plans. The first MOT consisted of the conventional plans used in Florida’s work zones. Whereas, the second MOT consisted of a simplified dynamic early merging system (early SDLMS). The third MOT consisted of a simplified dynamic late merging systems (late SDLMS). Field data were used to calibrate and validate the simulation models. Results indicated that in general, under different levels of drivers’ compliance rate and different percentages of trucks in the traffic composition. The early SLDMS outperformed the conventional MOT and the late SDLMS in terms of travel time and throughputs [5].

Chatterjee et al. developed a simple method for choosing appropriate values of driving behavior parameters in the VISSIM micro-simulation model to match the desired field capacity for work zones operating in a typical early merge system. The two most significant car-following parameters and one lane changing parameter were selected and varied to obtain different work zone capacity values. These parameters include the desired time headway (CC1), the longitudinal following threshold during a following process (CC2), and the safety distance reduction factor a-s representative of lane changing aggressiveness. Additionally, for each recommended set of driving behavior parameters, lane distribution of the closed lane at different points upstream of the taper is collected. It was verified that the recommended parameter values not only produce the desired capacities but also create traffic conditions consistent with traffic flow theory [6].

It should be mentioned that there limited studies on utilizing micro-simulation to study different work zone configurations at signalized intersections. This study has employed a well-designed micro-simulation experiments to achieve this goal.

III. Analysis Methodology

Due to the current increase in work zone activities in general and at intersections in particular, it is necessary to find new ways to alleviate the delay problem along these zones. As discussed in the literature review, simulation models are considered one of the best tools to study and develop new strategies to improve the traffic conditions along work zones. Some of the available simulation models include VISSIM, SimTraffic, CORSIM, and Paramics. These models can study work zones in addition to other situations. Furthermore, there are other models that are designed specifically to study work zones such as QuickZone and QUEWZ. Other researchers developed their own simulation models to study work zones [7].

SimTraffic was used for this study. This section describes the method of analysis and the input data needed for the traffic simulation analysis including the geometric characteristics of the studied intersection, the traffic volume data, the signal timing assumptions, and the optimization procedure used.

A. Method of Analysis

The method used for this analysis was microscopic simulation, which provides better estimation for the operational conditions of signalized intersections as compared to other methods such as analysis using macroscopic techniques. Microscopic models are commonly used for traffic simulation studies and have the capability of modeling different intersection designs, arterial and freeway operations, with a wide variety of highway geometric characteristics, traffic control and signalization functions.

B. Analysis Tool

The analysis was conducted with SimTraffic version 8.0. SimTraffic [8], was developed in 1999 by Trafficware Corporation. It is one part of a software couple consisting of the coordinated models, Synchro and SimTraffic. SimTraffic is a microscopic simulation model that has the capability to simulate a wide variety of traffic controls, including a network with traffic signals operating on different cycle lengths or operating under fully-actuated conditions. Synchro [8] is a macroscopic traffic software program that implements the Intersection Capacity Utilization method for determining intersection capacity. SimTraffic 8.0 was selected as the simulation tool for this study due to its capability of compiling and computing vehicle movement, as well as the many features associated with intersection coding and data entry.

SimTraffic has the capability to simulate a wide variety of traffic controls, including a network with traffic signals operating on different cycle lengths or operating under fully-actuated conditions. Most other traffic analysis software packages do not allow for a direct evaluation of traffic conditions operating under varying cycle lengths and traffic control [9].

C. Base Geometric Conditions and Traffic Volumes

A traffic simulation model usually serves as a pre-deployment evaluation test-bed where; different traffic management techniques, control strategies, and design configurations could be evaluated. A microscopic traffic simulation model generally includes replications of the traffic system physical components, such as the roadway network, traffic control systems, and driver-vehicle units, etc. In addition, associated behavioral models, such as driving behavior models and route choice models are defined.

The studied intersection was a four-leg intersection. Each of the four approaches had the same number of lanes; two shared through lanes (through-left and through-right). Different volume levels were studied, including low, average, near capacity, and above capacity volumes.

To emulate peak and off-peak traffic data that can be observed in the field, ten levels of traffic volumes, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 6000, vehicles/hour (vph) were designed in this study. These volumes were used since typically 1,000 vph represents low-entering flow at an intersection during off-peak periods whereas 6,000 vph represent high flow situation where conventional intersections are performing close to saturation. A constant left-turning traffic of 15% of the through traffic was assumed on all four approaches. The percentage of right-turning volume was set to 10% for all scenarios.

D. Measurement of Effectiveness

In intersection analysis, average delay is the most important index to evaluate the difference between different alternatives. Average delay per vehicle was used for measurement of effectiveness in this study. Average delay, in hours, is equal to the travel time for all vehicles on all lanes minus the travel time it would take the vehicles with no other vehicles or traffic control devices during one hour. This MOE was selected since it focuses on the operation of the intersection.

E. Operational Assumptions

By simplifying the traffic movements to only two shared through lanes, the studied intersection could operate on a two-phase cycle since there would be no need for protected left-turn phases. The optimization tool in Synchro was used to develop the signal timings and splits for each volume scenario. An actuated un-coordinated signal controller with four seconds yellow and one second all-red was used for all volume scenarios.

IV. DATA ANALYSIS AND RESULTS

A. Experimental Design

Two main strategies were studied: closing the outside lane or maintaining the number of lanes by reducing lane width from 12 feet to 10 feet. In addition to the ten level of traffic volumes, three additional variables were selected. The first variable was the speed limit with two levels (35 and 50 miles per hour). The second variable was the taper length with three levels (200, 400, 600 feet). The levels were selected based on the limits recommended in the MUTCD in relation to the speed limit [10]. The third variable selected was the percentage of heavy vehicles with three levels (0%, 10%, and 20%). The three variables selected in addition to the two alternatives studied resulted 360 simulation models.

Traffic and geometric data were used as input data into the computer simulation software. The measure of effectiveness (MOE) used in this research was the delay per vehicle obtained from SimTraffic. Each of the 360 simulation models was run twelve times with different seed numbers. Delay was extracted from each model. When determining the delays for each design, the highest and lowest values were ignored then the average was calculated.

B. Model Calibration

Micro simulation models require calibration, which is the adjustment of model parameters to reproduce local driver behavior and traffic operation characteristics. Microscopic simulation models contain several independent parameters to describe traffic control operation, traffic flow characteristics, and the driver behavior. These models contain default values for each parameter, but the user also is allowed to input a range of values for each parameter. Changing the values of these parameters during calibration should be based on field measurements or conditions. This calibration process is usually carried out by adjusting a set of parameter values for the model that best reproduces local traffic conditions.

In the case studied, the modeling and traffic analysis is at the stage far prior to the construction and operation. Therefore, using parameter values obtained from relevant studies in similar environment are appropriate to build the model and carry out analysis. A previous model, built and calibrated as part of previous research, was used for this study [11].

V. Results

A. Graphical Evaluation

To determine the appropriate alternative for each of the volume levels, it was found that both alternatives gave similar results for the low volume level (1,000 vph to 2,500 vph) as shown in Figures 3 and 4.

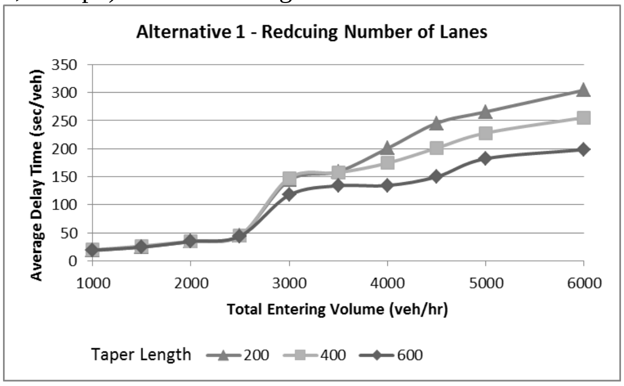

Figure 3. First Alternative Simulation Results

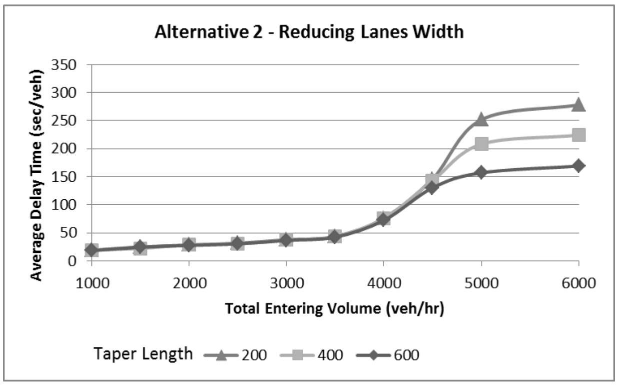

Figure 4. Second Alternative Simulation Results

For medium volume level (3,000 vph to 4,000 vph), Alternative 2 showed lower delay than Alternative 1. However, the different values of the taper length for alternative 2 did not show a significant difference. For high volume level (4,500 vph to 6,000 vph), alternative 2 showed lower delay than alternative 1 and the taper length showed a difference in delay.

B. Paired t-Test

In addition to the graphical evaluation and in order to statistically determine whether any difference or no difference exists between the two alternatives, a paired T-test was conducted on the data. The mean delay for each alternative was computed, and a two-tailed t-test was conducted. The null hypothesis was that the mean delay did not differ significantly between the two alternatives. The t-test returned a t statistic of 2.608 and a p-value of 0.010, so the null hypothesis could be rejected at a 0.05 probability of Type I error (α). Therefore, the delay for Alternative 1 differed significantly from that for Alternative 2.

VI. Conclusions

The goal of the research presented was to study two different strategies when dealing with work zones at signalized intersections. The results of this study will be of interest to traffic engineers responsible for designing and planning work zone schemes at signalized intersection. The first alternative included closing the outside lane to provide space for the work zone, and the second alternative included reducing the lane widths for the lanes from 12 feet to 10 feet for the same reason. To test the two alternatives, a single geometric test case was developed. Four variables including traffic volume (10 levels), taper length (three levels), speed (two levels), and percentage of heavy vehicles (three levels) were developed, which resulted 360 SimTraffic models (180 scenarios for each alternative).

The analysis conducted showed that for the geometric, volume, and the traffic control conditions tested, alternative two provided better system operational performance than alternative one. The signalized intersection studied had lower average delay after applying the second strategy in most cases. For low traffic volume, both alternatives provided similar results.

It should be noted that the results achieved were based on only one signal where phasing scheme was utilized (split phasing). Splits and cycle lengths were optimized using Synchro. The intersection was also assumed to be isolated for the analysis, meaning no other intersections affected the traffic patterns for the studied intersection.

In summary, reducing the lane width and maintaining the same number of lanes reduced the delay at the intersection for the cases studied. Future research could include studying additional geometric, volume, and signal data to determine how additional variations can affect the operational conditions at signalized intersections.

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