Evaluating Effect of Pavement Marking on Traffic Operation of Interchange Merging and Diverging Areas Using Synchro/SimTraffic – A case Study in USA

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***Abstract*- Interchange merging and diverging areas have always been one of the most unsafe areas due to vehicle conflicts at high speed. One of the major shortcomings in the entrance and exit lanes at interchanges is the lack of standard pavement marking. The implementation of proper pavement markings can improve the driver's understanding of the direction of the route and help them to have a safe turning maneuver on the ramps. In the present study, the on- and off-ramps of US 34/US 85 interchange located in Evans, Colorado, USA is considered as a case study to investigate the measure of effectiveness including travel time, total delay, total stops, and level of service. Two pavement marking plans were proposed. The impact of implementing these plans with respect to the current traffic volume (2019) and the forecasted one (2040) was evaluated using Synchro/ SimTraffic simulation software. Finally, based on the software simulation results, Jacobs Engineering Group proposed the best pavement marking design to Colorado Department of Transportation as an optimum pavement marking option in order to improve safety of the interchange.**

***Index terms*- Merging area, Interchange, Traffic calming, Operatorial analysis, Synchro/ SimTraffic**

1. INTRODUCTION

Nowadays, the role of transportation in the economic, political, and social aspects of societies is essential. Transportation is one of the key support of sustainable development in human societies, and in fact, transportation networks are closely linked to important components such as economics, security, and social equity. Due to the development of societies, population growth increased ownership of vehicles, and as a result of increased inter-regional exchanges, traffic accidents have become one of the major problems in the transportation field. In order to consider this issue, focusing on the safety of road users by minimizing accidents is crucial. Traffic accidents are one of the most important causes of deaths and injuries in the world and have severely damaged the social, economic and cultural impacts of those societies. According to the World Health Organization (WHO), about one million and 350,000 people are killed and 50 million injured worldwide each year due to traffic accidents [1]. According to this report, the average index of traffic accidents killed is about 18.2 per 100,000 population. Recently, safety measures such as traffic calming have been used by researchers as a potential tool affecting the behavior and performance of road users [2-5]. Traffic calming tools can indirectly influence driver perception, which improves road safety and operational condition. According to the results of various studies, the human factor in many traffic accidents is known to be the major cause of accidents, although the factors affecting the accidents are generally classified as human, environmental and vehicle factors [6-9]. Human factors include the lack of attention to the road, unauthorized overtake, and failure to keep longitudinal, and transverse spacing to other vehicles on the road. Environmental factors contain the width and geometrical characteristics of the road, signposts and other road control tools, the status of the road lighting, driver's vision barriers and so on.

Interchange merging and diverging zones are one of the places where the severity of crashes due to high speed is considerable. The conflicts of vehicles with each other in these areas of interchanges are very serious because of the high speed; therefore, improving safety at these areas with a cost-effective tool such as pavement marking is vital. Statistics show that 50% of the accidents occur in conflict areas; however, the exact rate varies based on geometrical, traffic, and control conditions [10-13]. Meanwhile, the accident statistics at the entrance and exit areas of interchanges are significant due to the weakness in the standard performance of the geometric design and pavement marking. Indeed, vehicle conflicts can be very hazardous if the lines of the merging and diverging are not clear or sufficient spaces are not provided. These problems at entrances and exits of interchanges can greatly distract drivers and increase the risk of severe accidents. Therefore, proper implementation of the pavement marking can improve safety by minimizing accidents by clarifying the route direction for drivers. In addition, this traffic calming tool (i.e., pavement marking) can boost the quality of road performance by reducing the travel delay and improving the level of service. The following studies are related to calming traffic tools that other researchers have been investigated.

2. LITERATURE REVIEW

Arnold and Lantz investigated the effect of optical speed bars as a traffic calming tool to determine possible changes in vehicle speed in both directions. Comparison between the speeds collected over different time periods showed that these measures were effective in reducing speeds in different areas by 1 to 3 miles per hour [14]. Hunter et al. studied the effectiveness of converging chevron pavement markings in reducing speed in a two-lane freeway in Atlanta, Georgia. The evaluations were performed before and after in the region and analyses were made on speeds at different percentages and mean speed to investigate the effect of these measures on deceleration. The results showed that Chevron marks up to about 2 miles per hour had an effect on slowing down vehicles [15]. Bella investigated the driving behavior in different two-lane rural on using a driving simulator. Three different roadside plans in a two-lane rural road covered with trees and also the effect of beginning a guardrail were investigated on driver behavior in left-hand, right-hand and straight-line. Statistical analysis of data on speed and lateral displacement of the 33 participants indicated that driver behavior was only influenced by cross-sections and geometrical elements of the road, whereas the road margin structure had little effect on driver performance. Moreover, the presence of trees along the road is an increasing factor in the severity of off-road traffic accidents and drivers do not change their behavior in the absence of a guardrail [16]. In 2015, Ding et al., Evaluated the effectiveness and adaptability of speed reduction markings in downhill sections on the urban road in China. Two types of traffic calming measures along steep slopes with different slopes of 1, 2 and 3% were investigated. Results show that longitudinal markings are effective at 3% slope roads and those transverse markings at 1% and 2% slopes are more efficient [17]. In 2016, Diamandouros and Gatscha studied the impact of road marking on drivers' performance on Lithuanian roads. Numerous arched routes, as well as direct paths of some cities, were subjected to solid and skip (broken) lines and behavioral studies of drivers under different climatic conditions were evaluated. It was found that comparing the results of pre- and post-lane studies indicate a reduction in the likelihood of risky driving behaviors such as rolling motions on the road, reduction of lateral displacement of vehicles and reduced speeds on study roads [18]. Gonzalo et al. (2016) examined the impact of a pedestrian crossing on two roads of Burgos in Spain. The speed of the vehicles was measured before and after the pavement marking implementation. The results showed that pedestrian crossing at high traffic intersections resulted in an average vehicle reduction of about 10 km / h and a decrease of about 15 to 10 km / h for 85% speed [19]. Gitelman et al. considered different roads in some European countries to examine the influence of crosswalk marking removal on pedestrian safety as reflected in road user behaviors. In this study, two sites including pedestrian crossing were studied before and after removing lines to effect this line design. Two-lane pedestrian lanes were cleared and the behavior of pedestrians and vehicle drivers was assessed after removing. Comparison of before and after studies on these routes, as well as comparing these sites with pedestrian lanes showed that pedestrians waited less time to cross the road

after removing lanes. In fact, pedestrians, knowing that their drivers would be less willing to allow them to cross the street, were trying to cross the road as soon as possible, without attention to increasing their potential collision traffic [20]. Akbari and Haghighi examined the possible effect of some traffic calming measures on driving speed and lateral distance. 39 participants with at least 3 years of driving experience took part in this study, and comparisons of driver reactions in case of speed and lateral position as a safety index in 4 scenarios and base scenarios were outputted. The results of the study showed that the speed of the vehicles, as well as the lateral changes, decreased after implementation of the pavement markings [2].

To the best of our knowledge, there is a lack of information regarding evaluating a new pavement marking plan for the existing interchange using simulation software. On the other hand, less attention has been paid to examining the operational analysis of interchange merging and diverging zones. In the present study, the effect of changing in pavement marking of an interchange on- and off-ramp as a traffic calming tool is studied by simulating two different striping plans in Synchro/SimTraffic simulation software in order to determine the optimum option. The current traffic volumes of 2019 and the forecasted traffic volume of 2040 have been used for this analysis. The goal of the study presented here is to determine if a proposed pavement marking and geometrical improvement outperform the existing marking or not.

3. METHODOLOGY

Traffic simulation software has got a special point in the engineering sciences, creating the conditions for researchers to simulate and analyze various plans before executing a plan in the real world and in the result choose the best plan. In the scope of traffic, such tools are used to stabilize more road safety, so that a wide range of studies related to road safety in recent years is entirely related to traffic flow simulator software. In this study, Synchro/SimTraffic simulation software is utilized for analyzing the traffic operation of proposed striping plans.

3.1. Case study

The US 34/US 85 interchange is on the southeast side of Greeley, Colorado. This interchange, last rebuilt in the 1970s, serves to connect US 34 (an east-west US highway) with US 85 (a north-south US highway), US 85 Business (a north-south US business route through eastern Greeley), and 8th Avenue (a City street used for some US route connections)

3.2. Study scenarios

Jacobs Engineering Group evaluated designs for improvements to the US 34 / US 85 interchange. An aerial view of the southbound interchange is shown in Figure 1. The existing interchange has many substandard design issues due to age and traffic growth. One significant area of concern is the ramps. Striping plans have been proposed to improve the existing condition of the ramps; however, changing the ramps' striping could lead to traffic operational issues. An operational analysis was performed using Synchro/SimTraffic simulation software to evaluate the existing conditions and the proposed striping changes for the on- and off-ramps at the interchange.

Fig.1 US 34/US 85 Interchange Aerial View

This paper summarizes the proposed changes and the analysis process based on the analysis. Ultimately, the analysis results confirm the merits of the proposed striping design, as it was shown to reduce travel time and delay, especially for higher traffic volumes. The existing striping and the proposed striping plans are shown below in Figures 2.1 and 2.2.

Fig.2.1 Existing Ramp Striping

The proposed plans were developed based on the existing geometry, traffic volumes and pavement widths with the goal of minimizing vehicle conflict points and increasing the traffic operations of the ramps, including reducing delay and increasing the capacity. For instance, as can be seen in Figure 2.1, the existing geometry of on-ramp at the gore is confusing for the drivers because of two lanes of the ramp must be merged into two lanes of US 85 SB without a yielding/stop signs or striping. Changing in striping can help drivers to merge into US 85 SB safely. For the on-ramp, two options are proposed. The main difference between these two proposed plans is the number of lanes in US 85 SB. Proposed Plan 1 merges southbound US 85 to one lane and the on-ramp to one lane prior to the gore. Proposed Plan 2 merges the on-ramp to one lane prior to the gore and adds a continuous auxiliary lane on SB US 85 from the on-ramp to 31st Street to keep two SB lanes on US 85. For the off-ramp, there is only one option. As shown in Figure 2.2, the off-ramp is currently a single lane exit. The overall width of the ramp pavement is approximately 35 feet which would allow for an additional exit lane, which is shown in the proposed striping plans. This change would require modifying the existing striping on northbound US 85, as well as the off-ramp. Operationally, this option provides an additional lane at diverging that could improve traffic operation by increasing capacity and potentially reducing the queue.

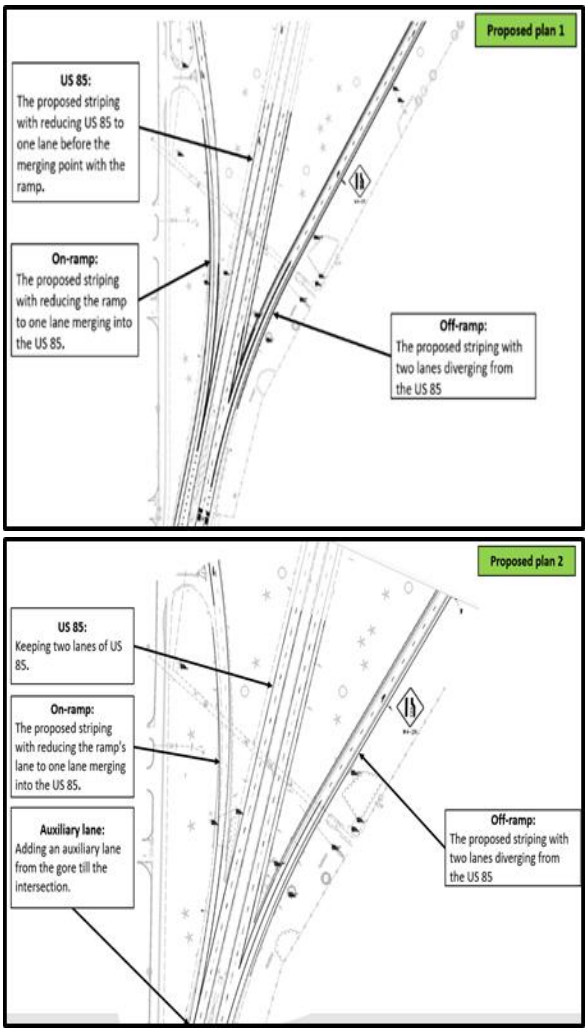

Fig. 2.2 Proposed Striping Plans

4. RESULTS

4.1. Existing traffic volumes

Most of the traffic counts for the interchange area were conducted in March 2017. However, we needed 2019 traffic volumes. Therefore, these volumes were calculated based on traffic growth that will be discussed in the next section.

4.2. Traffic forecasting procedure

The North Front Range Council of Governments (NFRCOG) maintains the region's traffic forecasting model to assist local agencies in evaluating and determining transportation infrastructure investments. The NFRCOG forecasts land use growth throughout the region, which the traffic forecasting model uses to determine vehicle production and attractions. The NFRCOG also forecasts roadway network changes

based on local investment plans. The NFRCOG maintains a base model (2015) to calibrate for existing conditions and a 25-year horizon model (2040) as a forecast of future conditions. The traffic forecasting model is provided to member governments for use in planning studies.

The procedure for developing 2040 forecasts at the peak hour traffic level used well-established processes to combine known traffic count information with regional traffic forecasting done by the local governments. The process for traffic forecasting at this interchange is explained using the following steps:

- Calculate the percent change between 2017 and 2040 volumes on each roadway or "link" in the study area
- Apply that growth percentage or growth factor to known peak hour traffic counts (2017) on each link to obtain the 2019 and 2040 traffic forecast for each of the links leading to and away from the interchange.

Figures. 3 and 4 provide a simplified illustration of the process described above for calculating 2019 and 2040 traffic volumes from existing 2017 traffic data.

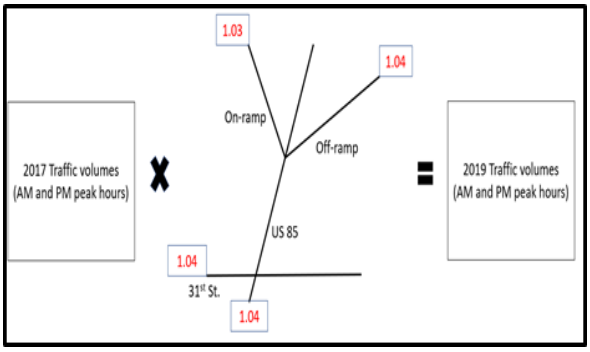

Fig.3 2019 Traffic volumes

A similar process was used to calculate 2040 traffic volumes associated with 2017 traffic data which is presented below.

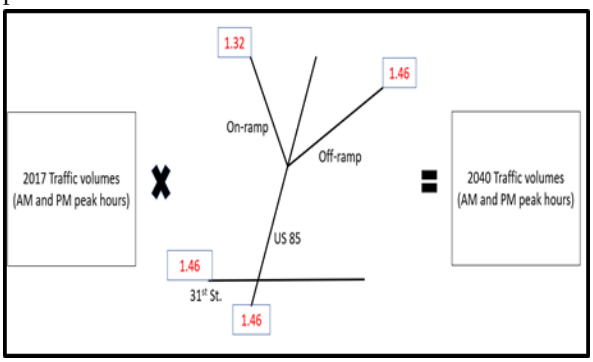

Fig.4 2040 Traffic volumes

4.3. Traffic volumes

The procedure for forecasting peak hour traffic volumes was described in the previous section. The resulting peak hour traffic forecasts for 2019 and 2040 are shown in Figures 5-8. The numbers in the figures represent traffic volumes by movement.

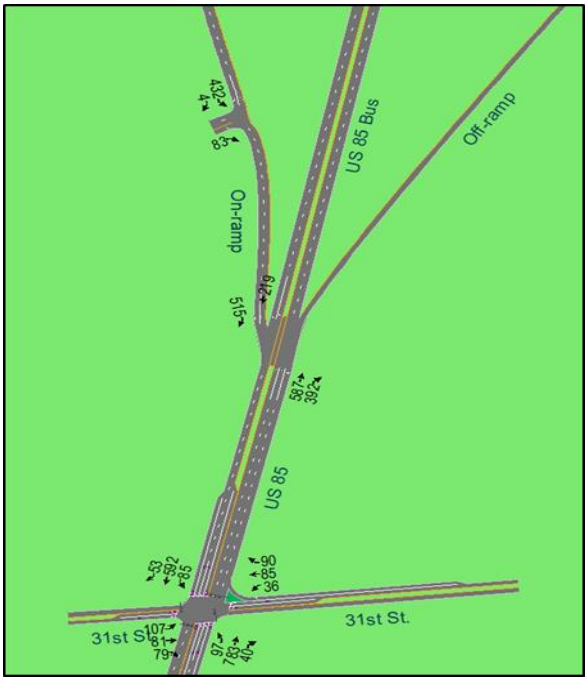

Fig.5 2019 AM Peak Hour Volumes

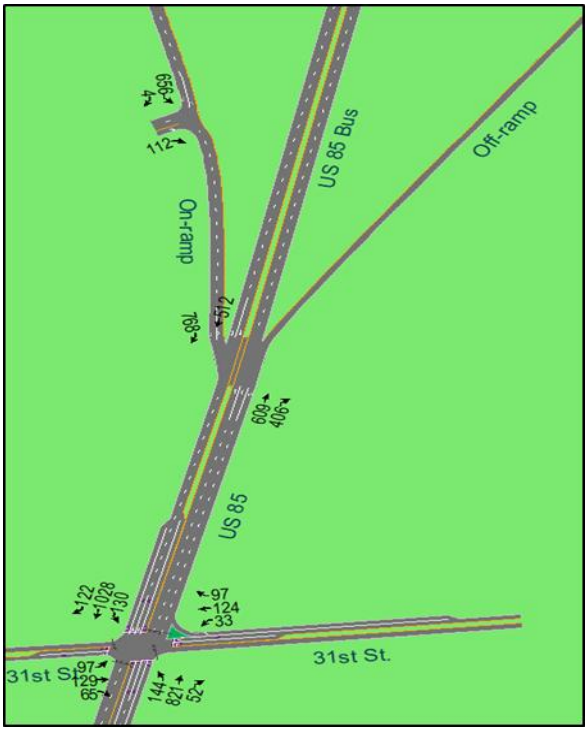

Fig. 6 2019 PM Peak Hour Volumes

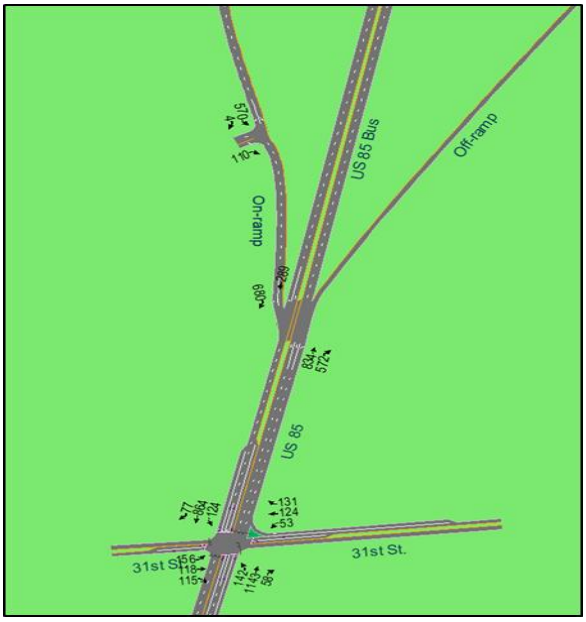

Fig.7 2040 AM Peak Hour Volumes

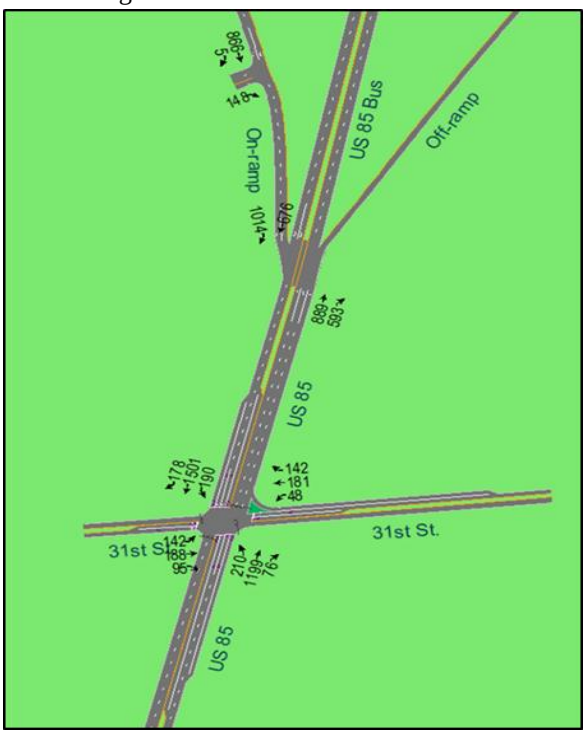

Fig. 8 2040 PM Peak Hour Volumes

4.4. Traffic operational analysis

Traffic operational analysis describes how well an intersection performs. The merging and diverging area modeled as an intersection without a left turn in Synchro software. This software is a macroscopic analysis and optimization software that is used to evaluate traffic operations. SimTraffic is the microscopic portion of Synchro software that offers the ability to match real-world existing and future conditions. The Synchro models for the existing conditions (Fig. 9.1), Proposed Plan 1 (Fig. 9.2), and Proposed Plan 2 (Fig. 9.3) are shown below. The pictures below show the area that was modeled using Synchro and SimTraffic simulation software. The analysis goal is to understand the impact the proposed striping plans have on SB US 85 and the on- and off-ramps when compared to existing conditions. The existing and proposed ramp striping was modeled for 2019 and 2040 AM and PM peak hour volumes. In traffic analysis, measures of effectiveness (MOE) quantify the achievement of a project's operational objectives. For this analysis, four measures of effectiveness (MOE) were evaluated and compared: (1) travel time, (2) total delay, (3) total stops, and (4) intersection capacity utilization ratio (ICU). The ICU is a ratio calculated by Synchro, used to describe an intersection's reserve capacity, mainly for planning purposes. The results shown are for the entire model and not specific to one roadway within the model. For precision, SimTraffic MOE's are based on a composite of 10 simulation runs. The simulation results of the numerical MOE's are shown in the following tables:

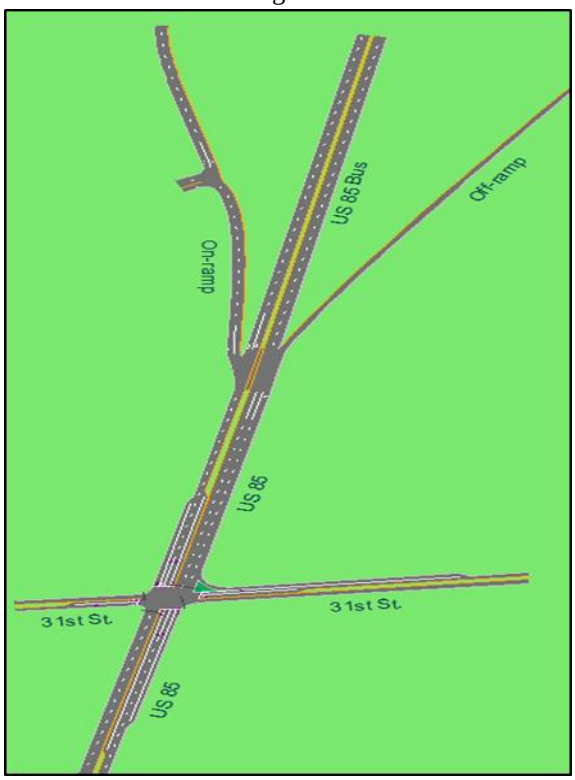

Fig.9.1 Synchro Model for Existing Condition

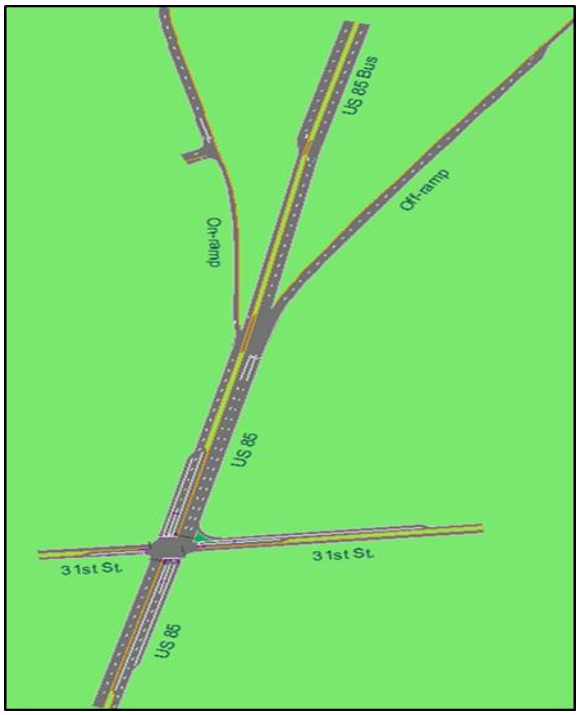

Fig.9.2 Synchro Model for Proposed Plan 1

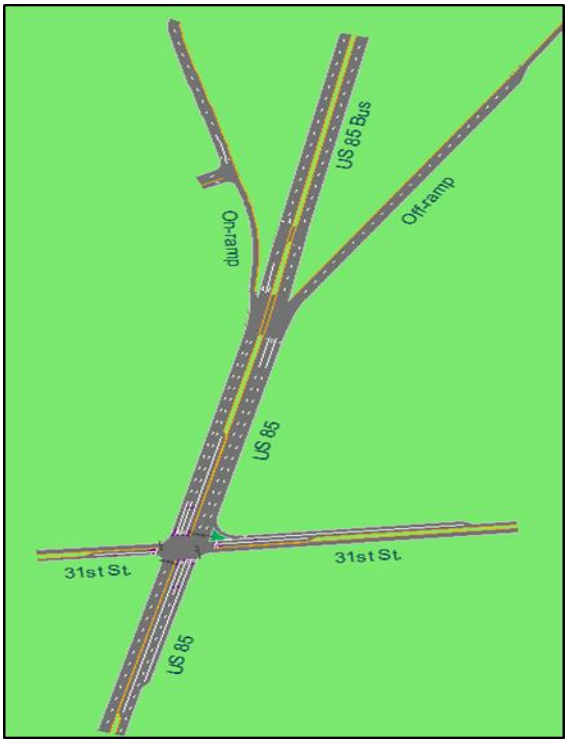

Fig.9.3 Synchro Model for Proposed Plan 2

Based on the results shown in Table 1 and Table2, both proposed striping plans show a reduction in total stops when compared to the existing conditions for both forecasted years. For instance, for the 2019 AM peak hour, 253 total stops were reported for Proposed Plan 1 and 249 total stops were reported for Proposed Plan 2, which is a 9% and 10% reduction in stops, respectively, when compared to existing conditions. A similar improvement in total stops was repeated for 2019 PM peak hours. The existing conditions equaled or outperformed the proposed plans for travel time and total delay during both peak hours, however. When looking at the 2040 results, both proposed plans outperform the existing conditions for all MOE's in both peak hours. Based on these MOE's, it seems that the proposed plans performed better than the existing conditions, especially in the 2040 scenario. The next step was to determine which proposed plan offers the best performance at the ramps. Synchro provides an ICU ratio which is described above. Synchro also assigns an ICU Level of Service (ICU LOS) based on this ratio. ICU LOS values range from ICU LOS "A" to ICU LOS "H". To analyze the on- and off-ramp with respect to ICU, the merge and diverge areas of the US 85 and the ramps were modeled as a single intersection without the left turns. The results are shown in Table 3 and Table 4 below. According to these tables, Proposed Plan 2 performs better than Proposed Plan 1. When considering the results in Tables 3 and 4, Proposed Plan 2 appears to be the preferred alternative.

Table1. 2019 Measures of Effectiveness

Measures	Total intervals					
	2019- AM			2019- PM		
	Existing	Proposed 1	Proposed 2	Existing	Proposed 1	Proposed 2
Travel time (hr)	7.9	8.4	8.2	11.8	11.8	10.6
Total delay (hr)	2.9	3.7	3.4	5.3	5.3	5
Total stops	277	253	249	462	386	362

Table2. 2040 Measures of Effectiveness

Measures	Total intervals					
	2040- AM			2040- PM		
	Existing	Proposed 1	Proposed 2	Existing	Proposed 1	Proposed 2
Travel time (hr)	14.7	13.3	13.4	28.8	25.8	20.6
Total delay (hr)	8	6.8	6.6	20.7	17.4	12.9
Total stops	590	296	421	1094	782	801

Table3. 2019 ICU and LOS

Measures	US 85& on-ramp and off-ramp intersection			
	2019- AM		2019- PM	
	Proposed 1	Proposed 2	Proposed 1	Proposed 2
ICU	50%	45%	81%	68%
LOS	A	A	D	C

Table4. 2040 ICU and LOS

Measures	US 85& on-ramp and off-ramp intersection			
	2040- AM		2040- PM	
	Proposed 1	Proposed 2	Proposed 1	Proposed 2
ICU	64%	57%	105%	88%
LOS	B	B	G	E

5. CONCLUSION

The present report focuses on evaluating the effect of changing in pavement marking on traffic operations of US 34/US 85 interchange's ramps located in Evans, Colorado, USA by considering two proposed plans. The purpose of this action was to improve the safety of conflicting areas in order to minimize the possibility of accidents. Different measures of effectiveness have been analyzed to evaluate the performance of each plan, including travel time, total delay, total stops, and LOS. Finally, according to the Synchro/SimTraffic simulation results, the best design (proposed plan 2) was selected by Jacobs Engineering Group as the optimum plan and proposed to Colorado Department of Transportation for further action.

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