A Decision-Making Framework to Evaluate Traffic Control Strategies on Freeway Work Zone

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Abstract

Road construction and maintenance activities cause significant impacts on traffic conditions. This paper developed a simple and practical work zone simulation model to provide a decision-making framework that can be used to evaluate various work zone traffic control strategies. This freeway work zone simulation model was programmed as Visual Basic language within a commercial spreadsheet program, EXCEL, in order to access and use easily. We expect that officials and contractors related to transportation will be able to make use of this software tool in regular work zone planning activities.

Keywords: *Work zone, Freeway, Simulation*

1. Introduction

Construction and maintenance activities around work zone areas will result in significant impacts on traffic conditions, such as reducing freeway capacities, increasing delay to road users, and increasing accident rates and fuel consumption. In particular, lane closures will be required for several types of work activities such as pavement repair, resurfacing, asphalt removal, installation of pavement markers, etc. Therefore, work zone traffic control strategies and methods must be carefully planned, selected, and applied to minimize those inevitable impacts. There are several issues that should be answered in work zone maintenance activities such as

- Is there any feasible work plan that minimizes delay costs among several types of work plans?
- When a specific work plan is selected, what is the maximum delay and maximum queue that encountered by a driver?
- When and how long can we work under the Department of Transportation (DOT) policy (*e.g.*, max. delay < 25 minutes)?

However, there have been not many studies to develop real decision-making framework, which can be used to help DOT officials or contractors answer those questions. Therefore, the purpose of this paper is to develop a simple and practical work zone simulation model to provide a decision-making framework that can be used to evaluate various work zone traffic control strategies.

2. Literature Review

Freeway maintenance issues concern transportation engineers, structural engineers, and construction management engineers, with different groups focusing on different aspects. Previous studies related to simulation model of work zone are very few and limited in scope.

Many studies were conducted to estimate work zone capacity based on field data analysis. Kermode and Myyra [1] collected capacity rates for some typical maintenance and construction operations on freeways in the Los Angeles area to determine the effects of lane closures and help improve operation of freeways during lane closures. Dudek and Richards [2] performed capacity studies at urban freeway maintenance and construction work zones in Houston and Dallas. Studies were conducted on 5-, 4-, and 3-lane freeway sections. These capacity values have been used as guidelines for the work zone analysis in the Highway Capacity Manual (HCM) [3]. Krammes and Lopez [4] updated these capacity values for short-term freeway work zone lane closures in the early 1990s. Other studies [5-7] also were conducted to obtain the mean capacity for different types of work zone lane closure configurations.

McCoy, *et al.*, [8] developed a method to optimize the work zone length by minimizing the road user and traffic control costs in construction and maintenance zones of rural four-lane divided highways. This method provided a framework for optimizing the lengths of work zones by minimizing the total cost, including construction costs, user delay costs, vehicle operating costs, and accident costs. Schonfeld and Chien [9] developed a mathematical model to optimize work zone lengths and traffic control on two-way highways where one lane at a time was closed. By considering the aggregate effects of various work zone lengths and combined flow rates, their method provided a practical approach for reducing both traffic delays and maintenance costs. In that study, traffic control and work zone lengths are jointly optimized, while unbalanced traffic flows in both directions were considered.

Memmott and Dudek [10] developed a computer model, called Queue and User Cost Evaluation of Work Zones (QUEWZ), and estimated the average speed in work zones to calculate user costs, including user delay costs and vehicle operating costs. A method for estimating vehicle delays and queue lengths on two-lane highways operating under one-way traffic control was developed by Cassidy and Han [11]. Recently, FHWA [12] developed an analytical tool to estimate and quantify work zone delays, called QuickZone. The QuickZone concept is to provide an easy-to-use, easy-to-learn tool that utilizes software tools that are familiar to the target user base. QuickZone compares the traffic impacts for work zone mitigation strategies and estimates the costs, traffic delays, and potential backups associated with these impacts.

3. Work zone simulation model development

Work zone simulation model developed in this paper is a user-friendly software, which is easy-to-use spreadsheet tool based on Excel with Visual Basic provided by Microsoft, US. The program will estimate and quantify work zone delays and queue lengths, and provide a decision-making framework that can be used to evaluate various freeway work zone traffic control strategies. In the model, it is assumed that the interarrival time follows exponential distribution and service time is deterministic. First Come First Service (FCFS) discipline was applied to this model.

The program is divided into 3 modules: Input Module, Control Module and Output Module as follows:

- Input Module: Enter 24-hour traffic volume data, project information related to work zone plan, interarrival seed.
- Control Module: Run the work zone simulation program and clear all demand and project data.
- Output Module: Provide delay graph and summary table.

Figure 1 and 2 show main screen of work zone program and delay graph over a day period from the simulation respectively.

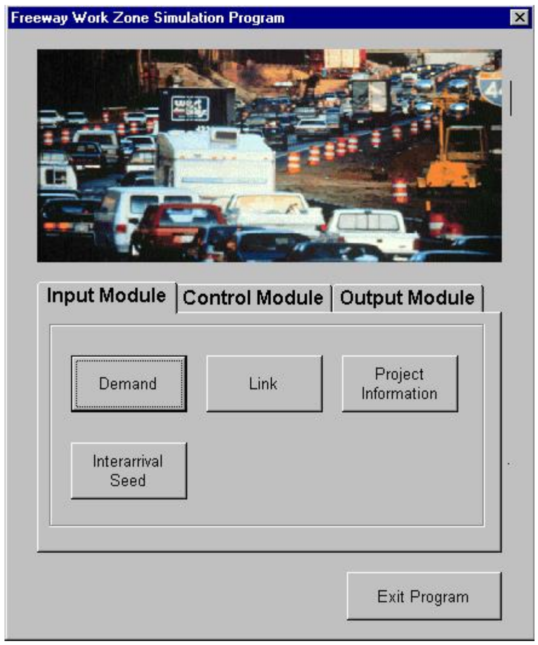

Figure 1. Main screen of work zone simulation program

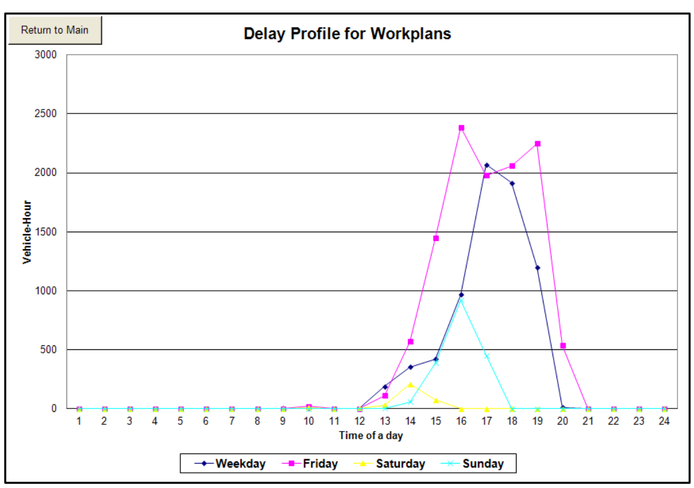

Figure 2. Example of delay graph over a day from the simulation

4. Model applications

To apply freeway work zone simulation model to different situations, three alternatives were considered in this paper. The following Table 1 and Figure 3 explain the configurations of each alternative respectively. Alternative 2 has the longest work zone length, 1.5 mile and light work activity. Alternative 1 has 1.0 mile of work zone and heavy activity and alternative 3 has the shortest work zone length, 0.5 mile and heavy activity. Alternatives 1 and 2 have the same work duration, but work duration of alternative 3 is shorter than those of other alternatives.

Table 1. Key factors on a one-way divided highway

Configuration	Alternative 1	Alternative 2	Alternative 3
Number of Closed lane	1	1	2
Location of Closed Lane	Right	Right	Right
Percentage of Heavy Vehicle	5%	5%	5%
Lateral Distance to Opened Lane	1 foot	1foot	1 foot
Work Zone Length	1.0 mile	1.5 mile	0.5mile
Work Zone Grade	1%	1%	1%
Intensity of Work Activity	Heavy	Light	Heavy
Work Duration	**Alternative 1**	**Alternative 2**	**Alternative 3**
Weekday	10:00-16:00	10:00-16:00	10:00-13:00
Friday	9:00-15:00	9:00-15:00	9:00-12:00
Saturday	7:00-14:00	7:00-14:00	7:00-10:00
Sunday	9:00-16:00	9:00-16:00	9:00-12:00

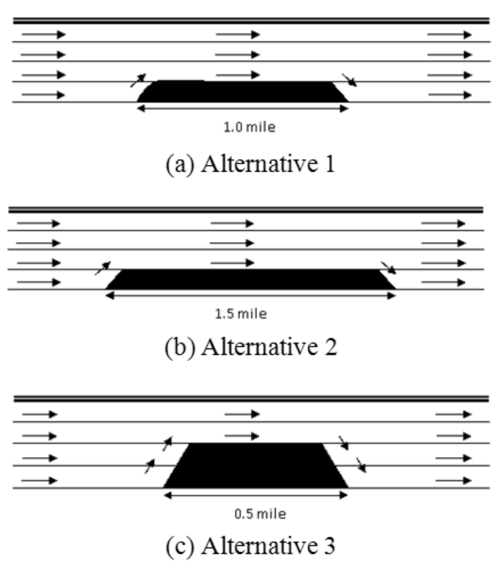

Figure 3. Visual configurations by each alternative

To perform multiple replications, each alternative was simulated by 10 replications, respectively and different seeds were used at each independent replication. For variance reduction technique, Common Random Number (CRN) method was used. Therefore, the same seeds were used to each alternative in order to perform multiple comparisons.

The results of simulations for alternatives 1, 2 and 3 are tabulated in Tables 2 and 3. The performance measures of interest are weekly total delay, max. delay and max. queue length. Figure 4 shows average total delay for day of week by each alternative.

Table 2. Average total delay for 10 replications

Alternative	Average Total Delay (veh-hour)				
	Weekday	Friday	Saturday	Sunday	Weekly total
1	12158.385	16572.686	1041.863	3819.277	70067.367
2	6678.754	11596.198	314.697	2036.111	40662.021
3	9829.101	11013.255	3366.250	1427.858	55123.766

Table 3. Max. delay and max. queue length

Alternative	Max Delay (min)				Max Queue Length (mile)			
	Weekday	Friday	Saturday	Sunday	Weekday	Friday	Saturday	Sunday
1	27.960	31.250	10.069	22.763	4.035	4.534	1.134	2.657
2	18.060	23.604	4.405	13.764	2.634	3.484	0.495	1.602
3	51.881	59.010	35.146	22.122	5.924	4.940	3.516	1.755

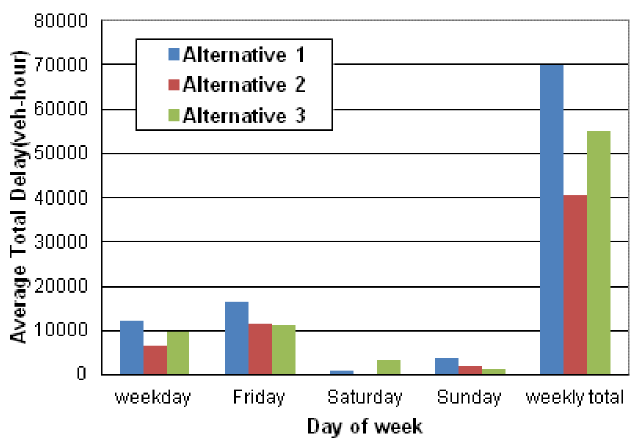

Figure 4. Average total delay for day of Week

As shown in Table 2 and Figure 4, weekly total delay of alternative 2 is smaller than other alternatives. But, we cannot decide yet which alternative really is the best of them.

In case of alternatives 1 and 3, specific days' max delays are more than 25 minutes. For example, Friday's max delay of alternative 1 is 31.25 minutes. As mentioned before, we can see intuitively alternatives 1 and 3 cannot be allowed to work based on Department of Transportation (DOT) policy.

We constructed 95% confidence interval of weekly average total delay for each alternative as shown in Table 4 and Figure 5. Three alternatives have the big differences from each other. Alternative 2 has better result than others.

Table 4. 95% C.I. of weekly average total delay(veh-hour)

Alternative	Average Weekly Total Delay	Variance	95% Half Length	Interval
1	70,067.367	3,507,602.32	1,339.670	[68,727.697, 71,407.037]
2	40,662.021	2,974,631.74	1,233.699	[39,428.322, 41,895.720]
3	55,123.766	3,051,639.24	1,249.566	[53,874.200, 56,373.332]

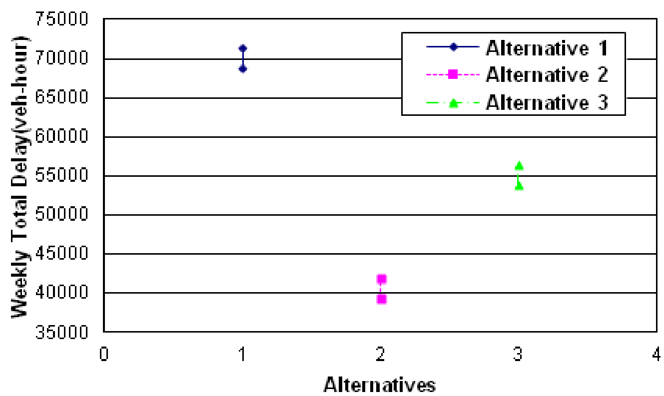

Figure 5. 95% C.I. of weekly average total delay

For multiple comparison procedure, multiple comparisons with the best (MCB) method were used as shown in Table 5 and Figure 6. The goal of MCB is to form simultaneously confidence interval for the differences between the mean of each of three alternatives and find the best among alternatives. From Table 5 and Figure 6, obviously alternative 2 is the best of them.

Table 5. MCB C.I. of weekly average total delay(α=0.2)

Alternative	$\overline{X}_i$	$\overline{X}_i - \min_{i \neq j} \overline{X}_j$	Half-Width	Interval
1	70,067.367	29,405.346	1,084.782	[0, 30,490.129]
2	40,662.021	-14,461.745	1,084.782	[-15,546.528, 0]
3	55,123.766	14,461.745	1,084.782	[0, 15,546.528]

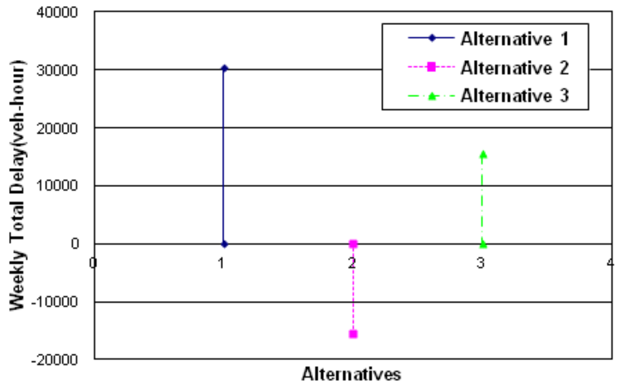

Figure 6. MCB C.I. of weekly average total delay(α=0.2)

Therefore, by this output analysis, we can say that alternative 2 is the best of them and in the cases of alternatives 1 and 3, they should be modified on work duration or other configurations of each alternative.

5. Conclusions

Throughout this project, user-friendly work zone simulation program has been developed to help decision makers evaluate various work plans. Freeway work zone simulation program was written as Visual Basic within a commercial spreadsheet program, Excel, in order to access and use easily. We hope that DOT officials and contractors will be able to make use of this software tool in regular work zone planning activities.

There are many traffic-related impacts of work zone and these impacts can be converted into an appropriate economic context so that they can be combined with real costs of providing traffic control, accident-related costs, and other costs to provide a decision-making framework for programming and deployment decisions. A framework needs to be developed for the economic evaluation of work zone traffic control strategies.

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