PLANNING HIGHWAYS RESURFACING USING COMPUTER SIMULATION

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ABSTRACT
Resurfacing highway project is one of the complex projects that are characterized by repetitive operations, difficult construction environment, and different construction tools. Such characteristics lead to uncertainties with respect to estimated duration and resurfacing cost. This paper presents a framework that is used for planning of highways resurfacing using computer simulation and optimization. The proposed framework has two features; 1) planning of repairing highways, and 2) selecting work zone length that achieves minimum total cost and total duration. A numerical example is presented to demonstrate the use of the proposed framework.

Keywords: highways resurfacing, computer simulation, optimization, generic algorithms

1. INTRODUCTION
Work zones often cause traffic congestion on high volume roads. As traffic volumes increase so does work zone-related traffic congestion. Negative impacts on road users can be minimized by bundling interventions on several interconnected road sections instead of treating each road section separately. Negative impacts on road users can be quantified in user costs. The optimum work zone is the one that results in the minimum overall agency and user costs. The minimization of these costs is often considered in planning. In order to achieve this goal the interventions on each asset type (pavement, bridges, tunnels, hardware, etc.) must be bundled into optimum packages. Hajdin and Lindenmann (2007) presented a method that enables road agencies to determine optimum work zones and intervention packages. The method allows the consideration of both budget constraints and distance constraints, including maximum permissible work zone length or minimum distance between work zones. The mathematical formulation of this optimization problem is a binary program that can be solved by existing techniques (i.e., the branch-and-bound method).

Pavements on two-lane two-way highways are usually resurfaced by closing one lane at a time. Vehicles then travel in the remaining lane along the work zone, alternating directions within each control cycle. Several alternatives can be evaluated. Each alternative is defined by the number of closed lanes and fractions of traffic diverted to alternate routes. Chen et al. (2005) defined an algorithm, referred to as SAUASD (simulated annealing for uniform alternatives with a single detour), to find the best single alternative within a resurfacing project. It searches through possible mixed alternatives and their diverted fractions, to minimize total cost, including agency cost (resurfacing cost and idling cost) and user cost (user delay cost and accident cost). Thus, traffic management plans are developed with uniform or mixed alternatives within a two-lane highway resurfacing project.

Wang et al. (2002) proposed a hybrid genetic algorithm-microscopic traffic simulation methodology for scheduling of pavement maintenance activities involving lane closures aiming at minimizing network traffic delay. Genetic algorithm is implemented as an optimization tool for the generation and selection of maintenance schedules. For each possible schedule, a microscopic traffic simulation model is used to simulate traffic operations in the network to estimate the delay caused by lane closures. This concept has been implemented using genetic algorithm written in the C language and simulation carried out by PARAMICS. This hybrid methodology combines two different approaches: genetic algorithm (GA) and microscopic traffic simulation.

In each GA generation, a population of schedule is generated. Each schedule refers to the spatial and temporal scenario of lane closures in a network over a 24-hour period. Each lane closure schedule is simulated several times, each with a different random number seed. This is to average out any bias in the results (total traffic delay) caused by the random number seed in the simulation input. At the end of each simulation run, the total travel time is fed back to the GA program for delay calculation. GA then evaluates the relative merit of each lane closure schedule by comparing the average total traffic delays, and uses better schedules to produce next generation of solutions. The process continues until a pre-defined generation size is met. Then, the schedule with least total traffic delay is recommended. To arrive at a near optimal lane closure schedule, the GA search process needs to evolve through many generations, and each generation contains a population of chromosomes. For each unique chromosome, several simulation runs need to be carried out with different random number seeds. Therefore, hundreds of simulation runs are anticipated. The impact on traffic due to construction projects is not completely inevitable. However, for a project that requires multiple work crews, the impact on traffic can be improved by means of the appropriate schedule. This is because of the “simultaneous operations”. Different types of construction projects set up work zones on roads. Especially in urban areas, lane-closures as a result of work zones have a considerable impact on local traffic. However, for a construction project that consists of several work zones and several work crews, the traffic impact may be improved by appropriate scheduling. Lee (2009) proposed a scheduling model based on the route-changing behavior of road users. The proposed model calculates traffic delay of vehicles by microscopic simulation, and applies team ant colony optimization to search for a near-optimal schedule.

2. WORK ZONE SAFETY

Work zone safety has been a research focus for many years and improving the safety in highway work zones is a high-priority task for traffic engineers. Yingfeng and Yong (2009) explained evaluating the effectiveness of the Temporary Traffic Control (TTC) methods used in highway work zones which would help traffic engineers to identify traffic control deficiencies, and thus, make continuous improvement in safety. In this study, the effectiveness of several TTC methods (including flagger/officer, stop sign/signal, flasher, no passing zone, and center/edge lines) in mitigating work zone crash severity and preventing common human errors from causing severe work zone crashes was quantified using a logistic regression technique. The findings may provide valuable knowledge for traffic engineers in understanding the effects of the TTC methods on the severity or involvement of certain human errors in work zone crashes. They may also provide insights on safety implications of the work zone environment associated with each evaluated TTC method. According to the logistic regression analyses, the presence of a flagger or officer directing traffic could reduce the odds of having fatalities in a severe crash; having flashers or center/ edge lines in work zones could reduce the odds. However, based on the available crash data, the statistics did not support close associations between the usages of stop signs/signals and no-passing-zone control in work zones and fatality involvement in severe crashes.

Regarding the effectiveness of TTC methods in preventing common human errors from causing severe crashes in work zones, the evaluation showed that flaggers/officers could considerably lower the odds of severe work zone crashes caused by human errors such as "disregarded traffic control," "inattentive driving," and "exceeded speed limit or too fast for condition." No-passing zone control in work zones was effective in reducing the odds of having severe crashes caused by "disregarded traffic control". In addition, having center/edge lines in work zones could lower the odds of having severe work zone crashes caused by human errors such as "exceeded speed limit or too fast for condition" and "followed too closely." However, having stop signs/signals in work zones would dramatically increase the odds of having severe crashes caused by "followed too closely" human error. Logistic regression analyses were used to assess individual TTC methods so that quantified estimations of the effectiveness of each TTC could be obtained. The actual effectiveness of these methods may vary when used in combination with other traffic control devices and/or work zone conditions. This research can be extended in several ways. Fatal crash data from other sources could be added to increase the total number of fatal cases in order to improve the reliability of the analysis (Yingfeng and Yong 2009).

3. PROPOSED SYSTEM

This research presents a framework, named *Resurfacing_Sim*, which helps contractors in planning of highway resurfacing operation (Fouad 2011). The developed framework performs planning and optimizing resurfacing highway and selects optimum length of work zone based on minimum total cost and total duration. These two functions are performed by two main components, simulation module and optimization module. The following sub-sections describe the developments made in these two modules.

3.1. Simulation Module

Developing a simulation model requires a sequence of tasks to represent the resurfacing operation, the relationships between these tasks. To simulate the process of highways resurfacing, the steps of simulation experiment are performed:

1. Define General data: General data include number of working hours per day, number of lanes, number of working days in week, number of work zones.
2. Define Zones data: Assigning labor crew types, number of crews, the number of utilized equipment, and production rates of the different crew types and equipment.
3. Define Tasks data: The contractor estimates the duration of involved tasks and materials costs. The framework provides the contractor with the probability distributions to estimate task duration; Normal, Uniform, Triangular, Part, and Pertpg distributions.
4. Run Simulation Module: After feeding input data, the Simulation Module estimates total duration and after that it calculates total cost for each zone. The contractor has to define two values of two simulation parameters; number of simulation runs and confidence level. These two parameters are required to account for probabilistic input data.

5. Output results: As referred to earlier, the simulation module estimates the total duration and total cost for each zone.

Converting traffic flow involves three main processes: 1) laying safety control devices, 2) breaking concrete platform and median, and 3) removing the broken concrete from work zone. Table 1 lists processes and tasks of converting traffic flow, whereas, Table 2 lists the types of resources that are needed to converting traffic flow. The input parameters that are used in the tasks are listed in Table 3. Figure 1 depicts the element of the network that captures the Converting Traffic Flow. Similarly, simulation networks are developed for the remaining processes including; modeling reconstruction of semi-rigid paving process and modeling reconstruction flexible paving and finishing process.

3.2. Optimization Module

The cost per lane-kilometer is the objective function for the optimization module. It consists of three components as shown in Equation 1. These components are; i) maintenance cost per lane-kilometer (C_m), ii) delay cost per lane-kilometer (C_u) including queue delay cost and moving delay cost, and iii) accident cost per lane-kilometer incurred by traffic passing the work zone (C_u).

Table 1: Processes and Tasks of Converting Traffic Flow

Process	Task
Laying safety control devices	Safetydevices
Breaking concrete platform & median	BrkenPlateform
Removing broken concrete from work zone	Load
	Haul
	Dump
	Retune

Table 2: Resources used in Converting Traffic Flow Tasks

Resource Type	Resources
Labors	Safety crew
Equipment	Loader – Jack hummer – Trucks
Materials	Area of Work Zone – Volume of Waste Materials

Table 3: Input Parameters of Converting Traffic Flow Model

Parameter	Description
AWZ	Area of Work Zone
VOSOIL	Volume of waste material
NOJAC	Number of jack hummer
NTRUCK	Number of trucks
NOLOD	Number of loaders
SC	Number of safety crew

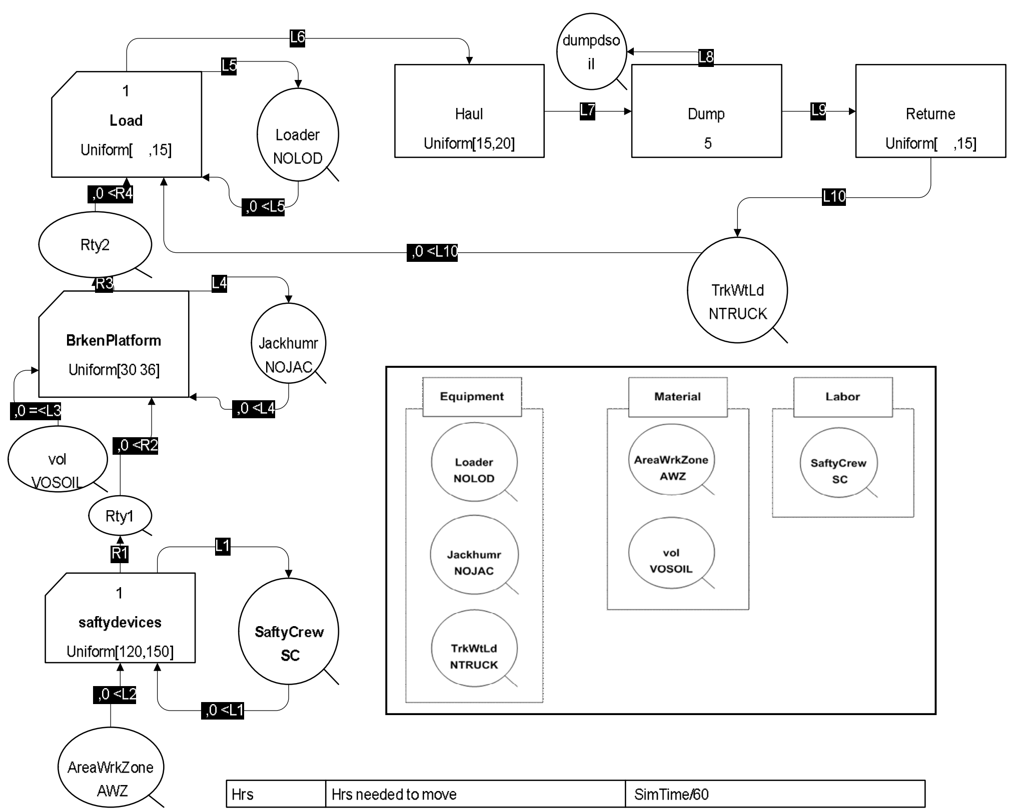

Figure 1: Converting Traffic Flow Simulation Network

$$C_T = C_m + C_u + C_a \quad (1)$$

The optimization variables are defined as any entities within studied system, where any change in this entity would seriously affect the observed optimization functions. Based on interviews with expert engineers and extensive analysis of resurfacing operation, optimization variables have been determined. Six optimization variables are considered:

1. *Hourly Flow Rate in Direction 1 (Q_1):* Number of vehicle in the same direction with work zone.
2. *Hourly flow rate in Direction 2 (Q_2):* Number of vehicle in opposite direction against work zone.
3. *Average maintenance time per lane-kilometer (Z_4):* the required duration for maintenance for each lane per kilometer
4. *Work zone length (L):* the optimum length for work zone that decreases delay in traffic time and decreases accidents.
5. *Average work zone speed (V):* speed of vehicle at work zone.
6. *Average headway (H):* the time of the distance between two vehicles as shown in Figure 2.

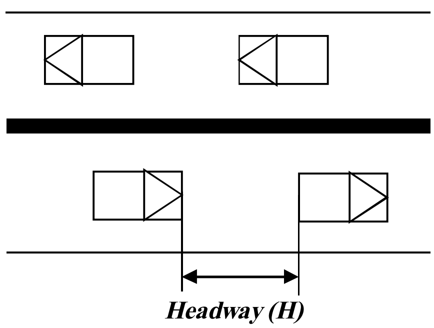

Figure 2: Average headway

4. NUMERICAL EXAMPLE

In order to demonstrate the use of the developed framework in optimization highways resurfacing operation, an actual project example is considered. The example involves a highway with a length of 15 Km. Some of parameters are considered constant for the project such as: 1) fixed cost for setting up a work zone (z_1), 2) average additional maintenance cost per work zone unit length (z_2), 3) setup time (z_3), 4) value of user time (v), 5) road original speed in normal conditions (V_0), 6) number of accidents per 100 million vehicle hours (n_a), and 7) average cost per accident (v_a). These parameters are listed in Table 4. The other parameters are considered optimization parameters which are listed in Table 5.

Several experiments have been carried out to test the performance of the optimization module against different values of crossover threshold (CO), mutation threshold (m), and number of generations (G). Figure 3 shows the change in Total cost at different mutation thresholds. Whereas, Figure 4 shows the change in total cost at different crossover thresholds. The results reveal that solutions are too sensitive to both crossover and mutation values. For this road example, best solutions for minimum cost are obtained at CO=0.5 and m=0.1.

Table 4: The Value of Input Parameters

Parameter	Value
Z_1	80 L.E/Zone
Z_2	160 L.E/Lane. Km
Z_3	10 hr/Zone
v	12.7 L.E/Veh. Hr
V_0	80 Km/ hr
n_a	67 Accident/ 100mvh
v_a	17.6 L.E/ hr

Table 5: Optimization Parameters

Parameter	Minimum Value	Maximum Value
Q_1	3000 Veh/hr.	5000 Veh/hr.
Q_2	3000 Veh/hr.	5000 Veh/hr.
Z_4	10 Hr/Lane.Km	20 Hr/Lane.Km
L	1 Km	15 Km
V	10 Km/ hr	15 Km/hr.
H	2 sec	10 sec

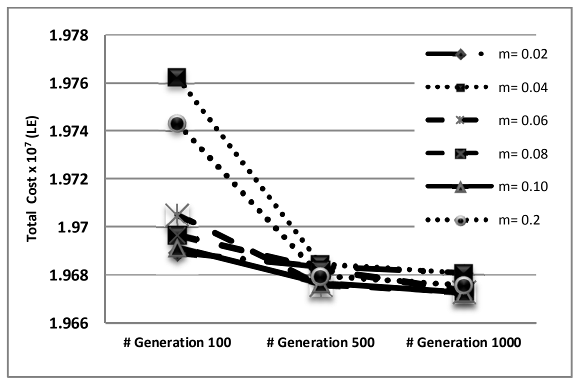

Figure 3: Total Cost vs. No. Of Generations at Different Mutation Thresholds (CO= 0.5)

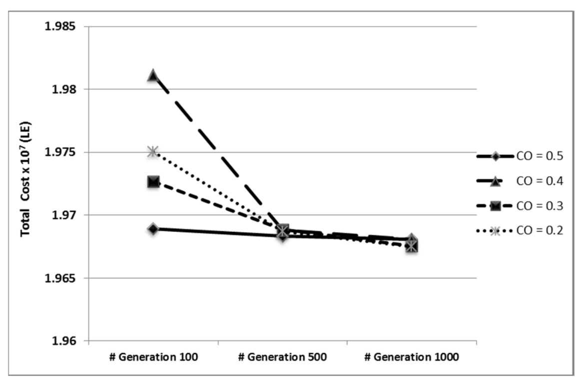

Figure 4: Total Cost vs. No. Of Generations at Different Crossover Thresholds (m = 0.02)

5. SUMMARY

This paper presented a framework that is dedicated for highways resurfacing using computer simulation and optimization. The framework consists of two main components; simulation module and optimization module. Simulation module is responsible for estimating total duration for each zone. The simulation module is implemented using the Microsoft Visual basic 6.0 programming language and it utilizes STROBOSCOPE (general purpose simulation language) as simulation engine. It estimates the duration for each resurfacing zone which is used to calculate the total duration and total cost for the overall highway resurfacing operation. The total cost is essentially the objective function of optimization module. This cost is calculated by summing up the direct cost (resurfacing operation cost), indirect cost, and the cost of the impact of work zone on road. The optimization module considers six optimization variables including; i) hourly flow rate in Direction 1, ii) hourly flow rate in Direction 2, iii) average maintenance time per lane-kilometer, iv) work zone length, v) average work zone speed, and vi) average headway. A numerical example was presented to demonstrate the main features of the proposed framework.

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