Incorporating User Delay Cost in Project Selection: A Canadian Case Study

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ABSTRACT

Multi-million dollar contracts, economic impact on industries and public satisfaction are factors agencies, dealing with transportation infrastructure, must deal with regularly. It is clear that construction is necessary to maintain or upgrade the current roadway infrastructure in Canada. The long-term result is a smooth, comfortable and safe road for motorists. Short-term effects, especially to the traveling public, will be difficult, primarily through delays and an increase in vehicle operating costs. Determination of such costs may be performed at the project level. However, this information is rarely implemented into the selection of the best alternative treatment, leading to potential disaster to the traveling public at the onset of construction.

The cost of delays associated with freeway repairs and upgrades is typically borne by the motorists themselves. As a means of alleviating public frustration, the costs that have been relegated to the public are being incorporated into the project selection. This will allow the agency to select an alternative that will be economically feasible with minimized public impact.

The purpose of this study is to analyze the user delay cost not only during construction on an existing facility, but the delays caused by routine maintenance activities. A computer model which utilizes a mechanistic-empirical design protocol was used to assist in determining a performance curve for various types of functional classes within the Ontario road network. Focus in this study is primarily on a two-lane facility that requires a single lane closure related to construction activities. Traffic control, such as flag persons, is assumed to be required. Converting time delays encountered by the motorist, a quantitative value of delay cost is revealed to be significant. It is recommended to incorporate user costs, including delay and vehicle operation, in project alternatives prior to final project selection.

INTRODUCTION

Construction is necessary to maintain or upgrade the current roadway infrastructure in Canada. The long-term result is a smooth, comfortable and safe road for motorists. Short-term effects, especially to the traveling public, will be difficult, primarily through delays and an increase in vehicle operating costs. Determination of these costs may be performed at the project level. However, this information is rarely implemented into the selection of the best alternative treatment (*1*). Yet the entire cost of the delay is associated to the traveling public.

American highway agencies have encountered staggering delay costs associated with lost production and vehicle operating costs. Financial impacts to the manufacturing sector, using the affected route as a major supply artery for just-in-time delivery, are staggering. In 1992, financial losses due to delays grew six percent from $48 billion US to $51 billion US in 1993 (*2*). This trend has resulted in highway agencies proceeding to quantify such values and investigate methods to reduce user delay costs over the life cycle of the facility.

Agencies, such as the Ministry of Transportation of Ontario (MTO), are shifting to include costs imposed to the public due to delays in forecasted maintenance activities and to mitigate such cost at the project level. A larger emphasis to select a design with less of an economical impact to the public is the goal. The purpose of this paper is to understand the magnitude of the delay cost not only at initial construction, but throughout the entire life cycle of the facility.

Prior to analyzing available systems to simulate cost of delays, it is important to understand the delays associated with construction zones. Examining the amount of time lost by the road user using predetermined models and several educated assumptions will be followed by an economic analysis of the value of time. Finally, the life cycle cost of different functional classes of highways will be analyzed with the assistance of the program Ontario Pavement Analysis of Cost (OPAC) 2000. This is a mechanistic-empirical design program which incorporates both engineering and advanced statistics.

OBJECTIVES AND SCOPE OF STUDY

As user delays are becoming an important factor in project selection, analysis of its magnitude is one goal of this study. It is not only the initial construction delay, but delays caused by future maintenance over the entire service life. Furthermore, the differences among functional classes, particularly in Ontario, are important to understand as their volume and configurations vary. Finally, methods to mitigate delays through construction zones are investigated.

This study will be based on Ontario highway facilities that encompass both two- and multi-(four) lane designs. Emphasis will be towards construction work zones that require a single lane closure for two-lane facilities. Multi-lane freeways will have a single lane closed in both directions. Both cases are based on an approximate capacity reduction of 50% through the construction zone. For the cases that require a common through lane for both directions, traffic flow control utilizing flag persons is assumed. Green and cycles time are based on AADT.

Traffic data, pavement structure and maintenance activities have been taken from the 1997 MTO study on heavy vehicles (*3*). Focus has been on Ontario scenarios, values and performances. Therefore variation on the final results may exist when compared to other provincial jurisdictions due to variability in the data used. Types of work zones are isolated to single lane closures while in the field, there exists many closure scenarios that may have dissimilar results. Delays due to an incident within the work zone are beyond the scope of this study.

The impact of heavy vehicles traveling through the work zone is substantial. Primary cause of such influence is due to the acceleration and deceleration ability of these types of vehicles. Analysis of such impact was also beyond the scope of this study but it is recommended to pursue such investigation as the proportion and types of heavy vehicles through a given work zone will impact the travel time of the motorist. Figure 1 describes the methodology used in this study to calculate delays and costs.

CAUSE OF DELAYS IN WORK ZONES

Construction zones are similar in nature to incident zones due to traffic accidents. Lane closures are common in both cases while the primary difference is the zone of influence. A construction work zone is typically stationary and scheduled with advanced public notice. Incident zones are frequently sporadic and unpredictable. Recently, changeable message signs have been deployed throughout high volume freeways allowing drivers to select alternative routes to avoid delays.

Lane Closures

Selection of the lane to be closed is predetermined prior to construction. With all lanes available to the motorists, normally the level of service is acceptable. However, once a particular lane is severed from the road network, capacity through the work zone reduced. This creates a localized drop in the level of service approaching the construction zone. On multi-lane facilities, vehicles will be required to merge to adjacent lanes. Figure 2a and 2b illustrates a typical work zone layout while Figure 2c and 2d illustrates the resultant congestion that occurs due to lane closures compared to the free flow scenario. This increases the traffic volume in the through lane causing the capacity within the work zone to potentially reach the ceiling value. It is analogous to the bottleneck in a manufacturing process. Throughput is dependant on the component that can process the least volume per hour, in this case the construction zone.

Safety and Delays

An inherent hazard exists for all construction workers dealing with road repairs or reconstruction. Safety of these workers is of great concern for the agency involved as there is a direct link between safety and the mobility of the motorist (*4*). In fact, as congestion increases, so does the risk of an incident occurring. Ironically, once an incident arises, congestion will continue increase as vehicle throughput is suddenly further restricted. Therefore maximizing the safety of the motorist and of the construction workers will lead to significant delay reductions and increased volume through the work zone.

The probability of an accident increases with the magnitude of the speed differential among surrounding vehicles. Location of the incident within the construction zone will vary, but there is a high likelihood that an incident will occur within the merge zone at the work zone approach. Results of studies investigating incident mitigation in construction zones suggest several recommendations (*5*). For instance, a gradual speed reduction at the approach will allow drivers to merge safely. This will control the slowing time while reducing or eliminating the queuing time. Advising drivers to merge at a "merge point" will maximize capacity through the construction zone. A "late-merge study" conducted by the University of Nebraska found an achievable capacity increase of 18%. Finally, by increasing the information to drivers, through portable changeable message signs, at the work zone approach will mitigate driver confusion and allow drivers to choose alternate routes if desired.

Delays and the Public

The traveling public demands several key issues to be met when traveling on public roads. A survey conducted by the Federal Highway Administration in 1995 investigating factors that affect public satisfaction on public highways found traffic flow, safety and pavement condition are priority to the public (*2*). Essentially, the public desires good quality repairs to be done without restricting capacity at the same time. One compromise is to perform repairs at night when traffic volumes are reduced. Unfortunately, quality of work under these conditions is an issue and will likely require frequent intervention to prolong its service life.

Constructing a quality product initially will reduce the frequency of work zones being erected to repair deficiencies. In some cases, short-term severe capacity reductions, although not publicly popular, may lead to a higher quality product. Ultimately, a life cycle cost analysis is required, incorporating user delay as a factor in the decision methodology.

DELAYS

A reduction in speed through an affected area will cause delays to the traveling public. A value associated with such delays will give a quantifiable measure of the economic loss to the road users. For example, slowing, queuing and detour delays are typically encountered in a construction zone.

Slowing Delay

The approach to a construction zone will typically require a reduction in speed. Travel at reduced speed results in an increase travel time compared to normal free flow conditions over the work zone length. This increase in time is the slowing delay.

Justification of enforcing reduced speed limits is primarily to enhance safety for both the construction workers and the traveling public. In the event construction requires a lane closure on a multi-lane highway or freeway, vehicles of the affected lane will begin to merge to adjacent through lanes. Most drivers will merge early once they are aware of the lane closure. Unfortunately, this reduces the throughput of vehicles through the construction zone. A reduction of 75% in the frequency of merging incidents resulted from the "late-merging" study (*5*).

Work zone layout will have an important role in dictating comfortable vehicle velocity for the driver. Rister and Graves (*6*) analyzed the cost of construction delays and studied various factors. Through their research, the positioning of the work activity with respect to the through lanes will affect the speed of vehicles. In fact a work zone shift of three feet towards the through traffic will inherently reduce vehicle speeds by two miles per hour (*6*). Also reduced throughput (vehicles per hour per lane) of 9 and 14 percent are observed if the lane widths are reduced from 3.4 m to 3.0 m and 2.7 m respectively.

Queuing Delays

Many studies have investigated the cause and modeling of such delays. Two categories of queuing exist: horizontal and vertical. A vertical queuing model, such as the Pollaczek-Khintchine formula, describes the time a vehicle spends in any given system (*7*). This formula will yield the mean queue length including the length of the construction zone through the inputs of the road capacity and the time standard deviation while in the construction zone. Through substitutions, a crude model depicting stationary queues is derived. However, this model is based on drivers attaining individual desired speeds and vehicles are stationary instantaneously prior to entering the work zone; a rare case for a partial lane closure for a multilane facility. The former assumption cannot realistically be achieved as an excessive number of vehicles would occupy the work zone boundary at any given point. Transient queues also described by Heidemann (*7*), are realistic in most situations for partial lane closures. Vehicles will vary their speed and density approaching the construction zone.

User Delay Costs

Construction of public infrastructure will typically involve two key players that share the costs. The agency will bear a substantial portion of expense. However, the community may also be affected, substantially in the case of road or freeway repairs or upgrades. The cost to the latter is typically borne by the motorists themselves (*8*). The cost to the public is being incorporated into project alternative selection ensuring a satisfied customer; the road users. This will allow the agency to select an alternative that will be economically feasible with minimized public impact.

Total user delay cost due to construction is divided into two factors: delay time and delay cost. The product of both time and cost will yield the user delay cost. Time delay may be divided into three categories. First is the speed reduction time, the second is the idle or queue time and third is detour time (if applicable). The former relates to the speed differential from normal flow, typically at the posted speed limit, to the construction zone speed. This can vary depending on the volume and the work performed. All delays have been calculated in accordance with the Transportation Research Board Highway Capacity Manual (*9*).

Normal vehicle velocity traveling through the work zone is first calculated. Reduced speed through the work zone due to delays is then calculated. These velocities are then used to calculate the slowing delay due to the aforementioned traffic control plan.

Queuing delays are also required for the overall delay calculation. Typically this occurs when volumes exceed capacity whereby queuing is forced. Detours may be necessary depending on the type of work so delays associated with detours are included in this analysis.

There exist several methods of obtaining the delay cost per hour for the user. Tighe et al. (*10*) utilizes a bi-weekly income range of $1750 to 2500 originally derived by Kazakov et al (*11*). This value is reduced to an hourly rate and may be used as a unit rate ($/hr) for delay cost calculations. In this study, an estimated hourly delay rate of $25/hr CDN (or $17/hr US) was used. Other hourly delay cost rates, adapted from Rister and Graves (*6*) range from $8.70/veh-hr US to $12.60/veh-hr US. This range of values illustrates the variability between values used by each agency in the United States of America to account for time lost on roads and highways.

Vehicle Operating Costs

Many factors are associated with an increase of vehicle operating costs (VOC). The obvious is the fuel consumption at idle or low speed during the slowing and queuing phases due to congestion. Depending on the length of the work zone and/or queue, combined fuel consumption of the queued vehicles may become significant.

Surface quality and roughness will affect the suspension and moving components of the vehicle. Rough surfaces, such as milled surfaces, along with horizontal discontinuities, entering or exiting a milled zone and potholes, will induce high stresses in the suspension and tires. Vehicle components, including brake components, will achieve its fatigue limit at an accelerated pace if the vehicle frequently encounters these severe surface distresses.

Accident or Incident Costs

Driver confusion and obstacle avoidance may lead to incidents. Depending on the severity and extent of an incident, the costs will vary. If a fatality occurs, it is difficult to assess a value for such a case. An estimated, yet arbitrary, value of $2.7 million per fatality has been recommended by the U.S. Department of Transportation (U.S.DOT) in 1995 (*6*). However, police investigation of such an event will force additional lane closures causing throughput to drop dramatically, leading to severe user delays. This will augment the cost of a fatality to over three million dollars. Rister and Graves (*6*) has published U.S. dollar values per fatality for several agencies to employ in their calculations. Values range from $3,025,984/fatality US to $3,414,179/fatality US for the U.S.DOT and FHWA respectively and are solely based on the immediate cost to compensate the families, medical costs and property damage. It is important to consider user delays for the other motorists and many researchers are currently investigating including such costs.

Rehabilitation Strategies and Long Term Costs

Understanding the long term effects on the road user is a key aspect of this study. Throughout the service life of a highway facility, remediation and rehabilitation strategies will occur to maintain acceptable ride quality. Each strategy deployed will have two differing aspects: time required to perform the repair and the projected service life of the repaired section. It is difficult to determine the exact values of each aspect as external factors will influence the result significantly.

Frequent minor intervention requires relatively reduced repair time at frequent intervals. The result of this type of strategy is a pavement structure that deteriorates at a reduced rate, prolonging major rehabilitation or intervention, hence reducing the delays associated with motorists.

Postponing remedial actions will reduce the frequency of minor delays. However, as the road structure is allowed to deteriorates, the required repair will be major and result in larger non-frequent delays. The lack of preventative maintenance on the facility will require significant intervention and increased delays and operating costs to the motoring public.

METHODOLOGY

Investigation of user delays on any given project alternative is the ultimate goal of this study. To achieve this, three areas are examined: delay time, delay cost, and the frequency of delays over the life of the alternative. It is assumed that agencies will elect to perform maintenance to prevent substantial loss on the initial asset investment.

Determining the delay time requires calculating the slowing and queuing delays. A third component, detour delay, was beyond the scope of this study. However, in the event significant deviation off the original alignment occurs, this component will contribute significantly to the total time delay. Lane closures will reduce the capacity of the facility causing an increase in congestion. Even though the actual capacity drop may range from 0% to 99% as presented by Maze et al. (*12*), the assumption of a 50% capacity drop is conservative. This variation is due to external factors including time of day, work zone layout, AADT and percent heavy vehicles. Values and schedules employed in the analysis are recommended structural, traffic and cost values based on 1997 figures (*13*).

Time delays, caused by slowing and queuing, are calculated per vehicle for each Ontario functional class listed in Table 1. Costs associated with delays are based on current market rates. As noted earlier there are a variety of values used by U.S. agencies. Tighe et al. (*10*) estimates a wage rate of approximately $25 per hour. This value was used in the delay cost calculation without modification as it is assumed to be in Canadian dollars and inflation is insignificant since the publication in 2002.

Changes in PCI with Maintenance Treatments

It is well known that performing maintenance on existing facilities will “extend” its service life. Each treatment will affect its performance. Quantifying such affects is difficult as there is variability within and between treatments. In addition, the extended life will be based on when the treatment is applied and whether or not it is appropriate for the given situation. Also, good workmanship can dramatically impact the performance of the maintenance. Overall, this variability associated with several factors is a primary factor in the overall ride and pavement quality improvement.

Publishing the change related to Pavement Condition Index (PCI), an index ranging from 0 to 100 (best) to summarize the state of the pavement at any particular time, is not common due to the variability discussed earlier. However, some studies have been published dealing with specific cases and situations. It should be known these PCI and International Roughness Index (IRI), an index rating system ranging from 0 to 10 (very rough) that illustrates the unevenness of the road surface, changes may not necessarily occur identically in the field due to the pavement system variation. The measured change in PCI and IRI quantifies the improvement or deterioration caused by various maintenance activities.

The Smadi et al. (*14*) study is based on data from the Iowa Department of Transportation Maintenance Management System. The study was simplified through combining similar maintenance activities and omitting those activities that do not directly improve the surface layer. Both programmed and routine maintenance activities were considered. PCI and IRI values range between 0 to 100 and 0 to 10 respectively.

The values in this study are similar to Samdi and were adopted for Ontario. In this case, the PCI which is used in Iowa is converted to IRI. Some caution is needed as for some of the activities there were very few results. For example the impact on the IRI value from an ACC resurfacing of a 2-lane facility, 51 to 64 mm lists only one observation. Using this value may not lead to a satisfactory assessment as the sample size does not invoke statistical reliability. Therefore maintenance activities that list low number of observations will require engineering judgment to improve the realistic values that are to be encountered in the field.

A limitation on OPAC 2000 is the performance graph that relates PCI with service life. Maintenance treatments are not included in this plot. This led to constructing an estimated plot of PCI with time incorporating the maintenance schedule. Due to the low number of observations for each maintenance activity, the values from Smadi et al (*14*) were modified to realistic values observed in the field. Values employed in the analysis are listed in Table 1.

Maintenance Activity Duration

In Table 1 there is a list of estimated maintenance activity durations that will be used in the calculation of user delay cost. Basis of these values are in hours per kilometer encompassing a single driving lane. Justification is based on experience in the field with delays caused by external factors not included. The time required to perform cold in-place recycling is unique compared to the rest of the activities in the analysis. It is estimated the milling, crushing and rolling operation with final overlay per kilometer-lane may be completed in two days. A two week delay for proper curing prior to final asphalt overlay is required for cold in-place recycling. However, this two week curing time may not affect the user delay as the lane(s) may be reopened to traffic during such time.

Assumptions associated with these activities includes setup and removal of the work zone including physical barriers, signage and equipment movement. These logistical activities are important and significant in the time allocated in the maintenance activity as the lane closures will begin at that time.

To determine the type and frequency of treatments throughout the life cycle of the facility, performance trends are acquired from OPAC 2000. This relates PCI and age of the facility with statistical database that is based on actual field data. Performance trends OPAC 2000 generates are not derived from a set model but through trends within the database considering all attributes based on historical data collected.

The scheduled maintenance is initially applied to the respective highway classes. As OPAC 2000 does not include the scheduled maintenance treatment in the analysis, performance trends that result is based on a no or little maintenance scenario. This is unrealistic as an agency would likely prefer to maintain such facilities to a specific level of service. Therefore, manual inclusion of the maintenance schedule was required, incorporating an estimate of the increase of PCI with such activities. The basic deterioration curve from initial construction to first major overlay was ascertained through curve fitting. This curve, unique for each functional class, was used as the general deterioration curve throughout the analysis period. Minimal acceptable serviceability levels are in accordance with MTO standards (*15*).

The schedule was initially followed arbitrarily whether or not the pavement condition index (PCI) reaches any trigger level. Ideally, through regular maintenance on the facility as prescribed in the schedule, the PCI will remain high. Unfortunately, it is not feasible to resurface at a PCI > 80 as the net gain per dollar is low. A secondary analysis was conducted whereby PCI trigger values, based on findings of a recent transportation symposium in 2003 (*16*), must be attained prior to treatment. This scenario is similar to that of agencies with a limited budget opting to achieve a cost-effective activity while remaining within the budget constraints.

Rout and seal is applied after four years of a new surface course. Light intervention such as mill and patch activities are deployed once PCI value drops below 80. Moderate intervention activities such as resurfacing are completed once a trigger value of 70 is reached. Finally major construction such as full depth removal or cold in-place recycling is done at the minimum acceptable PCI for each class of facility. In this analysis, typical sequence used is as follows: rout & seal (year 4), light intervention, moderate intervention, rout and seal, major construction. The types of activities are dictated by the original maintenance schedule.

Both scenarios yield a timeline of type and number of maintenance treatments to be applied throughout the service life of the facility. A 50 year analysis period was assumed. A simple economic analysis using a discount rate of 7%, leads to an estimated present worth of the delay costs incurred by the user throughout the 50 year analysis period.

Delay Calculation and Analysis

Calculation of the delay magnitude for a given maintenance activity is described in this section. All formulas have been adapted from Tighe et al. (*1*). Normal vehicle velocity through the work zone is calculated with Equation 1. Reduced speed through the work zone due to delays is calculated through Equation 2. These velocities are used in Equation 3 to calculate the slowing delay due to a given traffic control plan.

$$V_n = 99.322 - 71.047\left(\frac{HV}{CAP_n}\right) + 100.14\left(\frac{HV}{CAP_n}\right)^2 - 61.622\left(\frac{HV}{CAP_n}\right)^3 \quad (1)$$

$$V_r = 94.584 - 60.406\left(\frac{HV}{CAP_r}\right) + 90.133\left(\frac{HV}{CAP_r}\right)^2 - 58.505\left(\frac{HV}{CAP_r}\right)^3 \quad (2)$$

$$D_S = \left[\frac{1.5}{V_r} - \frac{1.5}{V_n}\right] \quad (3)$$

$$CAP_n = CAP_{IDEAL} \cdot F_{TRUCK} \cdot F_{WN} \quad (4)$$

$$HV = 1.2 \cdot DF \cdot AADT \cdot HF \quad (5)$$

where HV is the hourly volume (vehicles per hour), CAP_n is the normal capacity (vehicles per hour per lane), CAP_r is the reduced capacity (vehicles per hour per lane), V_r and V_n are the reduced and normal velocities respectively, F_{TRUCK} is the adjustment factor for the presence of heavy vehicles typically taken as 0.72, DF is the directional split factor, AADT is the average annual daily traffic and HF is the hourly factor (0.125 for two-lane highways and 0.07 for multi-lane highways). Equation 6 calculates the average queuing delay time in vehicles per hour.

$$D_q = \frac{0.38 \cdot C\left(1 - \frac{g}{C}\right)^2}{3600} + \frac{173 \cdot X^2\left((X-1) + \left((X-1)^2 + 16 \cdot \left(\frac{X}{CAP_r}\right)\right)^{1/2}\right)}{3600} \quad (6)$$

where C is the traffic cycle length in seconds, g is the green time in seconds and X represents the ratio of HV/CAP_r.

Delays associated with detours may be calculated through equation 7 if applicable. Detour velocity is represented by V_{detour} with length of detour as L.

$$D_d = \frac{L \cdot HV}{V_{\text{detour}}} \quad (7)$$

Equation 8 is a simple calculation of the average delay the road user is expected to experience traveling through the construction zone (*1*).

$$DL_j = \left(D_j + D_{qj}\right) \cdot JD_j \cdot HV \cdot JT_j \quad (8)$$

where DL_j is the user delay with traffic control plan j (in hours); D_j is the reduced speed (slowing) delay (in hours); D_{qj} is the queuing delay for traffic plan *j* (in hours); JD_j is the job duration with traffic control plan j (in hours); HV is the two way hourly volume (vehicles/hour) and JT_j is the number of job times with traffic control plan *j* (*1*).

Equation 9 simply illustrates the final cost per kilometer sustained by the road user.

$$DLC = DL_j \cdot WG \qquad (9)$$

where DLC is the cost per kilometer of the delay (in $/km); DL_j is the delay duration (in hours) of traffic control plan *j* and WG is the estimated hourly wage rate (in $/hour) (*1*). In this study, it is assumed each vehicle has a single occupant therefore the DLC may be denoted in $/veh-km.

The result is a delay cost for a given project. It is important to note this is a one-time estimate and due to several assumptions, will have a standard deviation that will exist. Further investigation on the magnitude of the variance is important but is beyond the objective of this study.

Life Cycle Cost Analysis

Utilizing available preventative maintenance schedule provided by the Ontario Ministry of Transportation (*13*) to create a baseline deterioration curve through OPAC 2000, analysis of all 20 Ontario functional classes was performed. Utilizing this deterioration curve, manual implementation of intervention activities was completed. Figure 3 illustrates the results for functional class 7S.

PCI Trigger levels were established at 80, 70 and 60 to manually invoke minor, moderate and major activities. A 50-year study period for each functional class was performed with only discrete delay costs considered. All projected delay costs were discounted to present value.

RESULTS OF THE STUDY

Results obtained from the analysis reveal the significance of user delay costs with respect to actual construction costs. Firstly, Table 1 summarizes the values employed for the various types of typical construction techniques. Table 2 summarizes initial construction delay cost from maintenance or rehabilitation related delay cost illustrating the relative cost between these two categories. The magnitude of the “triggered” maintenance delays is significant. Even though these future values are discounted back to the present value, it reveals facilities that accommodate higher AADT will incur significant user delays during the span of fifty years.

Most classes considered are two-lane facilities except for Class 4 and 8 which are designated as freeways or four-lane facilities. The latter incurred a lower delay time, therefore a lower cost, than the two-lane counterparts. This was due to only a one lane being closed in either direction. Capacity through the work zone is at 50% of normal, however as there exists multiple lanes for traffic to continue through without the constant interruption due to alternating traffic through a common driving lane.

CONCLUSIONS AND RECOMMENDATIONS

Costs associated to the motorist are substantial in terms of delays due to construction. In fact, a 10 kilometer section of highway being rehabilitated may have an estimated user delay cost of nearly one million dollars per lane of a work zone in Southern Ontario. Currently, the Ontario Ministry of Transportation Eastern Region has Contract 2004-4005 under tender for reconstruction of Highway 7 near Ottawa. Value of the tender is in the range of five to six million dollars (*17*). Therefore, user delay cost associated with full reconstruction is nearly ten percent of the actual construction cost.

Magnitude of delays, either cost or time, is directly related to the volume of daily traffic and the number of lanes of the facility. Higher volume roads, such as those in Southern Ontario will encounter an increase in delay time than the Northern population that has a lower AADT. Four lane facilities though carrying a higher volume will not experience as high a delay compared to the equivalent two-lane facilities. This is due to not having to share a common lane through the work zone, assisting in traffic flow. It is also possible this is an underestimation of the actual delay. In the event safety is an issue, traffic may be halted for certain construction stages that require major demolition such as blasting or erecting a pre-manufactured structure.

Limitations exist for all models. Static models assume an unrealistic queuing phenomenon that stacks stationary vehicles at the work zone edge. OPAC 2000 utilizes a database to extrapolate a performance curve given traffic and physical attributes without including the scheduled maintenance. User delay costs calculated is focused on the congestion delay due to daily traffic and does not include delays associated with construction or maintenance work. Incorporation of such factors into OPAC 2000 will be necessary as public agencies include user delays into the project selection formula.

Preventative maintenance will reduce the number of major repair or reconstructing projects on a road section. Apart from unforeseen issues, maintenance that is applied to the pavement structure will enhance its durability and performance. The performance curve will be affected as the enhancement of the structure will change the deterioration rate post treatment.

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LIST OF FIGURES

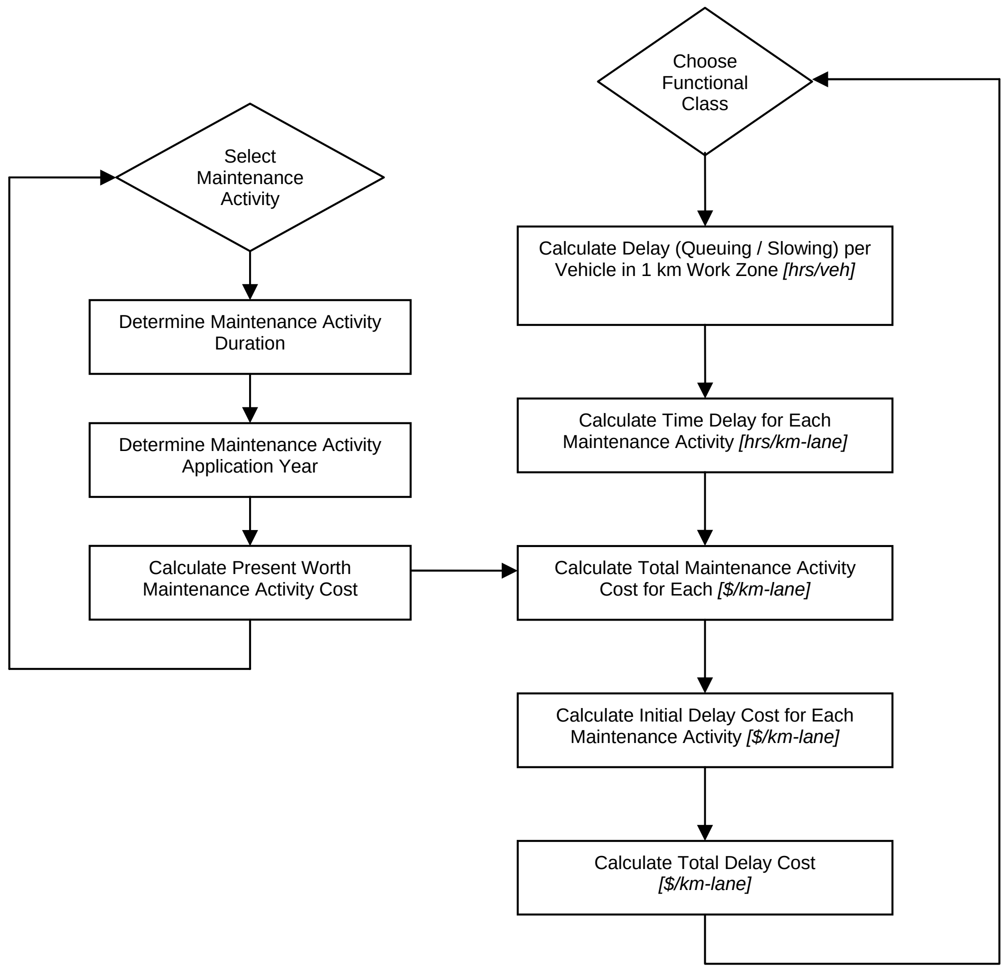

FIGURE 1 Methodology for user delay cost calculations in this study.

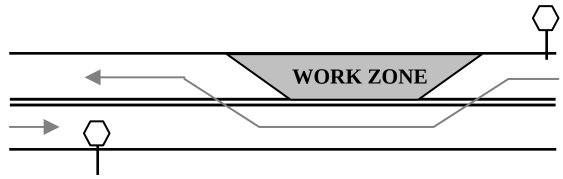

FIGURE 2a A typical two-lane undivided facility work zone closure with traffic control.

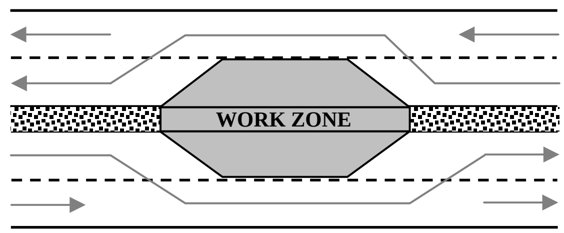

FIGURE 2b A four-lane divided facility with one lane work zone closure in each direction.

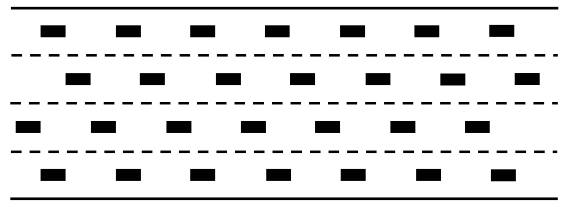

FIGURE 2c A free-flow on a multi-lane freeway section.

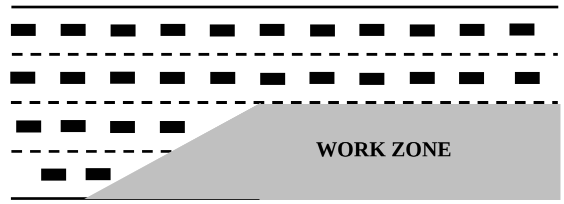

FIGURE 2d A forced-flow on a multi-lane freeway section with two right lanes closed for construction.

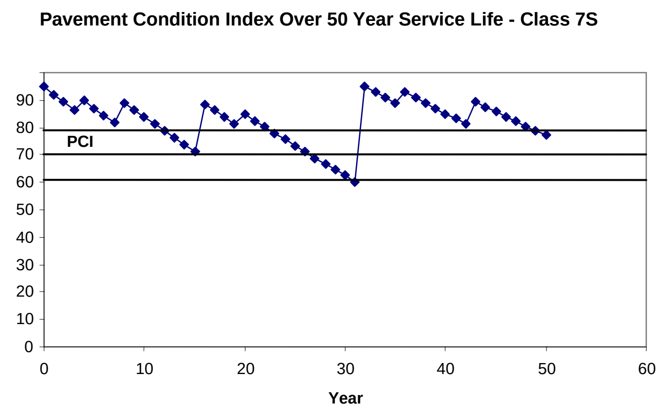

Figure 3 Performance curve for a Principal Arterial Ontario Facility (Class 7S) with trigger levels (PCI = 80 / 70 / 60) for minor, moderate and major interventions.

LIST OF TABLES

TABLE 1 Modified Values Incorporated in Pavement Performance at Time of Treatment Activity and Maintenance Activity Duration Used in the Study

Maintenance	Increase PCI	Duration
Rout and Seal	+ 6	1 hour
Mill and Patch 10% Spot Repairs	+ 6	4 hours
Mill and Patch 20% Spot Repairs	+ 10	5 hours
Resurfacing (Mill and Pave)	+ 20	1 day
Cold In-Place Recycling	+ 30	2 days
Rehabilitation (Full Depth Removal)	PCI = 95	3 days

TABLE 2 Attributes and Preliminary Cost Estimates of the Ontario Functional Classes Studied (*13*)

Class	*Description*	*AADT*	*% Trucks*	*# Lanes*	*ICC*	*SLMC*	*CUDC*
1N	Northern Urban Collector (Provincial)	1 100	4	2	$3747	$789	$4535
1S	Southern Urban Collector (Provincial)	7 800	4	2	$41559	$9199	$50758
2N	Northern Urban Minor Arterial (Provincial)	6 500	7	2	$30233	$6188	$36421
2S	Southern Urban Minor Arterial (Provincial)	11 800	7	2	$80028	$18543	$98571
3N	Northern Urban Principal Arterial (Provincial)	4 000	9	2	$17283	$3107	$20389
3S	Southern Urban Principal Arterial (Provincial)	12 200	9	2	$82741	$17071	$99811
4S	Southern Urban Freeway (Provincial)	18 700	12	4	$70714	$15651	$86365
5N	Northern Rural Collector (Provincial)	800	12	2	$2726	$539	$3265
5S	Southern Rural Collector (Provincial)	4 100	8	2	$17715	$4210	$21925
6N	Northern Rural Minor Arterial (Provincial)	3 800	16	2	$14021	$2806	$16827
6S	Southern Rural Minor Arterial (Provincial)	6 800	14	2	$31628	$7329	$38957
7N	Northern Rural Principal Arterial (Provincial)	3 500	22	2	$12914	$2609	$15523
7S	Southern Rural Principal Arterial (Provincial)	8 100	22	2	$45938	$31935	$77873
8S	Southern Rural Freeway (Provincial)	19 900	30	4	$75251	$16656	$91907
9N	Northern Local (Municipal)	300	4	2	$1024	$211	$1235
9S	Southern Local (Municipal)	500	4	2	$1705	$385	$2090
10N	Northern Collector (Municipal)	2 500	5	2	$8512	$1742	$10255
10S	Southern Collector (Municipal)	3 500	5	2	$12914	$2780	$15694
11N	Northern Arterial (Municipal)	3 500	7	2	$12914	$2643	$15557
11S	Southern Arterial (Municipal)	4 500	7	2	$19443	$4304	$23746

ICC – Initial Construction Cost

SLMC – Service Life Maintenance Cost

CUDC – Calculated User Delay Cost