Improved Models for User Costs Analysis

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16. Abstract

The user costs include the costs borne by highway users such as additional travel time costs, crash costs, costs of operating vehicles in work zone conditions, and environmental costs. The pavement type selection process currently used by ODOT doesn't include user costs quantitatively. This report provides a comprehensive review of literature and tools used to calculate user costs. The results of a questionnaire survey on the role played by user costs in pavement type selection processes of various state and regional agencies in US and Canada are provided.

Based on the findings from literature review and questionnaire survey, this report provides recommendations for including user delay costs quantitatively in ODOT's pavement type selection process. Three case studies presented in this research report illustrate the methods recommended in this study.

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Introduction

There is a growing awareness in the transportation community that the user costs may out weigh the initial construction and agency costs over the life of transportation facilities. The user costs are borne by the user of the transportation infrastructure and not the agency. They also have an impact on the economy of a region, state, or city on a macro level. Traffic disruptions, accidents, local businesses disruptions, increased vehicle operating costs in terms of fuel consumption and vehicle repair costs, increased travel time, and pollution can lead to high user costs which can have a detrimental impact on the competitiveness of local and even national economies. It is very important to factor these costs in when making decisions on pavement design and construction strategies.

A significant amount of research has been conducted in US and abroad over the last 50 years to identify and quantify the user costs. A synthesis of life cycle cost analysis practices for pavements published by NCHRP in 1984 found only 3 state agencies, out of the 49 surveyed, accounted for user costs in LCCA (Peterson, 1985). Another Survey conducted by the National Cooperative Highway Research Program in 1996 evaluated the extent of use of road user and mitigation costs in highway improvement projects by US and Canadian transportation agencies. This survey found that 44% of the agencies surveyed didn't consider user costs at all for most construction projects and programs. It also found that 55% of agencies didn't consider user costs either quantitatively or qualitatively in most maintenance projects and programs. The lack of adoption of user costs in transportation project analyses by many state DOTs can be attributed to difficulty in establishing the economic value of user costs and non availability of a nationwide standard method for quantification of user costs. The determination of economic value of travel time, accidents, and environmental impact has been a cause of contention for a long time.

Ohio Department of Transportation (ODOT) has created many policies to minimize the impacts on the traveling public resulting from the creation of the work zones caused by construction and rehabilitation activity. The ODOT policy "The Traffic management in work zones, interstate and other

freeways" describes construction strategies and work zone traffic control options which help in the reduction of road user costs while attaining one or more of the following objectives:

⇒ Reduce user complaints.

⇒ Maximize Corridor Capacity.

⇒ Minimize duration of motorist inconvenience.

⇒ Maximize motorist/work safety.

The user cost reducing construction strategies, options and objectives during pavement construction and rehabilitation mentioned include crossover construction, temporary pavements; temporary structures; reversible lanes; moveable barrier systems; control of contractor's access to work; temporary lane closures or restrictions; night work; week end work; etc.

In 2000, ODOT enacted the Maintenance of Traffic policy to minimize the impacts on the traveling public resulting from the implementation of the work zone. This policy requires districts to analyze the projected effect of construction on traffic flow and also takes the steps necessary to prevent traffic delays to the fullest extent possible. In 2003, the MOT Alternative Analysis (MOTAA) process was developed by ODOT to identify work zone impact and constraints. The analysis of impact on traffic involves the use of permitted lane closure maps, predicting the length of traffic queues and comparing it to allowable thresholds, and establishing traffic control strategies to ensure minimum impact on traveling public.

Even though the planning process takes the impact of construction on traffic flow into consideration, the pavement type selection process itself doesn't include quantitative analysis of the costs borne by the users as a result of impeded flow of traffic during construction. The current pavement type selection process (Policy Number: 20-006(P) published in 2006) includes only a comparison of traffic delay days for each alternative. The economic impact of each pavement type alternative is not calculated and factored into the pavement type selection process. This research report presents a careful analysis of research literature on user costs, pavement selection methods used by other state DOTs, tools

used to calculate user costs. In addition, it draws a comparison with ODOT methods and makes recommendations for inclusion of user costs in the ODOT pavement type selection process.

Objectives of the Study

The primary objectives of this study are to improve ODOT's user cost analysis and pavement selection procedures.

These objectives will be achieved through a very rigorous study of current user cost analysis practices used by other state agencies and other countries around the globe. To achieve the primary objectives of this research, several secondary objectives emerge as follows:

1) Carry out a comprehensive review of the current methodology used by ODOT to:
    i. Evaluate how user costs are currently considered in decision making and pavement selection processes; and
    ii. Identify the areas where room exists for improvement.
2) Perform a thorough search of available literature in the area of user costs.
3) With the advice and approval of ODOT, Conduct a comprehensive questionnaire survey of other state DOTs to:
    i. Identify those agencies that consider and use user costs as part of their decision making process;
    ii. Define the components of user costs that are used for the analysis and for pavement selection decisions;
    iii. Identify the models and methods used for calculating and evaluating user costs; and
    iv. Determine the range of measures and values that are used to define the various components of user cost models such as accident costs and delay time costs.
4) Conduct a similar survey to the provincial transportation departments in Canada.
5) Extend the literature search and survey (if needed) to United Kingdom, Australia, New Zealand, Sweden, Netherlands, Germany, Japan, and World Bank and other countries where significant research has been carried out on user cost analysis.
6) Study various components of user cost models and determine which components are more significant and should be included in user cost calculations.
7) Study available tools used for analysis of user costs in order to derive the best practices from them that can be used to enhance ODOT's pavement selection methods. A brief list of tools that will be evaluated is as follows:
    i. The Australian Road Research Board's Fuel Consumption Model

(ARFCOM);

ii. Cost Benefit Analysis (COBA) by the Ministry of Transport U.K.;

iii. Highway Design & Maintenance Standards Model (HDM IV) Developed by World Bank;

iv. MicroBENCOST developed by Texas Transportation Institute;

v. StratBENCOST developed by Hickling Lewis Brod Inc;

vi. Queue and User Cost Evaluation at Work Zones (QUEWZ) by Texas Transportation Institute;

vii. FREWAY Model by Center for Microcomputers in Transportation at University of Florida;

viii. DARWin by AASHTOWare; and

ix. FHWA models developed for Demonstration Project 115.

8) Determine the best methods of evaluating various categories of user costs and integrating them with the pavement selection method currently used by ODOT.

9) Establish a procedure for testing the validity of the proposed user cost models and pavement selection methods.

10) Objectively evaluate the applicability of a proposed user costs methodology as it applies to highway projects generally and ODOT's construction methods specifically.

Discussion:

The major objectives of the research study were achieved through thorough review of research and practice literature, questionnaire survey of US and Canadian state transportation agencies to establish the state of practice, review of software tools used to calculate user costs. A thorough review of ODOT's pavement type selection process and the role of user costs in this process was conducted through meetings with ODOT officials and review of ODOT policy documents. On basis of literature review, questionnaire survey and ODOT's current policies, the research team developed two alternative methods of including user cost in pavement type selection process. These methods have been discussed in detail in this report. Two case studies illustrating the use of these methods in pavement type selection processes on ODOT's past projects have also been presented in this report.

Structure of the Report

Chapter 2 of this report presents a review of user costs, components of user costs, and methods of calculations of user costs. The main components of user costs viz. user delay costs, vehicle operating costs, crash costs, and environmental costs have been discussed in detail. The cost of travel time, which is one of the most contentious issues, is reviewed and the approaches used to value travel time have been presented.

Various methods have been developed to quantify user costs. These methods include simple methods to manually calculate user costs as well as sophisticated computer programs and spreadsheet applications. Chapter 3 presents a review of tools available to quantify user costs.

A questionnaire survey was conducted to identify the extent to which state and regional transportation authorities in US and Canada include user costs in their pavement type selection process. Chapter 4 provides a comprehensive review of information collected through the survey.

The current pavement type selection process used by Ohio DOT has been reviewed in Chapter 5. A few key elements of the Maintenance of Traffic (MOT) policy and MOT analysis process have also been discussed in this chapter.

New approaches to include user costs in the ODOT pavement type selection process are discussed in Chapter 6 of the report. These approaches are based on the findings from the literature review, questionnaire survey, and feedback from ODOT officials through various meetings during the research study.

The pavement type selection process is conducted using the proposed approaches for two ODOT projects and the results are compared and contrasted with the actual pavement type selection in Chapter 7 where three case studies are presented.

The conclusions of the studies are presented in chapter 8 and recommendations have been provided to ODOT regarding inclusion of user delay costs in pavement type selection process.

Review of Literature

The term "user costs" applies to the wide array of effects of highway use beyond the cost of resources consumed in producing the transportation service. Lewis (1999) has defined highway user costs as costs incurred by highway users and the community at large as a result of planned changes in highway capacity and pavement condition and the effects of road construction and maintenance. The user costs essentially include the costs borne by highway users such as additional travel (i.e., delay) time costs, crash costs, costs of operating vehicles in normal as well as work zone conditions, and environmental costs (Reigle, 2000). In addition to this, user costs could also include other intangible parameters such as noise, reduced local business access, and driver tension (Wilde et al., 1999). However, for economic analysis, user costs typically are considered to be an aggregation of three separate components viz. Vehicle Operating Costs (VOC), Crash Costs, and User Delay Costs (FHWA, 1998). From LCCA perspective, user costs differential that is incurred by the motoring public between alternative construction strategies and associated maintenance and rehabilitation strategies over the analysis period is important. (Vadakpat et. al, 2000)

The user costs are not borne by the agency but by the users of the transportation infrastructure. The user costs tend to overwhelm the agency costs in cases where roadways have very heavy traffic. (Chien et. al, 1995). This, along with the complexity of method of calculation and lack of standard national guidelines for calculation of user costs, has been quoted as a reason for not considering user costs in LCCA. (Ozbay et. al, 2004) In a survey of pavement LCCA practices at State DOTs, 27 of the 39 responding state DOTs didn't consider user costs in their LCCA at all. Of the 12 agencies that did consider user costs in LCCA, they used systematic approaches for developing user costs. (Ozbay et. al, 2004)

Some researchers (Hall et. al, 2003) recommend using a weight factor for user costs instead of using absolute values of user costs. Hall et. al (2003) have recommended the following formula for balancing the impact of user cost:

$$PW_i = \Sigma \; a_1 \, (AC)_i + a_2 \, (UC)_i$$

Where: Pwi   = Total present worth of rehabilitation strategy i

            a1   = Weighting factor for all agency costs

            a2   = Weighting factor for all user costs

            ACi   = Present worth of agency costs over analysis period for strategy i

            UCi   = Present worth of user costs over analysis period for strategy i

However, they have not given any guidance about the values of factors a1 and a2. In the review of the pavement life cycle cost analysis practices of the state DOTs, no evidence of use of such a weighing strategy was found.

For pavement projects, the user costs can be classified as in-service (normal operations) user costs and work zone user costs. (Hall et. al, 2003) The in-service user costs are those user costs which are borne by the users of the transportation infrastructure during normal operation of roadway when construction work zones are not present. The work zone user costs include the delay costs at work zones, the increased cost of operating vehicles at work zones, and crash costs due to increased number of crashes in the work zone. (FHWA, 1998)

In Service (Normal Operations) User Costs

The in-service user costs are a function of pavement roughness. In a study conducted by The Road Information Program, it was found that deteriorated roadways cost motorists approximately $21.5 billion in 1994, or an average $ 122 per motorist. (TRIP, 1996) Deteriorated and rough pavements cause increased vehicle wear, reduced speeds of travel and thus cause increased vehicle operating costs as well as delay costs. FHWA doesn't recommend the use of in-service user costs for life cycle cost analysis because there is little difference in user costs on account of pavement design options under normal conditions. (FHWA, 1998) . This is because of the following two reasons:

1. The pavements in US are maintained at a high level of performance throughout their life. The performance differential in terms of roughness is not substantially different between asphalt and concrete.

2. Even if the performance differential becomes significant, the following information is needed for calculating difference in user costs for different options:

    a. Precise information about pavement performance over a long period of time.

    b. The cost implication in performance differential between the two pavement design options. (ACPA, 2002).

According to studies carried out in New Zealand, the additional user costs on account of increased pavement roughness begin to accrue at an IRI level of 170 in/mile (equivalent to PSR rating of 2.5) At this PSR level, most State Highway Authorities generally consider that the pavement has reached its terminal serviceability index and schedule its rehabilitation.

Wisconsin has developed a method to quantify the differences between the performances of different types of pavements. Under this system, the area under the curves of PSI v/s Age for each alternative is measured and the "Quality of Service" of each alternative is determined by comparing the areas under the curves. (ACPA, 2002) However, this method can't be used for quantifying the user cost differential amongst alternatives. A significant amount of research effort is being put into formulating models to calculate the in- service user costs. (Ozbay et. al, 2004) There is no widely accepted model for calculating this component of user costs at this time. However, there are well established models and tools for calculating delays through work zones and other vehicle operating costs. This component of user costs has been included in the pavement LCCA by many State Highway Agencies such as Pennsylvania, Texas, New Jersey, Michigan etc. This component is discussed in detail in the next section.

Work Zone User Costs:

The construction and rehabilitation of pavements requires creation of work zones which tend to disrupt the normal flow of traffic and thus contribute significantly to user costs. The work zone user costs are influenced by many factors such as current and future traffic demand, facility capacity, the timing, duration, and frequency of work zone-induced capacity restrictions, excess mileage caused by detours, and directional hourly traffic demand forecasts for the analysis year. (FHWA, 1998) The work zone user cost is the sum of the costs accrued on account of delay in the work zone, additional vehicle operating costs in work zones and work zone crash costs.

Arudi et. al (1997) have presented a formula for calculating work zone user costs:

$$THC = CQUE + CDWZ + CDSC + CSPC + CSPQ + OCQ + OC$$

Where:

THC = Total Hourly Work Zone Costs

CQUE = Cost of delay due to queue

CDWZ = Cost of delay while going through work zone at reduced speed

CDSC = Cost of delay due to speed change cycles.

CSPC = Additional operating cost of speed change cycle.

CSPQ = Additional operating cost of speed change cycle if queue is present.

OC = Vehicle running cost

OCQ = Vehicle running cost if a queue is present.

Jiang (1999) presented a formula for calculating user costs in work zones which comprised of same components.

Delay at Work Zones

Traffic delays at a work zone include:

1. Delays caused by deceleration of vehicles while approaching the work zone

2. Reduced vehicle speed through the work zone

3. Time needed for vehicles to resume freeway speed after exiting the work zone

4. Vehicle queues formed at the work zone (Jiang, 2001)

Value of Travel Time: Review of Approaches

Time itself is valuable to the users of transportation infrastructure because they can dedicate it to earning income or use it to engage in leisure activities. Since traveling requires people to sacrifice some time they would otherwise spend in one of these ways, it imposes an opportunity cost equal to the individual's value of time in the activity forgone. Travel time can have an additional cost because it may be spent in circumstances travelers find undesirable, such as riding aboard a crowded or uncomfortable vehicle, or driving in heavy traffic. The value of time consists of several different elements:

1. The hourly value of the individual's after-tax earnings, including any effect of working extra hours on the wage rate (e.g., an overtime pay premium)

2. The monetary value of any utility or disutility derived from additional time spent working

3. The value of relaxing any constraint that exists on the minimum or maximum number of hours spent working (such as a minimum-length work day or week or the unavailability of overtime work). (Office of Secretary of Transportation,1997)

While several models and computer software programs such as QueWZ have been developed to quantify the amount of delay which occurs in construction work zones on account of highway construction / rehabilitation activities, there is no single universally accepted model for determining the value of travel time. Despite a significant amount of research over last six decades, valuation of travel time remains one of the most contentious issues in quantification of user delay costs. (FHWA, 1994) Various important research studies in this area are summarized in this section.

Costs incurred as a result of the increase in travel time can be possibly quantified by classifying the time that needs to be evaluated as either productive (working) time or leisure (non-working) time and then evaluating the cost of each type independently (Reichman, 1976). Rogers and Townsend (1970) have defined the value of travel time as "*That amount of money which an individual is prepared to forego in order to save himself / herself one unit of time.*" It is very difficult to judge how an individual would use the savings in travel time. Various activities have different economic or social utility / value. While it is easier to quantify the value of productive time, especially in the case of commercial transportation activities, it is very difficult to quantify the value of leisure time.

The economic evaluation of working time can be carried out by linking it to the average rate of wage, fringe benefits, and allowances for overheads which are not utilized when the workers are in transit. This approach is based on the assumption that all the time wasted due to increased travel time would otherwise be used for productive work. This assumption is counterintuitive and has been challenged by many researchers and it has been found to be untenable (Reichman, 1976). Fowkes found that 29% to 35% car passengers would use additional time savings for additional leisure rather than productive work (Fowkes, 1986). This implies that the economic value of increased travel time may be lower than the value calculated from the simplistic approach outlined above.

Alternate techniques have been used to quantify the value of the working time. Survey techniques were extensively used by Fowkes, Fleisher, Hagging, Mcfarland, and Kemrud to evaluate how time savings are used by various categories of travelers such as business travelers, commercial vehicle operators & truckers. Hagging and Mcfarland (1963) surveyed the use of travel time savings by commercial vehicle operators. Kemrud (1983) surveyed the use of the time savings by truckers. A survey carried out by Fowkes (1986) established that work time savings converted into leisure time should be valued at 40 to 57% of gross wage rate.

Heshner (1974) carried out some case study analyses to evaluate the economic value of working time more comprehensively. He used the value of an employee's time not only in terms of wages but also in terms of value added to the employer and the community. He further refined this approach by

including additional resource costs such as meal allowances, benefits, pensions, overnight expenses, etc. (Heshner, 1976). A more mathematical approach was used by some researchers to derive a probabilistic model by observing the reaction of individuals traveling for work purposes and who faced a time trade-off. Gronau (1970) established that a positive correlation exists between value of travel time and wage rate. He derived a trip distribution function on the basis of home interview data. DeVany (1971) carried this approach farther and estimated the marginal value of time as a function of elasticity of demand for travel when considering time and price as variables.

The evaluation of non-working time poses an even more difficult problem because the value of time can't be directly linked to wages. The research associated with the quantification of the value of non-working time is generally based on welfare economics and the concept of compensating variation. (Lewis,1999). Many different models such as *Revealed Preference Approach, Stated Preference Approach, Speed Choice Approach* have been developed and used for finding the value of non – working leisure time.

The *Revealed Preference Approach,* used to value the non-working time, assumes that travelers reveal their implicit valuation of saving time through their choice from competing alternatives. This approach was first developed by Beesly (1965) to derive an implied value of time by comparing travelers who choose a time saving with extra cost with travelers who choose a cost saving at extra time. Lave (1969) furthered this approach by weighing the average travel time by the average wage and induced a factor *K* whose value is based on an individual's preference for more work time income versus more leisure. Miller (1989) used this approach to determine the value of travel time. He estimated the average value of travel time to be 60% of gross wage for auto drivers and 45% for auto and transit passengers on personal travel. After review of his earlier recommendations, Miller (1996) recommended a downward adjustment to 55 percent for auto drivers and 40 percent for auto and transit passengers.

An alternate approach called the *Stated Preference Approach* is based on the work of Lee and Dalvi (1971), Heshner (1976), and Heggie (1976). It uses the traveler's valuation of the reduced travel

time. This method was later used by Calfree & Winston (1988). They interviewed 1170 commuters from various major metropolitan areas in USA who regularly drove to work in congested driving conditions. They found that the travelers were ready to pay 14% to 26% hourly wage to save travel time. A more mathematical model is used in the travel demand approach where the traveler's willingness to pay for a reduction in travel time is estimated using *Modal Demand Analysis*. Small (1992) concluded from a survey of modal choice models that the value of travel time is nearly 50% of average wage rate.

Another approach known as the *speed choice approach* uses the choice of speed by the driver to evaluate the economic value of non-working time. This approach was used by Jondrow and Levy (1982) who compared the private optimum speed of a driver with the social optimum speed. This approach was further refined by McFarland and Chui (1987) who estimated specific cost curves of individual drivers. This model is extensively being used by Texas Department of Transportation for their estimation of value of travel time. The values developed by McFarland & Chui are adjusted to date by using Consumer Price Index. Small (1999) conducted a detailed study to develop methodologies for measuring the effects of congestion on the values highway users place on travel time savings and predictability. The study defined an approach to gauge the effect of various degrees of congestion on highway user costs.

Valuation of Travel Time: Review of Methodologies

Recommendations of Office of Secretary of Transportation:

In1997, the Office of Secretary of Transportation issued a departmental guidance to state DOTs for valuation of travel time for individuals in economic analysis. They conducted an extensive review of empirical models and underlying theory of valuation of travel time and formulated standard guidelines. (OST, 1997) Detailed discussion of theoretical underpinnings of the guidelines can be found in the said document. On the basis of established research, they have determined the guidelines for valuing travel time for local personal travel, intercity personal travel, local and intercity business travel, valuing travel time for truckers and established the procedures for arriving at these values. The intercity personal travel

is valued higher than local personal travel because "*intercity travel is usually consumed jointly with expensive services such as hotel rooms, restaurant meals, and entertainment, [therefore] travel time saved is freed for purposes that travelers value highly. Constraints on the total time available (e.g., school vacations or allowed leave) also increase the value of time savings.*" (OST, 1997)

The OST recommends the following for valuation of travel time:

1. **Local Personal Travel:** All local personal travel should be valued between 35 percent to 60 percent of the wage regardless of the mode employed

2. **Intercity Personal Travel:** All intercity personal travel should be valued between 60% to 90% of the wage

3. **Local and Intercity Business Travel:** All local and intercity business travel should be valued between 80% to 120% of the wage (plus fringe benefits)

4. **Truck Drivers:** All local and intercity travel by truck drivers should be valued at 100% wage rates plus fringe benefits.

5. **Per hour value for Personal Travel:** The wage rate for personal travel represent annual household income before taxes, converted to an hourly basis by dividing by 2,000. This can be established from the Census Current Population Reports, Series P-60.

6. **Per hour value for Truck Drivers:** The truck driver wage rate is computed by dividing Median Weekly Earnings for Truck Drivers (from Table 39 of the BLS monthly report "Employment and Earnings") by Average Hours per Week for all workers (full- and part-time) (in the Transportation and Materials Moving occupations, Table 23) in the same publication. Separate estimates are not available for truck drivers in local and intercity trucking. Fringe benefits are added, using the average figures for business travel derived above from the quarterly survey.

7. **Per hour value for Business Travelers**: For most surface business travel, the data series employed is from a quarterly survey of average hourly earnings in private, non-agricultural employment published by the Bureau of Labor Statistics in "News: Employer Costs for

Employee Compensation." The same survey provides estimates of hourly employer-paid fringe benefits that are added to the wage.

These guidelines are summarized in the following table:

Plausible Ranges for Values of Travel Time Savings (per person-hour as a % of wage rate)			
Category	Surface Modes *	Air Travel	Truck Drivers
Local Travel			
Personal	35-60%	--	--
Business	80-120%	--	100%
Intercity Travel			
Personal	60-90%	60-90%	--
Business	80-120%	80-120%	100%

* Surface figures apply to all combinations of in-vehicle and other transit time. Walk access, waiting, and transfer time should be valued at 100% of the wage rate when actions affect only these elements of transit time.

Sources: local personal travel, Miller (1996); local business travel, Miller (1996) and Morrison (1996); intercity personal travel, Brand (1996) and Miller (1996); intercity business travel, Morrison (1996) and Brand (1996); truck driver travel, Morrison (1996) and Miller (1996).

Table 1: Value of Travel Time as % of National Wage Rate (OST, 1997)

FWHA

In a policy level discussion organized by FHWA on pavement life cycle cost analysis (FHWA, 1994), no consensus could be reached on a standard method to value traveler time. Subsequently, FHWA listed a number of approaches for valuation of travel time in interim technical bulletin on pavement. (FHWA, 1998) and no guidance on the choice of method was provided. The approaches listed by FHWA in the said report are listed below:

1. **NCHRP Report 133**

   The NCHRP report no 133 (NCHRP, 1977) entitled "Procedures for estimating highway user costs, air pollution and noise effects" used 1970 dollar values of $3 per hour per passenger vehicles and $5 per hour per unit for all trucks (Single-Unit, Combination trucks). These values should be escalated to reflect more current/base year values. The escalation factor for the dollar

value of time is determined by using changes to the *All Items Component* of the CPI for the base year (1970) and the more current year (e.g. 2005)

Escalation Factor = All Component CPI (2005) / All Component CPI (1970)

Delay Cost (Passenger Cars) = $ 3.00 X Escalation Factor

Delay Cost (Single Unit, Combination trucks) = $ 5.00 X Escalation Factor

2. *Microcomputer Evaluation of Highway User Benefits*

The MicroBENCOST program was developed under NCHRP research project 7-12(NCHRP) This program uses 1990 default values of time for calculating value of time for various types of vehicles. An escalation factor needs to be used to bring these factors to reflect current values. The values (1990) for delay for different types of vehicles are listed below:

Passenger cars: $ 9.75 (1990 value)

Single Unit Trucks: (2 Axel 12 Kips): $ 13.64 (1990 value)

Single Unit Trucks: (3 Axel 35 Kips): $ 16.28 (1990 value)

Combination Trucks: (2S2 40 Kips): $ 20.30 (1990 value)

Combination Trucks: (3S2 63 Kips): $ 22.53 (1990 value)

3. **USDOT Office of the Secretary of Transportation**

This approach has been discussed earlier in this section.

4. **Highway Economic Review System (HERS model)**

The HERS model provides values for travel time on the basis of type of vehicle and the composition of traffic The following table shows the values of travel time used by the HERS model.

	Small Auto	Medium Auto	4-Tire Trucks	6-Tire Trucks	3-4 Axle Trucks	4-Axle Comb.	5-Axle Comb.
Business Travel							
Value per Person	$21.20	$21.20	$21.20	$18.10	$18.10	$18.10	$18.10
Avg. Vehicle Occupancy	1.43	1.43	1.43	1.05	1.00	1.12	1.12
Vehicle Depreciation	$1.23	$1.64	$2.15	$3.00	$8.11	$7.26	$6.98
Inventory Costs	--	--	--	--	--	$1.78	$1.78
Total Business	$31.55	$31.96	$32.47	$22.01	$26.21	$29.31	$29.03
Personal Travel							
Value per Person	$10.60	$10.60	$10.60	--	--	--	--
Avg. Vehicle Occupancy	1.67	1.67	1.67	--	--	--	--
Total Personal	$17.70	$17.70	$17.70	--	--	--	--
Percent Personal	89%	89%	75%	--	--	--	--
Weighted Average	$19.23	$19.27	$21.39	$22.01	$26.21	$29.31	$29.03

Table 2: Value of Travel Time (2000$) (USDOT, 2005)

This model classifies travel into two categories (viz. business and personal travel) for small and medium autos and 4 tire trucks on the basis of purpose of travel. Unlike other models discussed above, the HERS model considers average vehicle occupancy, vehicle depreciation and inventory costs when calculating value of travel time. The average vehicle occupancy is assumed to be 1.43 per vehicle for small autos and 1.67 per vehicle for medium autos. For 6 tire trucks, 3-4 axle trucks, 4 axle combination trucks and 5 axle combination trucks, the average vehicle occupancy is considered to be 1.05, 1.00, 1.12, 1.12, respectively. The HERS model values personal travel at 60% wage rate. Unlike the OTS guidelines, the HERS model doesn't differentiate between local and intercity travel.

Travel Time: Values Adopted By State Highway Authorities

The following table lists values of travel time adopted by various State Highway Authorities summarized by Rister and Graves (2002).

Agency	Reference Year	Delay Cost Rate Value Cars ($/Veh-Hr)	Delay Cost Rate Value Combination Trucks ($/Veh-Hr)
North Carolina	1998	8.70	N/A
New York	1998	9.00	21.14
Florida	1998	11.12	22.36
Georgia	1998	11.65	N/A
Texas	1998	11.97	21.87
Virginia	1998	11.97	21.87
California	1998	12.10	30.00
Pennsylvania	1998	12.21	24.18
Washington	1998	12.51	50.00
Ohio	2005	17.00	31.50
NCHRP Report 133	1996	11.78	20.35
MicroBENCOST	1996	11.37	25.86
US DOT Office of Secretary of Transport	1996	10.80	17.10
HERS	2000	19.23 ~ 21.39	22.01 ~ 29.03
AASHTO "Red Book"	1998	9.10	16.60

Table 3: Travel Time Costs for Cars and Trucks (Rister and Graves (2002))

Work Zone Crash Costs

The accident cost (AC) component generally reflects three different subcomponents: fatal accidents, non-fatal injury accidents, and accidents involving property damage only. Some methods also include a multiplier factor to account for accident costs for unreported property damage in damage-only accidents (Reigle, 2000) Accident costs can be expressed as:

$$AC = FA + NFA + (PDO) x$$

FA = cost of fatal accidents   PDO = cost of property damage only accidents

x = adjustment factor for unreported PDO accidents   NFA= cost of non-fatal injury

The crash rates for different roadway functional classes and different crash types under normal operating conditions are well documented. Research literature and available work zone crash data suggest that they are about three times higher than in-service accident rates. (Hall et. al, 2003) However, these data are lacking on the relationship between work zone accident rates and traffic control details,

such as lane narrowing, use of cones or other barriers, crossovers, etc. Data are also lacking on daytime versus nighttime work zone accident rates. (Soares et. al, 1999) (Arudi et. al, 1997) (FHWA, 1998) (Vadakpat et. al, 2000) Hence, even though there is general agreement on using crash costs in work zone user cost calculation, this component of user costs is not included in life cycle cost analysis.

Review of Tools to Calculate User Costs

The research on user costs dates back to 60s. The calculation of user costs on account of work zones involves complex analysis of flow of traffic and significant calculations of delay in work zone. In the past, the limited computational capacity available made it difficult to develop efficient tools for calculating user costs. Many transportation infrastructure life cycle cost analysis software packages now include a user cost component. One of the significant early attempts for developing software for calculating user costs was QueWZ, which was a MS DOS-based tool. It is still being used by various state DOTs for analyzing user costs. The widespread use of innovative contracting techniques such as A+B type contracts and lane rental contracts resulted in the development of software tools for calculating user costs.

This chapter discusses QueWZ, WorkZone-RUC, CO3 (Construction Congestion Cost), RealCost, New Jersey User Cost software. QueWZ is widely used to analyze work zone conditions. Co3 model, developed by the University of Michigan, has unique elements for calculating user delay while accounting for the detours and trip cancellations. RealCost, developed by FHWA, is a life cycle cost analysis software which was found to be widely used in the survey carried out for this study. The next section of the report discusses the salient features of the software. A table listing important details of software used in other countries is also presented.

QueWZ (Texas Transportation Institute)

QUEWZ-98 (Queue and User Cost Evaluation of Work Zones) is a tool for estimating the traffic impact, additional user costs resulting from short term lane closures on freeways. This software was developed as a part of study no. 0-1745 "Air Quality Impacts of Highway Construction & Scheduling", sponsored by Texas Department of Transportation in co-operation with USDOT and FHWA. QUEWZ simulates traffic flow through a freeway work zone with and without lane closure and estimates the changes in traffic flow characteristics such as average speeds, queue lengths etc. and the additional user

costs on account of lane closure. This model can be applied to freeways or divided highways with 6 or more lanes in each direction with any number of lanes closed in one or both directions. 24 consecutive hours of operation can be analyzed with this software. The software can also predict vehicle emissions based on speed and time spent in queues.

The data required by QueWZ-98 include data on lane closure configuration, schedule of construction work activity and traffic volumes approaching the freeway segment. The model also provides default values for factors such as cost update factor, percentage truck, speed-volume relationship, work zone capacity. The software also allows the user to define excessive queuing. Excessive queuing can be defined in terms of either critical queue length in miles or a maximum delay for motorists. This information can be used in the detour algorithm to identify the number of vehicles that will use the detour.

The output provided by QueWZ can be in two forms. It can be either road user cost output or lane closure output. The road user cost output includes estimates of traffic conditions (volumes, capacities, speeds and queue lengths) at work zone, and additional user costs for each hour during which traffic conditions are affected by lane closure and excess emissions. The lane closure output summarizes the hours of the day during which a given number of lanes can be closed without excessive queuing. QueWZ is essentially MS DOS based software. The screen shots of the software are shown in the following figure.
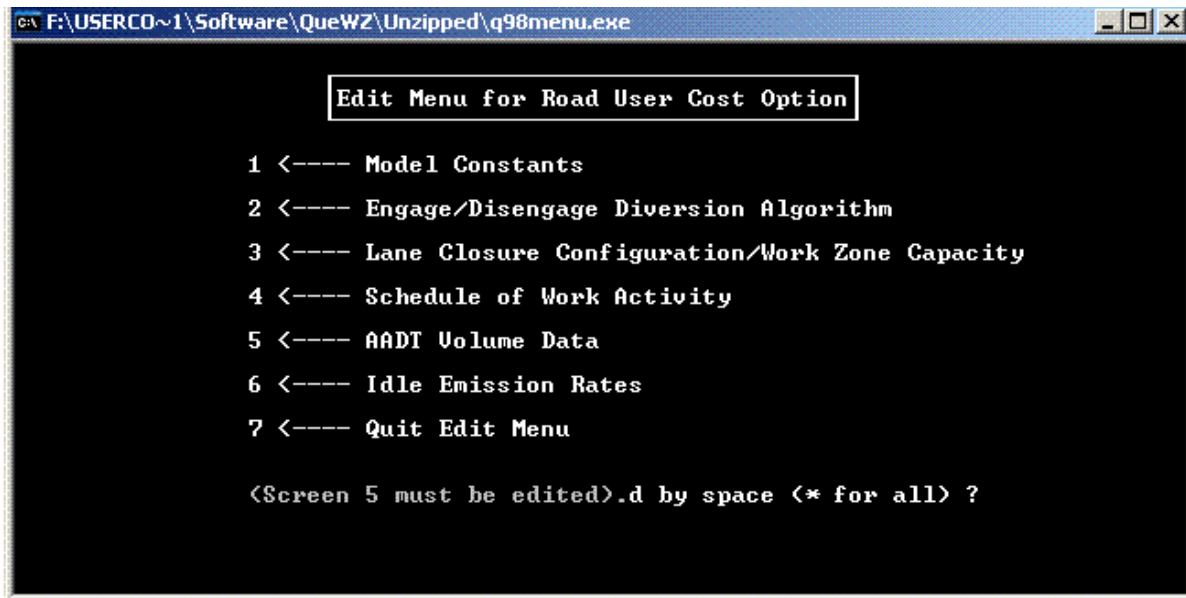
Fig 1: QueWZ Input Screen

WorkZone RUC (Colorado DOT)

The WorkZone-RUC software has been developed for the Colorado department of transportation. This software allows the user to analyze the road user costs on account of various maintenance and rehabilitation strategies. The unique feature of this software is that it allows the user to drill down to various activities that are involved during construction / rehabilitation of pavement (examples of activities: Aggregate base course, Stone Mastic Asphalt). The software uses unique work zone capacity for each activity. This work zone capacity can be modified by the user for various activities. The software also calculates the time required for each activity on the basis of the user provided productivity rates. In addition to this, the user can input the hourly traffic distribution, user costs rates for cars, single unit trucks and combination trucks. The typical data input screen is shown in the following figure:

Figure 2: WorkZone-RUC Input Screen

The output includes hourly breakup for each activity including information such as volume, normal capacity, work zone capacity, approach speed, work zone speed, queued traffic, queue length, and additional user costs. The software also provides graphs of queue lengths and user costs every hour for every activity. The following figure shows the graph showing hourly user cost for each activity.
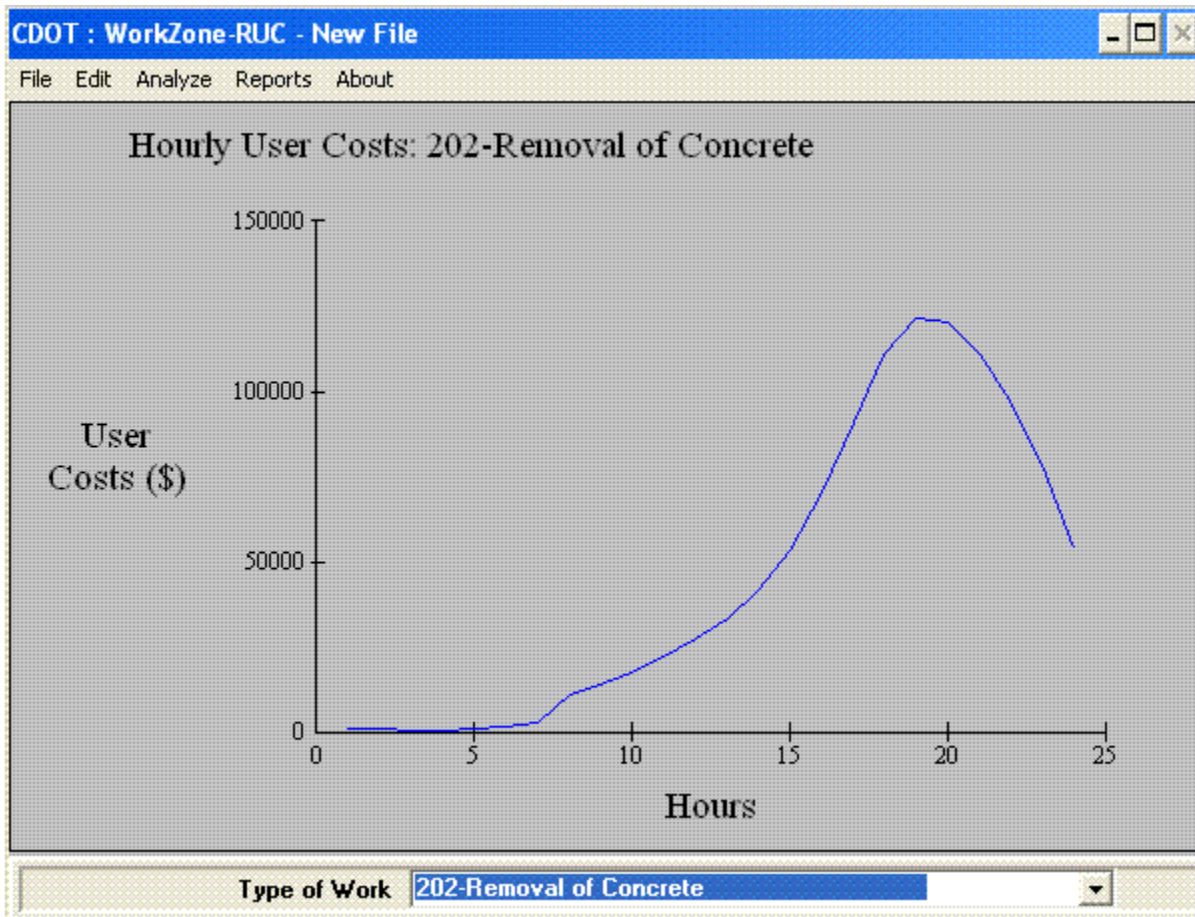
Figure 3: WorkZone RUC Output: Hourly User Cost for Removal of Concrete

Construction Congestion Cost Model (CO3)

The Construction Congestion Cost model, developed at the University of Michigan, is currently being used by Michigan Department of Transportation to estimate user costs for their pavement type selection process. The CO3 model calculates the road user costs resulting from traffic delays, from increased travel time and distance of alternate routes, and from trip cancellations caused by congestion. It calculates backups, delays, diverted traffic, and cancelled traffic to measure congestion. It models and estimates traffic delay due to traffic congestion as a function of demand and capacity and it estimates traffic cancellations and diversions as functions of traffic delay.

The unique feature of the Construction congestion cost model is that it models the circular dependency between work zone delay, diverted and cancelled traffic, and work zone demand. When the capacity of work zone is more than the design demand, there are no backups. However, when the design demand approaches and exceeds work zone capacity, delays occur. As delays increase, the motorists divert along the detour and thus the demand on the work zone is less than the theoretical design demand. CO3 models this circular interdependence and accounts for this circular dependency. The dependency between work zone delay and the fractions of car and truck traffic that divert and cancel trips is also modeled. CO3 calculates delays, diversions, cancellations, and actual demand. CO3 is unique in resolving the interdependency between work zone delay and work zone demand. Based on input of car and truck user cost per hour and mile of travel and per cancellation, CO3 calculates road user cost for work zone demand, diversions, and cancellations. The CO3 Output provides the user with detailed analysis of construction impact for each period and each day. The impact of alternative lane closure patterns and traffic maintenance plans can be compared. The CO3 software is in the form of Microsoft Excel sheet. The typical output obtained from CO3 analysis is shown in the following figure.

Figure 4: Construction Congestion Cost Output

RealCost

RealCost, developed by the Federal Highway Administration, is a tool for conducting life cycle cost analysis. The unique features of RealCost include a detailed user cost analysis component and the ability to conduct deterministic as well as probabilistic analysis of life cycle costs. RealCost allows the user to compare two pavement type selection alternatives at the same time. The user costs are calculated for each strategy for initial construction period and six rehabilitation/ reconstruction cycles within the strategy. RealCost is a Microsoft Excel based tool and hence it is customizable according to the user's needs.

The input parameters for the software include traffic profile (AADT Construction Year, Cars as Percentage of AADT, Trucks as Percentage of AADT, Annual Growth Rate of Traffic), traffic flow parameters (Hourly Traffic Distribution, Speed Limit, No. of lanes etc.). Work Zone details include work zone length, work zone speed, capacity, maximum queue length, lane closure times, etc. The user can also specify the unit rate for delay of cars and trucks. The user cost components calculated by the software include Work Zone Speed Change VOC, Work Zone Speed Change Delay, Work Zone Reduced Speed Delay, Queue Stopping Delay, Queue Stopping VOC, Queue Added Travel Time, queue Idle Time. The software is discussed in detail in Chapter 6. The following figure shows a screen shot of the main screen of the software.
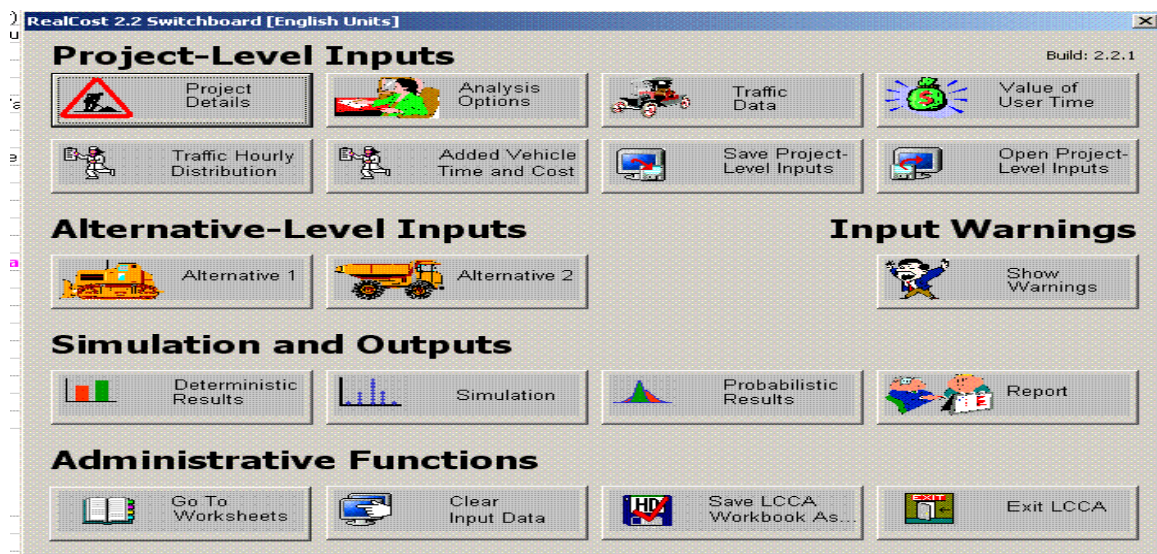
Figure 5: RealCost Input Screen

New Jersey Road User Cost Manual

The New Jersey Department of Transportation has developed a detailed manual for user cost calculation. A tool in the form of an excel sheet has also been developed to calculate user costs. This tool has been developed to help them determine the cost effectiveness of various alternatives including detours, temporary roadway or shoulder construction, off-peak hour day work, night work, and the most appropriate project delivery method (i.e., Incentive/Disincentive, A+B Bidding, etc.) This tool is also used to calculate user costs for life cycle cost analysis.

The excel sheet can calculate the following components of Work Zone User Costs.

1. **Work Zone Delay**

   This delay is the extra travel time that is required when a work zone is present as compared to the time when no work zone is present.

2. **Queue Delay**

   The queue delay is determined by subtracting the time it takes to travel the queue length when it is present, from the time it takes to travel the same distance when it is not present.

3. **Queue Idling VOC**

   The queue idling VOC is obtained by multiplying the number of vehicles that travel the queue, the overall queue delay per vehicle, and the current idling cost rate associated with "stop and go" driving in the queue.

4. **Circuitry VOC**

   The circuitry VOC is computed by multiplying the number of vehicles that travel the detour, the overall added travel length per vehicle, and the current VOC cost rate associated with driving the added distance.

5. **Circuitry Delay**

   The circuitry delay time through the detour is the difference between the time it takes to travel along the detour and the time it takes to travel when the work zone is not present.

   The summary road user cost sheet is shown in the following figure.

	3.5(A)	3.5(B)	3.5(C)	3.5(D)	3.5(E)	3.5(F)	3.5(G)	3.5(H)
	Road User Cost Component	Vehicle Class	Percent Class (%)	Total Vehicles (#)	Added Travel Length (mile/veh)	Added Time (hr/veh)	Cost Rate ($/veh-hr, $/mile)	Road User Cost ($)
4	Queue Delay	CAR						
5	(Added Time)	TRUCK						
6	Queue Idling VOC	CAR						
7	(Added Cost)	TRUCK						
8	Work Zone Delay	CAR						
9	(Added Time)	TRUCK						
10	Circuity Delay	CAR						
11	(Added Time)	TRUCK						
12	Circuity VOC	CAR						
13	(Added Cost)	TRUCK						

Worksheet 3.5: Road User Costs

14	Total Vehicles that Travel Queue:		Daily Road User Cost	
15	Total Vehicles that Travel Work Zone:		Calculated Road User Cost (CRUC)	
16	Total Vehicles that Travel Detour:		Number of Work Zone Days	
17	Percent Passenger Cars:		Total Road User Cost	
18	Percent Trucks:			
19				
20	Project:		Date:	
22	Description:			

Figure 6: New Jersey Road User Cost Work Sheet

The following table presents brief details about software tools used in other countries to calculate user costs.

Software	Agency / Location	Software Platform	Notes
COBA (Cost Benefit Analysis)	United Kingdom - TRL	Coded Data, then run with Dos-based program	The COBA (Cost Benefit Analysis) program compares the costs of providing road schemes with the benefits derived by road users (in terms of time, vehicle operating costs and accidents), and expresses the results in terms of a monetary valuation (for projects > £1m). The output contributes to the appraisal process in the following ways: 'Economy' Objective: Time and Vehicle Operating Cost (VOC) changes, 'Safety' Objective: Changes in Accident Costs and Casualties 'Environment' Objective: Changes in the amount of fuel used to assist in determining environmental changes
HDM-4 (Highway Design and Maintenance)	World Bank	Dos/Lotus (Recently Win)	The Highway Design and Maintenance Standards Model (HDM) computer program was developed by the World Bank for evaluating highway projects, standards, and programs in developing countries. HDM is designed to make comparative cost estimates and economic evaluations of different construction and maintenance options, including different time staging strategies, either for a given road section or for an entire road network. HDM considers construction costs, maintenance costs, and user costs mainly for lower traffic volume roads. Special emphasis is placed on estimating vehicle operating costs as related to roadway surface type and condition (e.g., dirt surface, gravel surface, and paved surfaces of varying degrees of roughness). The HDM program assumes that construction costs, maintenance costs, and vehicle operating costs are a function of vertical alignment, horizontal alignment, and road surface condition.
LCCA(for Asphalt)	Asphalt Pavement Alliance	Win	The Asphalt Pavement Alliance (APA) put together Life Cycle Cost Analysis Program software using the new FHWA recommended procedures. The procedures calculate user delays and vehicle operating costs, and incorporate this information in the analysis along with the agency costs.

Software	Agency / Location	Software Platform	Notes
Micro-BENCOST	TTI (Texas Transportation Institute) under NCHRP project 7-12	Dos	The computer program MicroBENCOST was developed by the Texas Transportation Institute in 1993 under NCHRP Project 7-12 (Ref 64). This program analyzes many types of projects including pavement rehabilitation, added lane capacity, bridge projects, and bypass projects. The program is modeled to take into consideration many input criteria. The Software is not mainly designed to compare alternatives but it is capable of doing that. The program does a particularly good job in calculating benefits and costs of constructing a particular project. Benefit Categories Considered are User travel times, Vehicle operating costs, Accidents, etc. Cost Categories Considered are Total initial cost, Salvage (residual) value at the end of the evaluation period, Rehabilitation and maintenance costs during the analysis period, etc.
OPAC 2000 (Ontario Pavement Analysis of Cost)	Ontario	Dos / Win	OPAC 2000 was developed for assisting pavement specialists in designing flexible pavements. It is a project level pavement design tool which incorporates structural analysis and life cycle cost analysis to evaluate pavement design alternatives. The system can be used to design new flexible pavements, as well as overlays of existing flexible pavements.
PennDOT - LCCA	Pennsylvania DOT	Excel	PennDOT 96 Delay Cost Model is an Excel based model which uses a procedure for conducting a LCCA for pavement type selection. The PennDOT LCCA procedure includes the Delay and operating costs resulting from (restricted capacity, lower speed, and travel) AND (stops caused by volume exceeding the capacity).

Software	Agency / Location	Software Platform	Notes
RPLCCA (Rigid Pavement Life cycle Cost Analysis)	TxDOT	Win	This LCCA model (RPLCCA) is specifically tailored for rigid pavements, using reliability concepts and the variability in all aspects of construction and cost models. It allows the design engineer to define a level of confidence for predicting total life cycle costs, user costs, accidents, and other output parameters considered in the methodology. The model is more readily updated with more appropriate or recent pavement design methods and user / construction costs. By predicting the distresses and the condition of the pavement following traffic & environmental loading, RPLCCA can determine when maintenance and rehabilitation activities are required.
Maryland - LCCP / LCCPR	University of Maryland	Excel	The University of Maryland developed a set of life cycle cost analysis Excel-based programs (LCCP / LCCPR) that analyze flexible and rigid pavements. These programs incorporate user operating costs associated with pavement roughness and other measures of user costs. These two computer programs are intended for project-level analysis. They are not as applicable to the comparison of alternate highway pavement designs.

Table 4: Other Software tools for user costs

User Costs in Pavement Type Selection: Questionnaire Survey

Background

The main objective of the questionnaire survey was to identify the role played by user costs in pavement type selection processes utilized by US State DOTs and Canadian regional transportation agencies. The scope of the questionnaire survey was broadened to encompass the whole pavement type selection process of state DOTs. The questions addressed included questions about pavement type selection process as well as in-depth questions about user costs. In the context of this survey , user costs were defined as the costs borne by highway users such as additional travel (i.e. delay) time cost, crash cost, and cost of operating vehicles in normal as well as work zone conditions.

The information collected on pavement type selection process included the type of pavement alternatives considered, life cycle cost analysis (LCCA) and its role in pavement type selection process. In addition, the type of maintenance and rehabilitation activities are considered in LCCA as well as types of roadways for which is LCCA carried out and the criteria used to evaluate equivalence of life cycle costs of two alternatives.

The questions on user costs included detailed information on the role played by the user costs in pavement type selection, whether user costs are a part of LCCA or if they are considered independent of LCCA. Detailed information on various components of user costs such as user delay costs, vehicle operating costs and crash costs was collected. The information collected included the methods used to calculate these costs, the software tools used for this purpose and methods used to monetize the user costs. A synthesis of information collected in this questionnaire survey is presented in this section. It is important to note that user costs are considered by many state DOTs for A+B type contracts and incentive/disincentive type contracts. This questionnaire survey focuses exclusively on the role played by user costs in pavement type selection process.

Questionnaire Survey Responses

The questionnaire survey was electronically sent to all state DOTs and Canadian regional transportation agencies using the listserv of AASHTO Standing Committee on Research (SCOR), and its Research Advisory Committee (RAC). Responses were received from 18 US and 4 Canadian state transportation agencies. The responding agencies are listed below:

US State DOTs

1. Oklahoma Department of Transportation

2. Florida Department of Transportation

3. Wisconsin Department of Transportation

4. Nebraska Department of Transportation

5. Texas Department of Transportation

6. Montana Department of Transportation

7. Arkansas Department of Transportation

8. Illinois Department of Transportation

9. Missouri Department of Transportation

10. Minnesota Department of Transportation

11. Michigan Department of Transportation

12. Washington State Department of Transportation

13. Indiana Department of Transportation

14. New Jersey Department of Transportation

15. Colorado Department of Transportation

16. Maryland Department of Transportation

17. Louisiana Department of Transportation

18. Ohio Department of Transportation

Canadian Regional Transportation Agencies

1. Alberta

2. Ontario

3. British Columbia

4. Quebec

User Costs in Pavement Type Selection Process

Of the 22 US and Canadian agencies that responded to the survey, 14 agencies don't consider user costs as a part of their pavement type selection processes. Oklahoma, Alberta, Florida, Ontario, Wisconsin, British Columbia, Nebraska, Texas, Montana, Illinois, Missouri and Minnesota currently don't consider user costs in the pavement type selection process. Eight agencies including Michigan, Quebec, Washington, Indiana, New Jersey, Louisiana, Colorado and Maryland include user costs in the pavement type selection decision making.

Role of User Costs in Pavement Type Selection Process	States
User Costs are considered	Michigan, Quebec, Washington, Indiana, New Jersey, Louisiana, Maryland, Colorado, Ohio (indirectly)
User Costs are not currently considered and there are no plans of incorporating them in the future	Nebraska, British Columbia
User Costs are not currently considered but will definitely be considered in the future (currently methods / approaches being studied)	Illinois
User Costs not currently considered but may be included in future.	Florida, Missouri, Montana, Oklahoma, Wisconsin, Ontario, Alberta, Texas, Arkansas

Table 5: User Costs in Pavement Type Selection Processes

User Costs & Life Cycle Cost Analysis

User costs can be considered as a part of the life cycle cost of pavement because these costs are accrued to the pavement users over the pavement life cycle. All the states that consider user costs in their pavement type selection process, including, Michigan, Quebec, Washington, Indiana, New Jersey, Louisiana, Maryland and Colorado, include user costs as a part of Life Cycle Costs of the pavement options. However, the role of life cycle cost analysis in pavement type selection process differs from state to state.

Of all the states that include user costs as a part of life cycle cost analysis, the decision of selecting pavement type is based on life cycle costs exclusively in Michigan alone. In all the other states, a two step process is employed. In the first step, the life cycle cost of all the competing alternatives is calculated and if the difference between competing alternatives is more than a certain predetermined limit, the alternative with lowest life cycle cost is automatically selected. If the difference between life cycle costs is less than this predetermined limit, all the alternatives are considered equal and the pavement type selection is based on the subjective analysis of a number of factors. The following tables illustrate the LLCA difference in various states at which life cycle costs are considered equal and the factors considered for the subjective analysis of pavement type alternatives.

State	Difference in Life Cycle Costs at which alternatives are considered equivalent
Washington	15%
Indiana	10%
Louisiana	20%
Maryland	15%
Colorado	10%
Ohio	10%
Michigan	Lowest LCC alternative automatically selected
New Jersey	Not Applicable

Table 6: LCCA Difference for pavement alternatives to be considered equivalent

State	Local Conditions (sub-grade, weather, traffic, drainage etc)	Type of Pavement in adjacent area	Engineering Judgment	Other Factors
Washington	✓	✓	✓	
Indiana	✓	✓	✓	Constructability and Politics
Louisiana	✓	✓	✓	
Maryland	✓	✓	✓	Cost, Construction, Design & Environmental factors
Colorado	Pavement type is in alignment with the unique goals of the project that may include individual elements of the LCCA or other non-monetary elements to ensure statewide consistency of decision making.			
Ohio	✓	✓	✓	
Michigan	Pavement type selection based on life cycle costs alone			
New Jersey			✓	Constructability Issues

✓ Factor Considered

Table 7: Factors for analysis when pavement alternatives are considered equivalent

Weighing User Costs V/S Agency Costs

One of the reasons that user costs are not considered as a part of life cycle costs is that, even though there is a wide agreement amongst the transportation community, they tend to overwhelm agency costs. The transportation agency officials have to budget for projects under increasingly stringent conditions. The user costs are not borne by the agency. In order to overcome this problem, Indiana DOT and New Jersey DOT have adopted a novel method. The user costs are weighed differently from agency costs so that user costs don't overwhelm agency costs. Indiana DOT caps the user costs a 10% of agency costs in some projects. The decision to take 10% for the user's cost is based on the decision by the INDOT Pavement Steering Committee a few years ago. The decision by the committee was based on the FHWA suggestion. The reason is because between 5 to 10% the user's cost will not "truly" dominate the life cycle costs, hence the decision for pavement strategies. Similarly New Jersey DOT caps user costs at 50% to 75% of agency costs in some projects.

User Cost Calculation: Activities Considered

User costs are the costs borne by highway users such as additional travel (i.e. delay) time costs, crash costs, costs of operating vehicles when normal flow of traffic is disrupted because of construction or rehabilitation work. Various state highway agencies consider different types of activities for calculating user costs. This information is summarized in the following table.

State	Initial Construction	Planned Major Rehabilitation	Annual Maintenance
Washington	✓	✓	X
Indiana	✓	✓	X
Louisiana	✓	✓	X
Maryland	✓	✓	X
Colorado	✓	✓	✓
Ohio	NA	NA	NA
Michigan	✓	✓	✓
New Jersey	✓	X	X

✓ Activity Considered   X Activity Not Considered

Table 8: Activities Considered for User Cost Analysis

User Cost Component: User Delay

The presence of work zone on highways reduces the capacity of the highways, resulting in reduction of free flow speed. When the reduced capacity is less than the traffic volume, it results in queue buildups and consequent delays for the highway users. User delay is the largest user cost component. All the state DOTs that include user costs in pavement type selection process include monetized user delay costs. The following table lists the components of user delay are considered by various state DOTs while calculating delay in work zone conditions

State	Delay due to queue	Delay while going through work zone at reduced speed	Delay due to speed change cycles	Other
Washington	✓	✓	✓	X
Indiana	✓	✓	✓	X
Louisiana	✓	✓	✓	X
Maryland	✓	✓	✓	X
Colorado	✓	✓	✓	X
Ohio	NA	NA	NA	X
Michigan	✓	✓	X	Delay on account of detour
New Jersey	✓	✓	X	X

✓ Component Considered   X   Component Not Considered   NA: Not Applicable

Table 9: Components of User Delay

User Delay: Impact of Traffic Setup

The traffic setup influences the flow of traffic through the work zone and thus impacts the amount of user delay. Different pavement type alternatives involve different types of construction and rehabilitation activities during their life cycle. The traffic set up for the work zone when each type of activity is in progress could be different. The following table discusses the assumptions (about maintenance of traffic setup and phasing) made by state DOTs while calculating user delay for various construction activities for different pavement types. This table illustrates the differences in the approaches adopted by various state highway agencies in determining the traffic setup and phasing approaches for different activities of different pavement type alternatives while calculating user delays.

	Traffic Setup and Phasing for different construction activities for different alternatives		Comments
State	Assumed to be same	Assumed to be different	
Washington	✓		
Indiana		✓	Each pavement type may or may not have the same traffic control strategy
Louisiana	✓		
Maryland		✓	All activities are made as project-specific as possible
Colorado	✓	✓	Single/multiple lane closure or a cross-over considered based on activity
Michigan			Prior to performing the LCCA, the region submits the most likely MOT scheme, and that is modeled. In general, they are the same, but not always.
New Jersey	✓		Traffic Setup could be different based on activity duration

Table 10: Traffic Setup Assumptions for Calculating User Costs

Total User Delay OR Incremental User Delay

In case of extremely congested roadways with a very low level of service (E or F), the congestion causes delays to users regardless of presence of construction work zones. In such cases, it might not be considered appropriate to include total user delay (delay due to normal traffic conditions + delay due construction activity) as a component of user costs. Some state agencies, such as Indiana, don't consider user delay costs in projects where the roadway is already extremely congested while some other agencies only consider the incremental delay caused by work zones (total user delay – delay experienced prior to construction). The following table illustrates the approach adopted by various highway agencies on this issue.

State	Total User delay is considered	Only increased user delay due to Construction is considered
Washington	✓	
Indiana	If the section of the road already congested without construction, user's cost is not at all included in the analysis.	
Louisiana	✓	
Maryland		✓
Colorado		✓
Michigan		✓
New Jersey		✓

Table 11: User Delay: Total or Incremental

User Delay Calculation: Capacity of Work Zone

The calculation of user delay involves estimating the capacity of work zones created for construction and rehabilitation activities. The capacity of the work zone depends, amongst other things, on configuration of work zone, type and intensity of activities, and type of traffic control strategies. While some state DOTs such as New Jersey, Louisiana and Washington assume that the capacity of work zones is equal regardless of the type of construction/ rehabilitation activity occurring in the work zone, other state DOTs such as Maryland, Colorado, Michigan and Indiana determine the capacity of work zone independently for each type of activity. The commonly cited resources for calculating work zone capacity include:

$\Rightarrow$ Table 6.1, 6.2 & 6.3 from 1994 Highway Capacity Manual

$\Rightarrow$ Michigan uses the values provided by their own traffic and safety division

$\Rightarrow$ Work zone capacity is estimated from the graph, "Cumulative distribution of observed work zone capacities", taken from page 15 of the Transportation Research Record 869.

$\Rightarrow$ FHWA-SA-98-079, page 50

$\Rightarrow$ Workzone-RUC software of Colorado DOT

User Delay Calculation: Tools Used by State DOTs

        The following table lists the tools used by various state DOTs to calculate user delay.

State	Tool used to Calculate User Delay
Washington	C4PRS software
Indiana	Custom Excel sheet based on FHWA **RealCost**
Louisiana	Custom Excel sheet based on FHWA **RealCost**
Maryland	Custom Excel sheet based on FHWA **RealCost**
Colorado	Workzone RUC Program
Michigan	Construction Congestion Cost Model Spreadsheet
New Jersey	NJDOT Road User Cost Manual Spread sheet
Quebec	FHWA **RealCost**

Table 12: Tools Used to Calculate User Costs

Value of Travel Time

        As discussed earlier in literature review, determining the value of travel time has been a contentious issue. Various state DOTs use different resources to identify the value of travel time for calculating user costs. The following tables list the resources used by various state DOTs to determine the value of travel time and the actual values adopted by them. The tables illustrate the variability in the sources and actually adopted values of travel time across states in US. The directive issued by the secretary of transportation in 1997 recommends using different values for local and intercity travel. In this survey, it was observed that all the surveyed state DOTs value the local and intercity travel equally. This could be attributed to the difficulty in separating local travel from intercity travel.

State	Sources for Unit Value of Travel Time
Washington	HERS, NCHRP report 133, NCHRP Research Project 7-12, USDOT Office of Secretary of Transport Directive
Indiana	Colorado DOT research results
Louisiana	FHWA RealCost Manual
Maryland	FHWA RealCost software with updates for inflation provided by the Transportation component of the CPI.
Colorado	Average wage in the state
Michigan	FHWA RealCost Manual
New Jersey	Values from NCHRP report 133

Table 13: Sources for Value of Travel Time

		Value of travel time ($/HR)		
State	Reference Year	Personal passenger car travel	Business passenger car travel	Trucks
Washington	1996	10~13	10~13	17~24
Indiana	2004	17.00	17.00	35.00
Louisiana	2005	14.83	23.75	28.58
Maryland	1996	11.50	18.50	22.50
Colorado	1999	17.00	17.00	35.00
Ohio	2006	17.00	17.00	31.50
Michigan	1996	14.83	14.83	26.17
New Jersey	2006	15.21	15.21	25.35

Table 14: Value of Travel Time

Vehicle Operating Costs

The vehicle operating costs are the costs incurred by the user on account of increased slowing, idling and stopping in the work zone. The slowing and stopping costs are not considered by most state DOTs. Idling costs, which are easier to estimate, are used by state DOTs to calculate the vehicle operating costs in the work zone. The following table lists the values of vehicle operating costs used by most states and the source of these values.

State	Vehicle Operating Costs			Source
	Passenger Cars	Single Unit Truck	Multiple Unit Truck	
Washington	$ 0.6927/hour	$0.7681/hour	$0.8248/hour	FHWA-SA-98-079 (1996)
Indiana	$ 0.8312/hour	$0.9217/hour	$0.9898/hour	FHWA guidelines (Updated)
Louisiana	$ 0.6927/hour	$0.7681/hour	$0.8248/hour	FHWA-SA-98-079 (1996)
Maryland	$ 0.6927/hour	$0.7681/hour	$0.8248/hour	FHWA-SA-98-079 (1996)
Colorado	$0.6944/ hour	$0.7713/ hour	$0.8283/ hour	NCHRP Report 133 Table 5 (Updated using CPI)
Michigan	$0.445/mile	$1.18/mile	$1.18/mile	For cars: Standard mileage rate. For trucks: Costs in the Motor Carrier Annual Report, on a per mile basis, with driver wages and benefits removed.
New Jersey	$0.277/ Mile	$0.553/ Mile	$0.553/ Mile	NCHRP Report #133

Table 15: Vehicle Operating Costs

Crash Costs

It is very difficult to exactly calculate the number of crashes resulting in fatal or property damage accidents on account of increased congestion. Currently there is no validated, proven method of calculating the number of crashes. Additionally it is difficult to monetize the cost on account of crashes.

This is reflected in the survey responses. None of the DOTs surveyed include crash cost component in their user cost calculation.

Pavement Type Selection Process: Essential Elements Summarized

The pavement type selection process used by state DOTs (Michigan, Quebec, Washington, Indiana, New Jersey, Louisiana and Maryland) and the role of user costs in the selection process is summarized in this section.

Michigan:

$\Rightarrow$ All projects that have over $1 million dollars in mainline pavement costs have an LCCA.

$\Rightarrow$ Pavement type selection based exclusively on Life Cycle Costs

$\Rightarrow$ User Costs included in life cycle costs

$\Rightarrow$ Only Initial Construction and Preventative Maintenance considered in LCCA

$\Rightarrow$ Major Rehab NOT Considered in LCCA

$\Rightarrow$ Construction Congestion Cost (CO3) model used for calculating user costs

$\Rightarrow$ Delay on account of detour is included in user costs.

Louisiana:

$\Rightarrow$ User Costs included in life cycle costs

$\Rightarrow$ If the difference between the life cycle costs of two alternatives is more than 20%, the alternative with lowest life cycle cost is automatically selected.

$\Rightarrow$ If the difference between the life cycle costs of two alternatives is less than 20%, the alternatives are considered equivalent.

$\Rightarrow$ If the total life cycle costs between competing typical section alternates differs by less than 20%, then both are included into the plans for bidding.

$\Rightarrow$ FHWA RealCost software is used for calculating user costs.

Colorado:

⇒ If the results of LCCA indicate that the percentage difference in the total net present value (NPV) between the alternate pavement types is greater than 10%, then the pavement type with smaller total NPV will be recommended by the designer for use in the design and construction.

⇒ User costs are included in life cycle costs.

⇒ If the results of LCCA are within 10%, the pavement types are considered statistically equivalent and a Pavement Type Selection Committee (PTSC) will be formed to make the recommendation to the Chief Engineer.

⇒ Pavement type is in alignment with the unique goals of the project that may include individual elements of the LCCA or other non-monetary elements to ensure statewide consistency of decision making.

⇒ Custom software(Workzone-RUC) is used for calculating user costs

Washington:

⇒ User Costs included in Life Cycle Costs

⇒ If the difference between the life cycle costs of two alternatives is more than 15%, the alternative with lowest life cycle cost is automatically selected.

⇒ Under 15% difference in LCCA the alternatives are considered equivalent, other factors (location, route continuity, environmental, etc) influence the selection

⇒ C4PRS software used for LCCA and calculating user costs

Maryland:

⇒ All projects that pass through MDSHA Project Planning Division enter into the project selection process. These planning projects are mostly handled on a corridor basis and can often be broken into many advertised projects of various sizes. Also, projects not going through the Project

Planning Division that have a construction cost greater than $15 million follow through the pavement type selection process.

⇒ User costs are a part of Life Cycle Costs

⇒ If the difference between the life cycle costs of two alternatives is more than 20%, the alternative with lowest life cycle cost is automatically selected.

⇒ Under 20% difference in LCCA the alternatives are considered equivalent, other factors such as Local Conditions (sub-grade, weather, traffic, drainage etc), Type of Pavement in adjacent area Engineering Judgment, cost, Construction, Design & Environmental factors influence the selection

⇒ RealCost software by FHWA is used for the analysis.

Indiana:

⇒ If the difference between the life cycle costs of two alternatives is more than 10%, the alternative with lowest life cycle cost is automatically selected.

⇒ User costs included in LCCA in some projects.

⇒ User costs capped at 10% of agency costs.

⇒ LCCA is "a tool" for pavement selection, but not an absolute tool for decision making process.

⇒ In the case that two pavement type alternatives are considered equivalent, the pavement type selection is based on: Local Conditions (sub-grade, weather, traffic, drainage etc), Type of Pavement in adjacent area, Engineering Judgment, Constructability

⇒ FHWA RealCost software is customized to calculate user costs

New Jersey:

$\Rightarrow$ User costs included in life cycle costs

$\Rightarrow$ Life cycle cost analysis is a guidance tool for pavement type selection

$\Rightarrow$ Pavement Selection is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues

$\Rightarrow$ User costs capped at ½ to ¾ of agency costs in some projects

$\Rightarrow$ Custom developed excel sheet used for user cost calculation.

Pavement Type Selection Process: Ohio DOT

This section briefly discusses the pavement type selection process currently used by Ohio DOT.

Current ODOT Pavement Type Selection Process

This section discusses the pavement type selection process discussed ODOT policy number 20-006(P) published in September 2006.

Step 1: Identification of Alternatives

In this step, all the feasible alternatives for the project are identified. For new pavement projects, this could include rigid pavement, flexible pavement, and composite pavement. For rehabilitation / replacements projects, the alternatives could be new flexible pavement, new rigid pavement and, depending on the type of existing pavement, rubblize and roll unbonded concrete overlay, crack and seat, and whitetopping.

Step 2: Engineering Review and Analysis

In this step principal selection factors are analyzed to determine the feasible alternatives. The factors considered for this analysis include:

- Geotechnical Concerns

- Amount of Replacement

- Amount of New Pavement

- Research

- Maintenance of Traffic

- Adjacent Existing Sections

- Municipal Preference

If only one alternative is judged to be appropriate at this point, the pavement selection process ends here and life cycle cost analysis is not carried out.

Step 3: Life Cycle Cost Analysis

The life cycle cost analysis is carried out for the feasible alternatives. The period for life cycle cost analysis is 35 years. The future maintenance work is determined on the basis of the ODOT pavement design & rehabilitation manual. The completed draft selection package is sent to the district and the pavement industry representatives for comments. After their comments are received and the needed corrections made to the package, it is sent to the pavement selection committee.

Step 4: Final Pavement Selection

Alternatives that are not within 10% of lowest life cycle cost are automatically eliminated from consideration. If no alternative is within 10% of the lowest LCCA alternative, the lowest alternative is automatically selected. If the alterative of any two alternatives is within 10% of lowest alternative, the selection is based on the following secondary factors.

1. Transverse Uniformity of Cross-Section

2. Longitudinal Uniformity of Cross-Section

3. Drainage

4. Re-cycleability / Re-usability

5. Risk of Design

6. Risk of Construction/Constructability

7. Availability of Local Materials

8. Stop and Go Trucks

9. **User Delay Days**

10. Noise

11. Stimulation of Competition

12. District/Local Concerns

13. Other Factors

User Delay in the ODOT pavement selection process

In ODOT pavement type selection process, *"User Delay Days is a comparison of the theoretical time to construct and maintain each alternative based on predetermined production rates. It is not a measure of the actual time needed to construct each alternative as many factors exist which are not considered. Particularly for the initial construction, the pavement may not be the controlling factor."* (ODOT Pavement Selection Policy) Thus, in the current ODOT pavement type selection policy, the actual user delay is not calculated. The user delay days provides a comparison between the delay caused by each alternative. Instead, it is a comparison between the total time for which work zones will exist for each alternative.

ODOT MOT Policy

The main objective of ODOT's maintenance of traffic policy is to ensure that the impact of construction work zones on traffic is minimized and all reasonable countermeasures to eliminate or reduce traffic delays in freeway work zones have been considered prior to implementation of the work zone. The countermeasures recommended by the policy include:

Construction/Traffic Maintenance Strategies: Part Width, Close & Detour, Crossover Construction, Temporary Pavements (Runaround), Temporary Structures, Closure of 1-Direction of Mainline

Administrative Options: Traffic Management Program, Enforcement Incident Management, Demand Management

Corridor Options Outside Work Zone: Temporary Signals, A + B Bidding, Lane Rental, Reversible Lanes, Movable Barrier Systems, Signed Alternate Routes, Unsigned Alternate Routes, Highway Advisory Radio, Advanced Signing (Time or Distance)

Contracting Procedures Options: Incentive/Disincentives,

Traffic Flow Options Inside Work Zone: Temporary Pavements (Widen), Use Existing Shoulders Temporary Signals, Reversible Lanes, Ramp Closures, 50" Barrier, Movable Barrier Systems,

Highway Advisory Radio, Owner Imposed Design Restrictions, Use of Owner Supplied or Stockpiled Materials, Control of Contractor's Access to the Work

<u>Time Limitations with Liquidated Damages Options:</u> Temporary Lane Closures or Restrictions, Time Limitations, Night Work, Weekend Work (Only), Lane Rental, Interim Completion Dates, By Phase

MOT Policy Process

The MOT policy process basically involves the analysis of impact of construction on the flow of traffic. Each District is required to prepare a Permitted Lane Closure Map (PLCM) that defines the allowable times a lane(s) may be closed on the Interstate/Freeway system within that District. This map is available online on the ODOT website. The analysis of impact of construction on the flow of traffic needs to be done during the planning process after the pavement recommendation has been formulated and before the final scoping for the design begins. This analysis includes a quantitative analysis to determine queues that will be generated any time a lane(s) closure is proposed outside of the PLCM allowable times, except in the case of an emergency. Whereas queues are normally present even without lane closures, the analysis compares existing queues to expected queues caused by the lane closure(s). Under the MOT policy, a condition that causes driver frustration due to stop and go operations is considered a queue. A vehicle is considered part of a queue if its average operating speed is approximately 10 mph or less.

The following thresholds are used for the evaluation of project queue lengths:

1. For queues less than 0.75 miles, the work zone impacts are acceptable.

2. For queues greater than 0.75 miles and less than 1.5 miles, the work zone impacts are acceptable if the queue exceeds 0.75 miles for two hours or less. Where queues are expected to exceed 0.75 miles for any period of time, additional advanced work zone warning signing are required to be specified.

3. For queues longer than 0.75 miles for more than two hours or longer than 1.5 miles for any

period of time, the work zone impacts are unacceptable. Alternate strategies have to be considered per the provisions of this policy.

If the projected queues exceed the thresholds described earlier, the district is required to submit an exception request to the Multi-Lane Coordinator (MLC). The exception request includes the Conceptual Maintenance of Traffic submission and identifies the alternative selected by the District as their preferred option and the reasoning for their selection. Upon receiving the exception request, the MLC distributes it to appropriate Central Office specialty sections for review and comment. The MLC prepares and presents a recommendation for approval or rejection from the MOT Exception Committee (MOTEC). The MOTEC can approve an alternative, reject all, or request additional information. The conceptual elements of the MOT Process are shown in the following diagram.
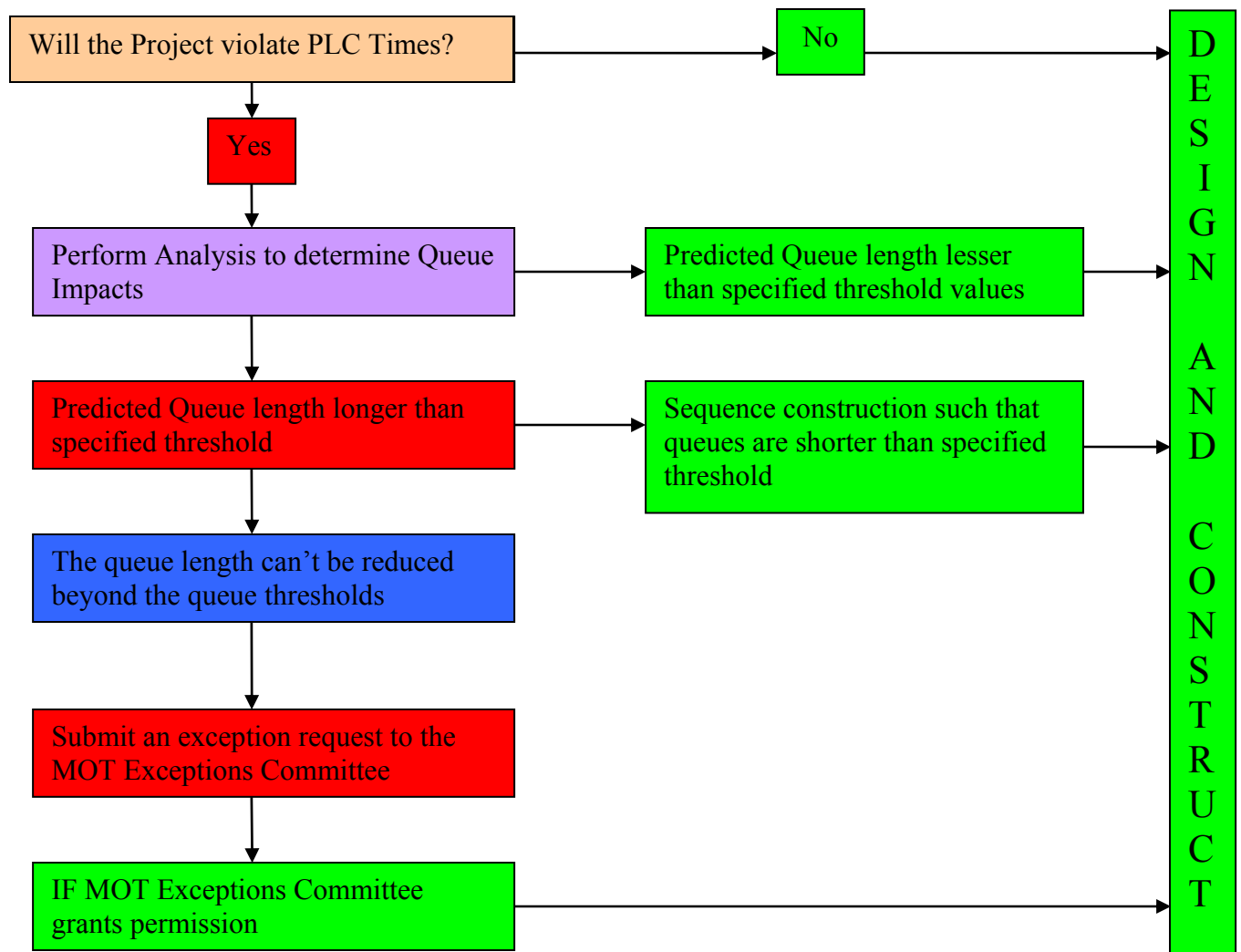
Figure 7: MOT Process

MOT Policy and its Implications to User Costs

The main objective of the MOT process is to minimize the impact of construction work zones on the traveling public through smoother flow of traffic and reduced queue lengths. As discussed above, the MOT policy only allows construction if certain standard requirement of minimum impact on traffic flow is met. If construction is done only during permitted lane closure times, in most cases, the impact on users is likely to be minimal because the lanes are allowed to be closed during off peak hours when traffic volume is very low.

Major pavement construction and rehabilitation projects may require construction work to be carried out outside the permitted lane closure times and result in queue build ups. The MOT policy allows queues of up to 1.5 miles to build up for 2 hours and this, over the long construction schedule, may add up to significant user costs. If the MOT exceptions committee allows for longer queue build up, the user costs are likely to be high. It is possible that significant user costs are incurred in spite of strict adherence to requirements of MOT Policy.

User Costs in Ohio DOT Pavement Type Selection Process: New Approaches

In the current pavement type selection process used by Ohio Department of Transportation, user costs are considered indirectly and qualitatively in the form of "User Delay Days". It is a comparison of the theoretical time to construct and maintain each alternative based on predetermined production rates. It is not a measure of the actual time needed to construct each alternative. It is clear from this information that user costs are, at best, considered as a qualitative secondary factor in an indirect way in the pavement type selection process. As described earlier, the current ODOT pavement type selection process consists of the following steps:

Step 1: Identification of Alternative Pavement construction / rehabilitation strategies for the project.

Step 2: Engineering Review and Analysis

Step 3: Calculate life cycle costs of each alternative. Eliminate the alternatives that have a life cycle cost more than 10% that the alternative with lowest life cycle costs. If only one alternative remains, choose that alternative.

Step 4: Assume that the life cycle cost of all the remaining alternatives is equivalent and select pavement type alternative based on secondary factors currently listed in the pavement type selection policy.

The current pavement type selection process can be summarized in the flow chart presented in figure 8.
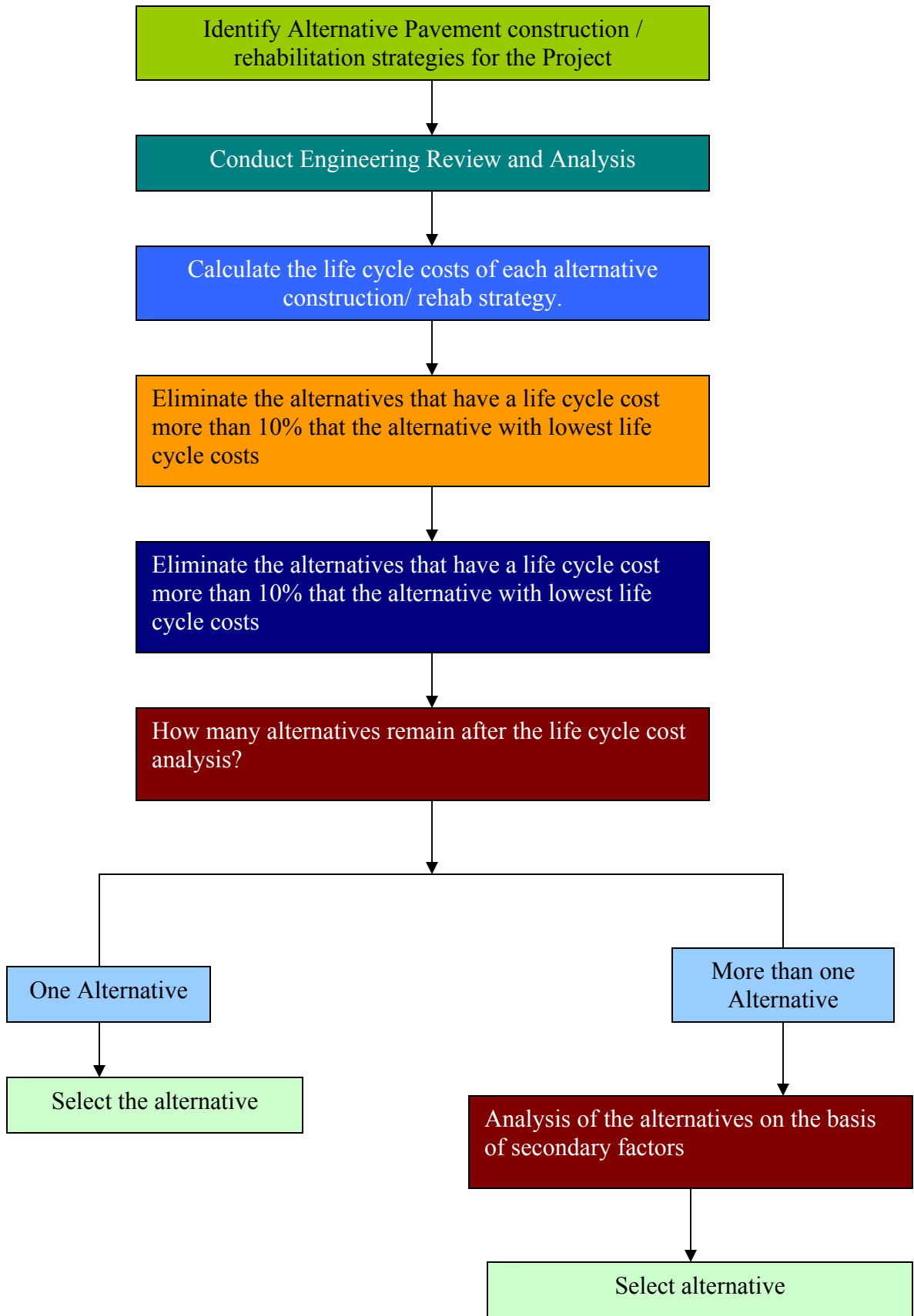
Figure 8: ODOT Pavement Type Selection Process

State of Practice: User Costs in Pavement Type Selection

Of the 22 US and Canadian agencies that responded to the survey, 14 agencies don't consider user costs as a part of their pavement type selection processes. Eight agencies including Michigan, Quebec, Washington, Indiana, New Jersey, Louisiana, Maryland, and Colorado include user costs in the pavement type selection decision making. Some of the commonalities in their pavement type selection practices are listed below:

- All the states (Michigan, Quebec, Washington, New Jersey, Louisiana and Maryland, Colorado) include user costs as a part of life cycle cost analysis. In Indiana, user costs are included in life cycle costs in some of the projects.

- In Michigan, the pavement alternative with lowest life cycle cost is automatically selected. In New Jersey, the life cycle costs are used as a guiding factor in pavement type selection. In Washington, Louisiana, Maryland, and Colorado, the pavement type selection process follows a two step procedure:

  a. If the life cycle costs of different pavement alternatives is within certain predefined limits, the life cycle costs of the different alternatives is considered to be equivalent and the pavement type selection is based on other secondary factors.

State	Difference in Life Cycle Costs at which alternatives are considered equivalent
Washington	15%
Indiana	10%
Louisiana	20%
Maryland	15%
Colorado	10%
Ohio	10%

Table 16: Equivalence of LCC of Pavement Alternatives

b. If the life cycle costs are not within this limit, the alternative with lowest life cycle cost is automatically selected.

- Indiana and New Jersey cap the user costs so that these costs don't overwhelm the agency costs. In Indiana user costs are capped at 10% of agency costs whereas in New Jersey the user costs are capped at 50% to 75% of agency costs.

- All the agencies consider user delay cost and vehicle operating cost (idling) component of user costs.

- A majority of these state transportation agencies only include the cost of user delay increased by construction.

- FHWA's RealCost software is used by Maryland, Louisiana, Indiana and Quebec for calculating user costs.

User Costs in ODOT Pavement Type Selection Process: New Approaches

Over last decade ODOT has enacted many policies to reduce the impact of construction and rehabilitation on the users of infrastructure. The inclusion of user costs in pavement type selection process will shift this consumer orientation to the project selection stage. The impact of construction on infrastructure users has been extensively researched over last 50 years. Now various computerized tools are available which can easily enable the state DOTs to calculate and monetize user costs.

Based on the results of the review of literature, review of methods used by several transportation agencies for including user costs in pavement type selection and feedback from ODOT, the following two approaches can be recommended to include user costs in pavement type selection.

Approach 1: Include user costs in Life Cycle Costs

Among the state agencies that include user costs in the pavement type selection process, every agency (except Indiana) includes user costs in life cycle cost analysis. Researchers have advocated the inclusion of user costs in life cycle cost analysis for many years. The user costs are not borne by the agency, they are borne by the users of the infrastructure. A life cycle cost analysis including user costs would result in a comprehensive economic evaluation of all the pavement type alternatives and result in the selection of an alternative that will ensure selection of an alternative that has lowest overall economic impact.

The new pavement type selection process would be exactly the same as the current pavement type selection process. This process can be summarized in the following steps:

Step 1: Identification of Alternative Pavement construction / rehabilitation strategies for the project.

Step 2: Conduct Engineering Review and Analysis

Step 3: Conduct Life Cycle Cost Analysis. Include User Costs in Life Cycle Costs.

Step 4: Eliminate the alternatives that have a life cycle cost more than 10% that the alternatives with lowest life cycle costs. If only one alternative remains, choose that alternative.

Step 5: Assume that the life cycle cost of all the remaining alternatives is equivalent and select pavement type alternative based on secondary factors currently listed in the pavement type selection policy.

Figure 9: Pavement Type Selection Process: Alternative 1

Approach 2: Compare User Costs of Alternatives with Equivalent Life Cycle Costs

The user costs in some projects where the traffic volume is very high can be enormous. For example, the user costs during the construction of Dead Run Bridge and Turkey Run Bridge in Virginia was estimated at more than $ 100,000 per day of the project. In such projects, the user costs can eclipse the agency costs. The agency has to select projects for execution from a number of candidate projects because of budgetary constraints and this concern has resulted in limited inclusion of user costs in pavement type selection process. The following approach can alleviate these concerns.

Instead of including user costs in the life cycle costs as suggested in the previous approach, the user costs of the alternatives with equivalent life cycle costs can be compared to select the alternative. The alternate pavement type selection process would be similar to the current pavement type selection process. This process can be summarized in the following steps:

Step 1: Identification of Alternative Pavement construction / rehabilitation strategies for the project.

Step 2: Conduct Engineering Review and Analysis

Step 3: Conduct Life Cycle Cost Analysis. (Do not include user costs in Life Cycle Costs.)

Step 4: Eliminate the alternatives that have a life cycle cost more than 10% that the alternatives with lowest life cycle costs. If only one alternative remains, choose that alternative.

Step 5: Calculate user costs of each of the remaining alternatives. Eliminate the alternatives that have a user cost more than x % (The value of x needs to be decided by ODOT) that the alternative with lowest user costs. If only one alternative remains, choose that alternative.

Step 6: Assume that the life cycle cost and user costs of all the remaining alternatives are equivalent and select pavement type alternative based on secondary factors currently listed in the pavement type selection policy.

The alternative pavement selection policy can be summarized in the following figure.

```
┌─────────────────────────────────────────────────────────────────────────┐
│     Identify Alternative Pavement construction / rehabilitation strategies for the Project │
└─────────────────────────────────────────────────────────────────────────┘
                                      │
                                      ▼
┌─────────────────────────────────────────────────────────────────────────┐
│                      Conduct Engineering Review and Analysis              │
└─────────────────────────────────────────────────────────────────────────┘
                                      │
                                      ▼
┌─────────────────────────────────────────────────────────────────────────┐
│     Calculate the life cycle costs of each alternative construction/ rehab strategy. │
└─────────────────────────────────────────────────────────────────────────┘
                                      │
                                      ▼
┌─────────────────────────────────────────────────────────────────────────┐
│     Eliminate the alternatives that have a life cycle cost more than 10% that the alternative │
│     with lowest life cycle costs                                          │
└─────────────────────────────────────────────────────────────────────────┘
                                      │
                                      ▼
┌─────────────────────────────────────────────────────────────────────────┐
│     Eliminate the alternatives that have a life cycle cost more than 10% that the alternative │
│     with lowest life cycle costs                                          │
└─────────────────────────────────────────────────────────────────────────┘
                                      │
                                      ▼
┌─────────────────────────────────────────────────────────────────────────┐
│     How many alternatives remain after the life cycle cost analysis?      │
└─────────────────────────────────────────────────────────────────────────┘
                  │                                   │
                  ▼                                   ▼
         ┌──────────────────┐              ┌────────────────────────┐
         │  One Alternative │              │ More than one Alternative│
         └──────────────────┘              └────────────────────────┘
                  │                                   │
                  ▼                                   ▼
      ┌───────────────────────┐         ┌──────────────────────────────────┐
      │ Select the alternative│         │ Calculate the User Cost for each alternative │
      └───────────────────────┘         └──────────────────────────────────┘
                                                      │
                                                      ▼
                                   ┌──────────────────────────────────────┐
                                   │ Eliminate the alternatives that have user costs more than │
                                   │ x % that the alternative with lowest user costs │
                                   └──────────────────────────────────────┘
                                                      │
                                                      ▼
                         ┌────────────────────────────────────────────────┐
                         │ How many alternatives remain after the user cost analysis? │
                         └────────────────────────────────────────────────┘
                                  │                          │
                                  ▼                          ▼
                         ┌──────────────────┐      ┌────────────────────────┐
                         │  One Alternative │      │ More than one Alternative│
                         └──────────────────┘      └────────────────────────┘
                                  │                          │
                                  ▼                          ▼
                      ┌───────────────────────┐   ┌──────────────────────────────┐
                      │ Select the alternative│   │ Analysis of the alternatives on the │
                      └───────────────────────┘   │ basis of secondary factors   │
                                                  └──────────────────────────────┘
                                                               │
                                                               ▼
                                                  ┌──────────────────────────────┐
                                                  │      Select alternative      │
                                                  └──────────────────────────────┘
```

Figure 10: Pavement Type Selection Process: Alternative 2

User Costs: Components to be Included

The components of user costs included in the analysis by various state DOTs include costs accrued by users on account of the presence of the work zones. These costs include the user delay costs and vehicle operating costs in the work zone. The user delay in a work zone can be classified as following:

1. Frequently traffic flows slowly through the work zone slower than the free flow speed allowed on the adjacent sections of the road. Vehicles have to decelerate from the upstream approach speed to the work zone speed and then to accelerate back to the free flow speed after traversing the work zone. The delay caused on account of this speed change cycle is known as **Speed Change Delay.**

2. The slower speed of traffic while traversing through work zone causes additional delay. This delay depends upon the upstream traffic speed, speed through work zone and the length of the work zone. This delay is known as **Reduced Speed Delay.**

3. When a queue is present in the work zone, instead of just slowing to the work zone speed, vehicles have to come to a complete stop from the upstream approach speed and the additional time to accelerate back to the approach speed after traversing the work zone. This delay is also known as **Stopping Delay** in the work zone.

4. In addition to this, when queue is present, vehicles have to move slowly through the work zone under forced flow conditions. This delay is also known as **Queue Delay** in work zone.

Delay in Work Zone = Speed Change Delay + Reduced Speed Delay + Stopping Delay + Queue Delay

In addition to the delay in work zone, motorists incur additional vehicle operating costs (VOC). Vehicles have to slow down as they approach work zone and stop. In situations where queues are present, the vehicles have to remain idle in work zone as long as they are stopped. The vehicle operating costs in a work zone can be classified as following:

1. The user costs associated with the decelerating from the upstream approach speed to the work zone speed and then accelerating back to the approach speed after leaving the work zone. This VOC component is called as *Speed Change VOC.*

2. The user costs associated with stopping from the upstream approach speed and accelerating back up to the approach speed after traversing work zone. This VOC component is called as *Stopping VOC.*

3. The user cost associated with *stop-and-go* driving in the queue. This VOC component is called as *Idling VOC*.

Vehicle Operating Costs = Speed Change VOC + Stopping VOC + Idling VOC

User Costs: Software Tool for Calculating User Costs

RealCost, developed and distributed by FHWA, is a versatile package that allows the user to conduct life cycle cost analysis for infrastructure assets. The unique features of RealCost include a detailed user cost analysis component and the ability to conduct deterministic as well as probabilistic analysis of life cycle costs. In the survey of state DOTs, it was found that Indiana, Quebec, Maryland and Louisiana were found to use RealCost to calculate user costs. This software, based on Microsoft Excel, is the most versatile software for calculating user costs. It provides the user with detailed breakdown of user costs for each alternative for initial construction and every rehabilitation/ reconstruction during the life cycle. It allows the comparison of two alternatives and each alternative can have 6 reconstruction / rehabilitation options. The user cost components calculated include WZ Speed Change VOC, WZ Speed Change Delay, WZ Reduced Speed Delay, Queue Stopping Delay, Queue Stopping VOC, Queue Added Travel Time, Queue Idle Time. The excel spread sheet calculates these components of user cost for each state (initial construction, rehabilitation # 1,2,3,4,5,6) for each alternative. The details for each component are provided in the spread sheet for each alternative. The input parameters and output obtained are described in the next section.

Input for RealCost: Data Required

RealCost is a life cycle cost analysis software. In this section, the input parameters required for user cost computation component are listed and discussed.

<u>Traffic Profile</u>

- ❖ AADT Construction Year

- ❖ Cars as Percentage of AADT (%)

- ❖ Single Unit Trucks as Percentage of AADT (%)

- ❖ Combination Trucks as Percentage of AADT (%)

- ❖ Annual Growth Rate of Traffic (%)

- ❖ Maximum AADT

  The analysis of pavement type option covers a period of at least 30 years. It is possible that, with the current annual traffic growth rate, the projected traffic can exceed the capacity of the roadway. RealCost allows the user to specify the Maximum AADT for the roadway so that the software doesn't use AADT values higher than the capacity of the roadway itself!

<u>Traffic Flow</u>

- ❖ Hourly Traffic Distribution

  RealCost provides the user with the opportunity to input the hourly traffic distribution for the roadway for accurate calculation of user costs. If this data is not available, the software uses the standard hourly traffic distribution numbers derived from Texas Transportation Institute's MicroBENCOST software. The two main profiles of hourly traffic distribution are urban traffic and rural traffic.

- ❖ Speed Limit Under Normal Operating Conditions

- ❖ No of Lanes in Each Direction During Normal Conditions

- ❖ Free Flow Capacity (vphpl)

Work Zone

- ❖ Work Zone Length

- ❖ Work Zone Speed

- ❖ Work Zone Capacity

    The work zone capacity is determined from the tables provided in the Highway Capacity Manual Table 6-11 which are based on observed capacities of many work zones under different lane closure scenarios. User can enter custom values in this field.

- ❖ Queue Dissipation Capacity (vphpl)

- ❖ Maximum Queue Length (miles)

    Models the effects of self-imposed detours (traffic exiting from the work zone route yet still incurring some user costs). Queue related user costs, which are based upon queue length, are calculated with this figure instead of the calculated queue length. This feature can be used in conjunction with the queue thresholds specified in ODOT MOT Policy.

- ❖ Lane Closure Times

    The software allows the user to specify the hours each day of the work zone duration during which the work zone is in effect. During these hours, capacity is limited to work zone capacity. The software allows the user to specify three lane closure times when work zone is in effect.

RealCost Output: User Cost Calculations.

The RealCost software outputs a very detailed analysis of user costs incurred by users on account of creation of work zones. The software provides output for every alternative and every construction/ rehabilitation activity. The output includes detailed step-by-step calculations and hourly break-down of user costs. The software allows the user to specify the hours each day of the work zone duration. It provides the user costs when work zone is present and also in case of normal conditions where no work zone is present.

The following user cost components are calculated by the software:

- ❖ Work Zone Speed Change VOC

- ❖ Work Zone Speed Change Delay

- ❖ Work Zone Reduced Speed Delay

- ❖ Queue Stopping Delay

- ❖ Queue Stopping VOC

- ❖ Queue Added Travel Time

- ❖ Queue Idle Time

<h1 style="text-align: center">Case Studies</h1>

The new alternative pavement type selection approaches presented in the previous chapters are illustrated in this chapter. This section presents the analysis of two pavement type selection projects in which pavement selection has already been completed. The two projects selected here provide examples of application of the two approaches that have been recommended in this research study. In the first case study (WAR-75-3.40), none of the alternatives were within 10% of the alternative with the lowest life-cycle costs. This example has been used to illustrate the use of the first recommended decision making process where the user costs are included in the life cycle costs. In the second case study (LAK-2-332), the life cycle costs of the two alternatives were within 10% of each other. This case study has been used to present the second recommended decision making process, where the user costs of two alternatives are compared (when the life cycle costs are within 10% of the lowest) is illustrated.

Case Study 1: WAR-75-3.40 (PID 10754)

This case study involves the rehabilitation of I-75 expressway in Warren County in Ohio. The project length was 8.8 miles and four pavement construction strategies were considered in the decision making process. These strategies included flexile pavement, rigid pavement, rubblize and roll, and unbonded concrete overlay. These strategies are detailed below:

Rubblize & Roll

Remove the existing asphalt, rubblize and roll the existing reinforced concrete pavement and overlay with 12-1/2" of Item 880 Asphalt Concrete (7-year Warranty). Fifteen percent (15%) removal is required to meet elevation of mainline bridges and provide 16'-6" clearance under overhead bridges, assuming bridges are not jacked.

Unbonded Concrete Overlay

Remove the existing asphalt, place a 1" asphalt bondbreaker layer and overlay with 10" of Item 884 Portland Cement Concrete (7-year Warranty). Thirteen and a half percent (13.5%) removal is required to

meet elevation of mainline bridges and provide 16'-6" clearance under overhead bridges, assuming bridges are not jacked.

Flexible Replacement

Remove the existing pavement and place 14.5" of Item 880 Asphalt Concrete (7-year Warranty) on 6" of Item 304 Aggregate Base.

Rigid Replacement

Remove the existing pavement and place 14.5" of Item 884 Portland Cement Concrete (7-year Warranty) on 6" of Item 304 Aggregate Base.

The future maintenance strategies are summarized in the following table.

	Pavement Construction Strategy			
Time of Rehab	Rubblize & Roll	Unbonded Concrete Overlay	Flexible Replacement	Rigid Replacement
12 Years	1.5" overlay with planing (mainline only)		1.5" overlay with planing (mainline only);	
22Years	3.25" overlay with planing (full width of mainline and shoulders), 1% patching planed surface (percent of planed area)	Diamond grinding (mainline plus one foot of shoulder), full depth repair 4% of mainline surface area;	3.25" overlay with planing (full width of mainline and shoulders), 1% patching planed surface (percent of planed area);	Diamond grinding (mainline plus one foot of shoulder), full depth repair 4% of mainline surface area;
32 Years		3.25" asphalt overlay, full depth repair 2% of mainline surface area.		3.25" asphalt overlay, full depth repair 2% of mainline surface area.
34 Years	1.5" overlay with planing (mainline only).		1.5" overlay with planing (mainline only).	

Table 17: Future Maintenance for WAR-75-3.40 project

The impact on user of the infrastructure was done by comparing the estimated total days when the lanes will be closed. The analysis is shown in the following table:

LANE CLOSURE SUMMARY*

Action	Rubblize	UBCO	Flexible	Rigid
Initial Construction**	824	515	1,088	929
Future Maintenance				
@ 12 Years	28		28	
@ 22 Years	142	115	142	115
@ 32 Years		74		74
@ 34 Years	28		28	
Total of Future	198	189	198	189
Total Number of Days	1,022	704	1,287	1,118

Table 18: Lane Closure Summary for WAR-75-3.40 project

Decision Making Process

The discounted life cycle costs of various strategies, as calculated by ODOT, are shown in the following table:

Discounted Life Cycle Costs @ 3.5 %			
Rubblize & Roll	Unbonded Concrete Overlay	Flexible Replacement	Rigid Replacement
$23,115,293	$26,014,438	$27,543,667	$34,823,591
Lowest LCC	12.54% higher	19.16% higher	50.65% higher

Table 19: Life Cycle Cost Summary for WAR-75-3.40 project

Since the life cycle costs of the Rubblize and Roll strategy were the least and the life cycle costs of other strategies were more than 10% higher than the life cycle costs of rubblize and roll strategy, the project was constructed using rubblize and roll strategy.

The same project is now analyzed using the first recommended decision making process:

Recommended Decision Making Process: Include User Costs in Life Cycle Costs

According to this approach, the life cycle costs, inclusive of the user costs, are calculated. FHWA's RealCost software is used for the calculations. It was assumed that only one lane (of three lanes) of I75 were closed during all construction and rehabilitation work. Two lanes were assumed to be open for traffic. The FHWA research has indicated that the average queue dissipation capacity at work zones is 1818 vehicles per lane per hour. This value was used for analysis. Ohio DOT's permitted lane closure map (PLCM) was used to identify the timing of closure of one lane on this stretch of the expressway. It was found that the permitted lane closure hours were from 8PM to 6AM. The work zone capacity was also determined from PLCM at 1390 vehicles per lane per hour. The detailed summary sheet showing all the inputs made to the RealCost software can be found in appendix 4.

The user costs calculated by RealCost for the different alternatives are shown in the following table:

	Discounted User Costs @ 3.5%			
Activity	Rubblize & Roll	Unbonded Concrete Overlay	Flexible Replacement	Rigid Replacement
Initial Construction	7,707,717	4,817,323	10,177,180	8,689,890
12 Years	246,461		246,461	
22Years	3,829,717	3,101,531	3,829,717	3,101,531
32 Years		5,904,234		5,904,234
34 Years	2,098,638		2,098,638	
Total	13796227.13	13744421.07	16249508.55	17591612.08

Table 20: User Cost Summary for WAR-75-3.40 project

The total life cycle costs for all the alternatives in this project are summarized in the following table.

Activity	Discounted Life Cycle Costs @ 3.5%			
	Rubblize & Roll	Unbonded Concrete Overlay	Flexible Replacement	Rigid Replacement
Agency Costs	23115293	26014438	27543667	34823591
User Costs	13796227.13	13744421.07	16249508.55	17591612.08
Total Life Cycle Costs	36911520	39758859	43793176	52415203
% Greater than Lowest	Lowest	7.71%	18.64%	42.00%

Table 21: Life Cycle Cost (Including User Cost) Summary for WAR-75-3.40 project

From the above table, it is clear that the life cycle cost of Unbonded Concrete Overlay alternative is within 10% of the alternative with the lowest life cycle cost (Rubblize and Roll). Thus, the decision making process narrows down to these two alternatives and a detailed comparison of the alternatives can be carried out on the basis of the secondary factors listed in the ODOT Pavement Type Selection Policy.

Case Study 2: LAK-2-322 (PID 13486)

This project involves the major rehabilitation from Biedler Road to Richmond Street (SR-283) in Willoughby, Lake County, Ohio. The project length is 4.28 miles and two pavement construction strategies were considered in the decision making process. These strategies included flexile pavement and rigid pavement. The future maintenance/rehabilitation work for each type of pavement is shown in the following table.

	Pavement Construction Strategy	
Time of Rehab	Flexible Pavement	Rigid Pavement
12 Years	1.5" overlay with planing (mainline only);	
22Years	3.25" overlay with planing (full width of mainline and shoulders), 1% patching planed surface (percent of planed area);	Diamond grinding (mainline plus one foot of shoulder), full depth repair 4% of mainline surface area;
32 Years		3.25" asphalt overlay, full depth repair 2% of mainline surface area.
34 Years	1.5" overlay with planing (mainline only).	

Table 22: Future Maintenance for LAK-2-322 project

The impact on user of the infrastructure was done by comparing the estimated total days when the lanes will be closed. The analysis is shown in the following table:

Action	Flexible	Rigid
Initial Construction	160	118
Future Maintenance		
@ 12 Years	10	
@ 22 Years	37	35
@ 32 Years		30
@ 34 Years	10	
Total of Future	58	66
Total Number of Days	218	183

Table 23: Lane Closure Summary for LAK-2-322 project

The discounted life cycle costs of various strategies, as calculated by ODOT, are shown in the following table:

Discounted Life Cycle Costs @ 3.5 %	
Flexible Replacement	Rigid Replacement
$9,517,006	$9,911,878
Lowest LCCA	4.15% higher

Table 24: Life Cycle Cost Summary for LAK-2-322 project

Since the discounted life-cycle cost of rigid pavement is within 10% of that of the flexible pavement, the final selection is based on a number of secondary factors listed in the pavement type selection policy.

Recommended Decision Making Process: Comparison of User Costs

According to this recommended approach, when the life cycle cost of one or more alternatives is within 10% of the lowest alternative, these alternatives should be considered equivalent and further analyzed. Instead of conducting the analysis of secondary factors, as is done in the current decision making process, the user costs of the alternatives should be compared. If the user costs of the alternatives are found within 10% of the alternative with lowest user costs, such alternatives should be considered to be equivalent and analyzed further using the secondary factors listed in the pavement type selection policy. It was assumed that only one lane (of two lanes) of SR-283 were closed during all construction and rehabilitation work. One lane assumed to be open for traffic. The FHWA research has indicated that the average queue dissipation capacity at work zones is 1818 vehicles per lane per hour. This value was used for analysis. Ohio DOT's permitted lane closure map (PLCM) was used to identify the timing of closure of one lane on this stretch of the expressway. It was found that the permitted lane closure hours were from 8PM to 6AM. The work zone capacity was also determined from PLCM at 1490 vehicles per lane per hour. The detailed summary sheet showing all the inputs made to the RealCost software can be found in appendix 5.

The user costs calculated by RealCost for the different alternatives are shown in the following table:

Activity	Discounted User Costs @3.5%	
	Flexible	Rigid
Initial Construction	609,142	449,202
12 Years	310,868	
22Years	812,025	768,132
32 Years		462,280
34 Years	163,432	
Total	1,895,469	1,679,654
% Difference from lowest	12.8%	Lowest User Cost

Table 25: User Cost Summary for LAK-2-322 project

From the above table, it can be seen that the user costs of the rigid pavement option are lowest and the

difference between the two discounted user costs is 12.8 %. If this value exceeds the spread value

(determined by ODOT) then rigid pavement option should be selected. If not, the selection can be made

on the basis of secondary factors much like the current ODOT selection process.

Conclusions & Recommendations

The Ohio Department of Transportation's focus on minimizing impact of construction on the users of infrastructure has resulted in formulation of policies such as Maintenance of Traffic Policy. It is important to gauge the economic impact of the delays created by construction work zones and incorporate it in the decision making process when selecting the pavement construction alternative.

The user costs are the costs borne by highway users such as additional travel (i.e. delay) time costs, costs of operating vehicles in work zone conditions. A significant research effort has been put in over the last 50 years to identify the components of user costs and quantify them. There is an increasing awareness in the transportation community about including these costs in the pavement type selection decision making process. Of the 20 state transportation agencies surveyed as a part of this research project, 8 include user costs quantitatively as a part of their pavement type selection process, Illinois DOT is currently studying methods to include user costs in the pavement type selection process while 11 indicated that they may do so in the future.

The current pavement type selection process (Policy 20-006(P)) used by the Ohio Department of Transportation considers user costs indirectly in the form of user delay days which don't involve quantification of user delay. It is a comparison of number of days required for construction and rehabilitation of various alternatives. This can be improved upon by quantifying user costs and using the monetized user costs in pavement type selection process. The user costs can be introduced seamlessly into the current ODOT pavement type selection process. There are two options for achieving this objective.

In the first recommended approach, user costs can be directly included in the life cycle cost analysis. It is worthwhile to note that the eight DOTs that include user costs in the pavement type selection process include them as a part of life cycle costs. The role of life cycle cost analysis in the pavement type selection process in these DOTs is similar to that of ODOT. The pavement type selection process in this case will follow the following steps:

Step 1: Identification of Alternative Pavement construction / rehabilitation strategies for the project.

Step 2: Conduct Engineering Review and Analysis

Step 3: Conduct Life Cycle Cost Analysis. <u>Include User Costs in Life Cycle Costs.</u>

Step 4: Eliminate the alternatives that have a life cycle cost more than 10% that the alternatives with lowest life cycle costs. If only one alternative remains, choose that alternative.

Step 5: Assume that the life cycle cost of all the remaining alternatives is equivalent and select pavement type alternative based on secondary factors currently listed in the pavement type selection policy.

In the second approach, the current pavement type selection process can be modified slightly by adding a step involving user cost analysis. If the life cycle costs of pavement type alternatives are found to be equivalent (within 10% of lowest life cycle costs), the user costs of the alternatives should be calculated and compared before comparing secondary factors as per the current process. If the user costs of alternatives are found to be within a certain percentage (to be decided by ODOT) of the lowest user costs, the user costs of the alternatives could be considered equivalent and pavement type selection carried out on the basis of secondary factors. The process can be summarized in the following steps:

Step 1: Identification of Alternative Pavement construction / rehabilitation strategies for the project.

Step 2: Conduct Engineering Review and Analysis

Step 3: Conduct Life Cycle Cost Analysis. (Do not include user costs in Life Cycle Costs.)

Step 4: Eliminate the alternatives that have a life cycle cost more than 10% that the alternatives with lowest life cycle costs. If only one alternative remains, choose that alternative.

Step 5: Calculate user costs of each of the remaining alternatives. Eliminate the alternatives that have a user cost more than 10% than what the alternative with lowest user costs. If only one alternative remains, choose that alternative.

Step 6: Assume that the life cycle cost and user costs of all the remaining alternatives are equivalent and select pavement type alternative based on secondary factors currently listed in the pavement type selection policy.

Many software tools have been developed over the last decade that enabled the calculation of user costs. Though many software tools can be used to calculate user costs, RealCost software developed and promoted by the FHWA will best suit ODOT's needs. It is currently being used by Indiana (Modified), Maryland, Quebec and Louisiana for life cycle cost analysis in pavement type selection process. It is a Microsoft Excel based software that calculates the user costs in a transparent manner. The excel worksheets provide a detailed break up of the step-by-step process used to calculate user costs. RealCost is basically life cycle cost analysis software that can also conduct probabilistic life cycle cost analysis. It will have to be slightly modified to use it to exclusively calculate user costs.

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APPPENDIX 1: Questionnaire Survey

APPENDIX 1: Questionnaire Survey

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The Ohio Department of Transportation is developing a methodology to integrate user costs in the pavement type selection process. In this questionnaire survey, we would like to know if your organization includes the analysis of the user costs of pavement alternatives in the **pavement type selection process**. In the context of this survey , *user costs may be defined as the costs borne by highway users such as additional travel (i.e. delay) time costs, crash costs, costs of operating vehicles in normal as well as work zone conditions*. We would like to know which components of user costs are considered in the analysis and the method used to calculate and assign monetary value to user costs. The information collected through the questionnaire survey will be used in the research study and shared with transportation research community through peer reviewed journals.

Please be assured that any information gathered from these surveys will be held in the strictest confidentiality by Ohio Department of Transportation and the University of Cincinnati.

Thank you for your participation in this survey.

1. What are the types of pavements considered in the Pavement Selection Process by your organization?

__ HMA   __PCC   __Other: Please Describe _____

2. Do you perform Life Cycle Cost Analysis (LCCA) while selecting the pavement type in a project? (If you answered "No" please skip to question 15)

__ Yes   __ No

      a. In what size projects is LCCA performed? (indicate all that apply)

         ___ Small Projects: <u>Project Cost up to $ million.</u>

         ___ Medium Projects: Projects: <u>Project Cost up to $ million.</u>

         ___ Large Projects: Projects: <u>Project Cost up to $ million.</u>

         ___ Mega Projects: Projects: <u>Project Cost up to $ million.</u>

3. Which method of financial analysis is used in LCCA?

__ Net Present Value   __Future Value

__Equivalent Uniform Annualized Cost

__Other: Please Explain_____

4. What is the analysis period in LCCA?

HMA: _____ years

PCC: _____ years

5. What discount rate is currently being employed in LCCA?

_____ %

6. Do you consider inflation rate in LCCA?

___ No   ____Yes Please Specify Value _____%

7. Do you consider the cost of controlling traffic during rehabilitation in LCCA?

___No

___ Yes: Please Explain the Methodology for calculating costs of controlling traffic.

_____

_____

_____

_____

_____

8. While conducting LCCA, when is major rehabilitation work scheduled for HMA and PCC type pavements?

HMA: 1._____ years   Type of Work:_____

        2._____ years   Type of Work:_____

        3._____ years   Type of Work:_____

PCC: 1._____ years   Type of Work:_____

        2._____ years   Type of Work:_____

        3._____ years   Type of Work:_____

9. What type of maintenance and rehabilitation activities are considered in LCCA?

___ Annual Routine Maintenance

___ Scheduled Major Rehabilitation

___ Other: Please Describe _____

10. For which of the following types of roadways is LCCA carried out?

___ Interstate   ___ Urban Highway   __ Rural Highway

___ Arterials   ___ Side Streets   __ Other _____

11. How would you characterize the role played by LCCA in pavement type selection process in your organization?

_____ Pavement type selection is based exclusively on LCCA.

_____ LCCA is conducted but final decision is based on initial construction costs.

_____ Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.

11 a .Please explain the Role of LCCA in Pavement Type Selection Process briefly:

_____

_____

_____

_____

12. Is a sensitivity analysis performed while comparing various pavement type alternatives?

___Yes   ___ No

13. Is a salvage value (Remaining Life) included in the Life Cycle Cost Analysis?

___Yes   ___No

(Material? Salvage Value?) _____

14. Is there a percentage difference in Life Cycle Costs at which two alternatives are considered equivalent?

___ Yes   Value _____%   ___ No

14a. In the case that two pavement type alternatives are considered equivalent, the pavement type selection is based on:

___ Local Conditions (sub-grade, weather, traffic, drainage etc)

___ Type of Pavement in adjacent area

___ Engineering Judgment

___ Other Factors: Please Describe _____

15. How would you characterize the analysis of user costs in the pavement type selection process? (If you answered b / c / d, please skip to question 41)

   a. User Costs are considered ____
   b. User Costs are not currently considered and there are no plans of incorporating them in the future _____
   c. User Costs are not currently considered but will definitely be considered in the future (currently methods / approaches being studied)_____
   d. User Costs not currently considered but may be included in future. _____

In this section of the questionnaire, we would like to know about the analysis of user costs when comparing various pavement alternatives.

16. How are user costs accounted for in the pavement type selection process used by your organization?

___Quantitatively as a part of Life Cycle Cost Analysis

___Quantitatively, but independent of Life Cycle Cost Analysis

___ Qualitatively (Please skip to question 40)

17. Are the user costs weighted differently from the agency costs (construction cost and rehabilitation costs)? (e.g.: the User cost might be given a factor of ½ while the agency costs might be given a factor of 1)

___ No [Weighted Equally]

___ Yes [Weighted Differently] Please Explain _____

_____

_____

18. In the user cost analysis, when is construction assumed to be performed?

    (You may choose more than one alternatives)

    __ Day

    __ Night

    __ Off Peak hours

19. For which of the following activities are user costs considered?

    __ Initial Construction

    __ Planned Major Rehabilitation

    __Annual Maintenance

20. If a pavement rehabilitation project involves rehabilitation of a non-pavement structure (i.e. bridge), how are the user costs on account of such non-pavement activity considered?

    __ Considered separately from pavement user cost analysis

    __ Considered as a part of pavement user cost analysis

21. Are user delay costs (Increased costs to the user on account of increased travel time due to congestion) considered in the pavement type selection process?

    (If you answered "No", please skip to question 34)

    ___Yes   ___ No

22. How is user delay accounted for in the pavement type selection process?

    ___ In terms of total user delay (e.g. User Delay Days)

    ___ Monetized in terms of delay costs (in $$ terms)

    ___ Other __: Please Specify _____

23. Which of the following components of user delay are considered while calculating delay in work zone conditions?

    a. Delay due to queue ___

    b. Delay while going through work zone at reduced speed ____

    c. Delay due to speed change cycles ___

    d. Other __: Please Specify _____

24. While calculating user delay for various construction activities for different pavement types is maintenance of traffic setup and phasing assumed to be the same for every alternative?

    __ Assumed to be the same

    __ Assumed to be different

COMMENTS _____

_____

_____

25. While calculating user delay, is total user delay [Delay due to normal traffic conditions + Delay due construction activity] considered or only increased user delay due to construction considered?

___ Total User delay is considered

___ Only increased user delay due to Construction is considered

26. What level of passenger vehicle occupancy is assumed when calculating user delay costs?

___ 1 occupant / vehicle

___ More than 1 occupant / vehicle: Please Specify: _____

27. Is the capacity of work zone considered to equal for different type of construction / rehabilitation activities? (E.g. Heating and Scarifying, Microsurfacing, Cross stitching etc.)

___ Considered to be equal

___ not considered to be equal

28. Please briefly describe the method used to calculate the capacity of work zone?

_____

_____

_____

_____

29. How is the user delay for major construction / rehabilitation activities calculated?

a. Uniform delay is assumed for every day.

b. Duration of sub-activities (excavation, PCC etc) is calculated and delay during each activity is calculated and added up.

30. Which tool is used in your organization to calculate user delay costs?

___ QueWZ

___ QuickZone

___ MicroBENCOST

___ Tables developed by Texas Transportation Institute

(Techniques for manually estimating user costs)

___ Custom Developed Excel Sheet/ Software Please Give details:

_____

___ No tool is used to calculate user delay costs. Delay is calculated using specialized software and multiplied by unit delay cost. (Please identify the name

Of software used)

    ____ FREQ

    ____CORSIM

    ____ HCS Model

    ____PASSER Model

    ____ QuickZone

    ___ Other: Please Specify _____

31. How is the unit value of travel time calculated?

    ___ Using AASTO Red Book Values

    ___ Using Values from HERS

    ___ Using values from NCHRP report 133

    ___ Using NCHRP Research Project 7-12 (MicroBENCOST)

    ___ USDOT Office of Secretary of Transport Directive

    ___ Using Average National Wage

    ___ Using Average Wage in State

    ___ Using Average Wage at District level

    ___ Other: Please Specify _____

32. Is local travel and intercity travel valued equally?

    ___Yes   ___ No

33. What is the value of travel time for the following types of vehicles:

Local Travel:

    a. Personal passenger car travel: $_____   Reference Year _____

    b. Business passenger car travel: $_____   Reference Year _____

    c. Truck Drivers: $ _____   Reference Year _____

Intercity Travel: (Skip this part if values are same as Local Travel)

    a. Personal passenger car travel: $_____   Reference Year _____

    b. Business passenger car travel: $_____   Reference Year _____

    c. Truck Drivers: $ _____   Reference Year _____

34. Are vehicle operating costs (increased costs of operating vehicles) considered in the pavement type selection process? (If you answer "No" please go to question 37)

    ___Yes   ___ No

35. What are the values for vehicle operating costs for the following different types of vehicles?

    Passenger Cars: $_____/ _____

    Single Unit Trucks: $_____/ _____

    Multiple Unit Trucks: $_____/ _____

36. What is the source from which the Vehicle Operating Cost values are attained/ derived?

    _____

    _____

    _____

37. Are crash costs (Increased costs on account of crashes) considered in the pavement type selection process?

    ___Yes   ___ No

38. What values are assigned to the following types of crashes?

    Fatal crash: $_____

    PDO crash: $_____

39. How is the number of these crashes estimated?

    _____

    _____

    _____

40. Please describe the qualitative approach used to account for user costs in the pavement type selection process.

    _____

    _____

    _____

    _____

    _____

41. Why are user costs not included in the pavement type selection process by your organization?

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APPPENDIX 2: Questionnaire Survey
Responses: User Costs Included in
Pavement Type Selection Process

	What are the types of pavements considered in the Pavement Selection Process by your organization?	Do you perform Life Cycle Cost Analysis (LCCA) while selecting the pavement type in a project?	In what size projects is LCCA performed? (indicate all that apply)
Colorado	HMA PCC	Yes	Any appropriate projects with greater than $1 million in initial cost
Indiana	HMA PCC	Yes	Mega Projects (High Profile and High cost)
Louisiana	HMA PCC	Yes	Medium Projects Large Projects Mega Projects
Maryland	HMA PCC	Yes	All Projects Size/Money are only a portion of the criteria used by MDSHA. All projects that pass through our Project Planning Division enter into our project selection process. These planning projects are mostly handled on a corridor basis and can often be broken into many advertised projects of various sizes. Also, projects not going through our Project Planning Division that have a construction cost greater than $15 million follow through our pavement type selection process. We estimate that 5 to 10 LCCA projects are done in a year.
Michigan	HMA PCC Major Rehabilitation	Yes	Projects are not broken up into categories, but by law, all projects that have over $1 million dollars in mainline pavement costs have an LCCA.
New Jersey	HMA PCC Other: Composite	Yes	Large Projects: Project Cost > $25 Million
Washington State	HMA PCC	Yes	Based on location, length, and type of construction (1/2 mile in length, >$500,000)
Quebec	HMA PCC	Yes	Large Projects (Cost up to $1 million) **Note:** this is a non-written rule, few of the regional office follow this rule

	Which method of financial analysis is used in LCCA?	What is the analysis period in LCCA?	What discount rate is currently being employed in LCCA?	Do you consider inflation rate in LCCA?
Colorado	Net Present Value	HMA: 40 yrs PCC: 40 yrs	4%	N
Indiana	Net Present Value, Equivalent Uniform Annualized Cost	HMA: 40 yrs PCC: 40 yrs	4%	N (See suggestion from FHWA about inflation)
Louisiana	Net Present Value	HMA: 40 yrs PCC: 40 yrs	4%	N
Maryland	Net Present Value	HMA: 40 yrs PCC: 40 yrs	3%	N
Michigan	Equivalent Uniform Annualized Cost	The analysis period is based on historical data, and is from reconstruction to reconstruction, or major rehabilitation to reconstruction. **HMA:** 26yrs (30 for low volume route), 20 years for HMA on rubblized concrete. **PCC:** 26yrs for reconstruction (30 for a low Volume route), 21yrs for an unbounded concrete overlay.	3% (the current rate for OMB)	N
New Jersey	Net Present Value	HMA: 40 yrs PCC: 40 yrs	4%	Y 4%
Washington State	Net Present Value	HMA: 50 yrs PCC: 50 yrs	4%	Y CPI%
Quebec	Net Present Value	HMA: 50 yrs PCC: 50 yrs	5%	Y Value: NA

	Do you consider the cost of controlling traffic during rehabilitation in LCCA?	While conducting LCCA, when is major rehabilitation work scheduled for HMA and PCC type pavements?
Colorado	To account for traffic control, CDOT uses an average value of 15% (range of 10 to 18%) of the cost of pavement materials used in the initial construction and each rehabilitation.	**HMA:** 10 - 2" HMA overlay full width (total both sides) **PCC:** 22 - 0.5% full depth slab replacement of travel lanes along with 1/4" deep diamond grinding for 50% of the project length (total both sides)
Indiana	The traffic control is abased on the scenario during construction. The user's cost is calculating based on traffic flow and traffic control during construction as a result of the traffic control strategy. The "real" cost of traffic control (equipment, signs, etc) is not included.	**HMA:** 25 - Mill & Fill, Structural Overlay 40 - Reconstruction **PCC:** 30 - PATCHING and HMA overlay 42 - Reconstruction
Louisiana	NO	**HMA:** 15 - Cold plane & overlay 30 - Cold plane & overlay **PCC:** 20 - Clean/seal, patch, resurface AC shoulders 30 - Clean/seal, patch, retexture
Maryland	Use avg. $2,000 per day, and determine how many days a particular project lasts	**HMA:** 15 - New Constructions 12 - Patch, Grind, OL 11 - Patch, Grind, OL **PCC:** 20 - New Construction 10 -Patch, Grind 10 - Patch, HMA OL
Michigan	It is only considered when the MOT schemes are different for the alternatives being evaluated. The costs are calculated by our region offices, using the actual pay items and prices.	We don't include a major rehab in our LCCA's, since we have to perform LCCA's on the major rehabs. We define a major rehab as an unbounded overlay, HMA over rubblized conc., HMA over a crush & shaped HMA base.
New Jersey	Percentage of Project Costs (Historical)	**HMA:** 15 - Mill 2" & Pave 2" 24 - Mill 2" & Pave 4" 32 - Mill 2" & Pave 2" 40 - Mill 2" & Pave 4" **PCC:** 30 - 5% repair & diamond grind 40 - 30% Repair/Repl & 4" HMA overlay
Washington State	Determine resources required for task. Estimate task cost based on historical bidding.	**HMA:** Varies - Inlay/Overlay **PCC:** Varies - Diamond Grind and Seal
Quebec	It is a percentage of the value of work cost. We have used 17% in the past years, now, we are at 22% for (re) construction work and 25% for rehabilitation	**HMA** (Depends on the number of Trucks): 9 to 14 - Mill and Overlay 16 to 25 - Mill and Overlay 23 to 36 - Reconstruction of HMA pavement only **PCC**: 19 - Light CPR, surface texturing and joint reseal 29 - Heavy CPR, surface texturing and joint reseal 39 - HMA Overlay 43 to 51 - Reconstruction of PCC only

	What type of maintenance and rehabilitation activities are considered in LCCA?	For which types of roadways is LCCA carried out?	How would you characterize the role played by LCCA in pavement type selection process in your organization?
Colorado	Annual Routine Maintenance Scheduled Major Rehabilitation	Interstate Urban Highways Rural Highways Arterials	Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.
Indiana	Scheduled Major Rehabilitation. Other: Preventive and reactive maintenance (not necessary every year)	Interstate	Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.
Louisiana	Scheduled Major Rehabilitation	Interstate Urban Highways Rural Highways Arterials	Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.
Maryland	Scheduled Major Rehabilitation	Interstate Urban Highways Rural Highways Arterials	Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.
Michigan	Preventative Maintenance	Interstate, Urban Highways Rural Highways, Arterials	Pavement type selection is based exclusively on LCCA
New Jersey	Annual Routine Maintenance Scheduled Major Rehabilitation	Interstate, Urban Highways Rural Highways	Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.
Washington State	Scheduled Major Rehabilitation	Interstate,Urban Highway Intersection	Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.
Quebec	Annual Routine Maintenance - Only for PCCP vs. ACP not for just ACP options Scheduled Major Rehabilitation	Interstate, Urban Highway Rural Highway	Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.

	Please explain the Role of LCCA in Pavement Type Selection Process briefly:	Is a sensitivity analysis performed while comparing various pavement type alternatives?	Is a salvage value (Remaining Life) included in the Life Cycle Cost Analysis?	Is there a percentage difference in Life Cycle Costs at which two alternatives are considered equivalent?
Colorado	If the results of LCCA are within 10%, the pavement types are considered statistically equivalent and a Pavement Type Selection Committee (PTSC) will be formed to make the recommendation to the Chief Engineer. If the results of LCCA indicate that the percentage difference in the total net present value (NPV) between the alternate pavement types is greater than 10%, then the pavement type with smaller total NPV will be recommended by the designer for use in the design and construction.	No	No Considered identical after analysis period of 40 years.	Yes 10%
Indiana	LCCA is "a tool" for pavement selection, but not an absolute tool for decision making process.	Yes	Yes	Yes 10%
Louisiana	LCCA is a mechanism used to foster competition between the asphalt and concrete industries in Louisiana. It serves as a tool for pavement type selection. If the total life cycle costs between competing typical section alternates differs by less than 20%, then both are included into the plans for bidding.	No	No	Yes <20%
Maryland	LCCA is calculated to determine if there is a clear best economic alternative. If there is a clear winner, that choice is selected. If multiple alternatives are within 20% of one another in terms of LCCA costs, the Pavement Type Selection process continues	Yes	Yes Salvage value based on life remaining at 40 years	Yes 15%
Michigan	It is an unbiased way to choose between an asphalt and concrete alternative. According to state law, the low cost alternative must be chosen.	No	No	No
New Jersey	As a Guide or Reference Tool	Yes	No	No
Washington State	Establishes which selection protocol is used based on LCCA cost difference. Above 15% the lowest cost alternative is selected. Under 15% other factors (location, route continuity, environmental, etc) influence the selection	Yes	Yes Residual Remaining Life	Yes Below 15%
Quebec	See Paper on Pavement Policy in Quebec	Yes it could be done	Yes It is the remaining portion of the last major work	Not Answered

	In the case that two pavement type alternatives are considered equivalent, the pavement type selection is based on:	How would you characterize the analysis of user costs in the pavement type selection process?	How are user costs accounted for in the pavement type selection process used by your organization?	Are the user costs weighted differently from the agency costs (construction cost and rehabilitation costs)?
Colorado	Other Factors Pavement type is in alignment with the unique goals of the project that may include individual elements of the LCCA or other non-monetary elements to ensure statewide consistency of decision making.	User Costs are considered	Quantitatively as a part of Life Cycle Cost Analysis	No [Weighted Equally]
Indiana	Local Conditions,Type of Adjacent Pavement, Engineering Judgment, Constructability and Politics	User Costs are considered	Quantitatively, but independent of LCCA.	Yes User Cost is capped at 10%
Louisiana	Local Conditions (sub-grade, weather, traffic, drainage, etc.),Type of Adjacent Pavement,Engineering Judgment	User Costs are considered	Quantitatively as a part of Life Cycle Cost Analysis	No [Weighted Equally]
Maryland	Local Conditions (sub-grade, weather, traffic, drainage, etc.), Type of Adjacent Pavement,Engineering Judgment, Cost, Construction, Design & Environmental factors	User Costs are considered	Quantitatively as a part of Life Cycle Cost Analysis	No [Weighted Equally]
Michigan	-	User Costs are considered	Quantitatively as a part of Life Cycle Cost Analysis	No [Weighted Equally]
New Jersey	Engineering Judgment, Constructability Issues	User Costs are considered	Quantitatively as a part of Life Cycle Cost Analysis	Yes [Weighted Differently] User Cost Weight Factor = 3/4 or 1/2 Agency Cost Weight Factor = 1
Washington State	Local Conditions, Type of Adjacent Pavement, Engineering Judgment	User Costs are considered	Quantitatively as a part of LCCA	N [Weighted Equally]
Quebec	Engineering Judgment, Multi Criteria	User cost are considered (But only user delay cost)	-	-

	In the user cost analysis, when is construction assumed to be performed?	For which of the following activities are user costs considered?	If a pavement rehabilitation project involves rehabilitation of a non-pavement structure (i.e. bridge), how are the user costs on account of such non-pavement activity considered?	Are user delay costs (Increased costs to the user on account of increased travel time due to congestion) considered in the pavement type selection process?
Colorado	Day Night Off-Peak hours	Initial Construction Planned Major Rehabilitation	Considered separately from pavement user cost analysis	Yes
Indiana	Day Night Off-Peak hours	Initial Construction Planned Major Rehabilitation	Considered separately from pavement user cost analysis	Yes
Louisiana	Day Night Off-Peak hours	Initial Construction Planned Major Rehabilitation	Considered as a part of pavement user cost analysis	Yes
Maryland	Day Night Off-Peak hours (Depends on the particular project)	Initial Construction Planned Major Rehabilitation	Considered separately from pavement user cost analysis	Yes
Michigan	Day (but it is the regions' decision, on a project by project basis)	Initial Construction Planned Major Rehabilitation Preventative Maintenance	Considered separately from pavement user cost analysis	Yes
New Jersey	Day Night Off-Peak hours	Initial Construction	Considered as a part of pavement user cost analysis	Yes
Washington State	Day Night	Initial Construction Planned Major Rehabilitation	Considered separately from pavement user cost analysis	Yes
Quebec	-	-	-	Yes

	How is user delay accounted for in the pavement type selection process?	Which of the following components of user delay are considered while calculating delay in work zone conditions?	While calculating user delay for various construction activities for different pavement types is maintenance of traffic setup and phasing assumed to be the same for every alternative?	While calculating user delay, is total user delay [Delay due to normal traffic conditions + Delay due construction activity] considered or only increased user delay due to construction considered?
Colorado	Monetized in terms of delay costs (in $$ terms)	Delay due to queue Delay while going through work zone at reduced speed Delay due to speed change cycles	Assumed to be the same for the setup(Please see question #7) Assumed to be different. In the Colorado program, they have an option for a single/multiple lane closure or a cross-over.	Only increased user delay due to construction is considered
Indiana	Monetized in terms of delay costs (in $$ Terms)	Delay due to queue Delay while going through work zone at reduced speed Delay due to speed change cycles Other: Due to traffic control strategies	Assumed to be different (Each pavement may or may not have the same traffic control strategy)	Other: It depends on the capacity (without construction). If the section of the road already congested without construction, user's cost is not at all included in the analysis.
Louisiana	In terms of total user delay (e.g. User Delay Days) Monetized in terms of delay costs (in $$ terms)	Delay due to queue Delay while going through work zone at reduced speed Delay due to speed change cycles	Assumed to be the same	Total User delay is considered
Maryland	Monetized in terms of delay costs (in $$ terms)	Delay due to queue Delay while going through work zone at reduced speed Delay due to speed change cycles	Assumed to be different (All activities are made as project-specific as possible)	Only increased user delay due to Construction is considered
Michigan	Monetized in terms of delay costs (in $$ terms)	Delay due to queue Delay while going through work zone at reduced speed Other: Extra time and distance if a detour present	Prior to performing the LCCA, the region submits the most likely MOT scheme, and that is modeled. In general, they are the same, but not always.	Only increased user delay due to construction is considered
New Jersey	Monetized in terms of delay costs (in $$ terms)	Delay due to queue Delay while going through work zone at reduced speed	Assumed to be different Traffic Setup could be different based on activity duration	Only increased user delay due to Construction is considered
Washington State	Monetized in terms of delay costs (in $$ Terms)	Delay due to queue Delay while going through work zone at reduced speed Delay due to speed change cycles	Assumed to be the same	Total user delay is considered
Quebec	Monetized in terms of delay costs (in $$ Terms)	Delay due to queue Delay while going through work zone at reduced speed Delay due to speed change cycles	Assumed to be the Same	Total User delay is considered

	What level of passenger vehicle occupancy is assumed when calculating user delay costs?	Is the capacity of work zone considered to equal for different type of construction / rehabilitation activities? (e.g. Heating and Scarifying, Microsurfacingetc.)	Please briefly describe the method used to calculate the capacity of work zone?	How is the user delay for major construction / rehabilitation activities calculated?
Colorado	1 occupant / vehicle	Not considered to be equal.	We have assigned various capacities based on the type of construction work.	Uniform delay is assumed for every day. Duration of sub-activities (excavation, PCC etc) is calculated and delay during each activity is calculated and added up.
Indiana	Other: User's cost for passenger cars is only based on value of time in dollars.	not considered to be equal. (Different construction type or treatment has different traffic control strategy.)	Use Workzone-RUC software from Colorado DOT which is based on the TRB capacity Manual	Uniform delay is assumed for every day.
Louisiana	1 occupant / vehicle	Considered to be equal	Work zone capacity is estimated from the graph, "Cumulative distribution of observed work zone capacities", taken from page 15 of the Transportation Research Record 869. This graph is based on research performed on various lane closures on multi-lane facilities.	Duration of sub-activities (excavation, PCC etc) is calculated and delay during each activity is calculated and added up.
Maryland	Not Sure; based on $ value per vehicle type	Not considered to be equal.	Number of lanes closed/open, depending on the activity	Duration of sub-activities (excavation, PCC etc) is calculated and delay during each activity is calculated and added up.
Michigan	1 occupant / vehicle	Not considered to be equal.	Based on a document from our Traffic and Safety Division	Uniform delay is assumed for every day.
New Jersey	1 occupant / vehicle	Considered to be equal	Table 6.1, 6.2 & 6.3 from 1994 HCM	Uniform delay is assumed for every day.
Washington State	Only vehicle operating cost is considered	Considered to be equal	Use Highway Capacity Manual, 1994, observed work zone capacity chart (FHWA-SA-98-079, page 50), and other available resources.	Uniform delay is assumed for every day.
Quebec	1 occupant / vehicle	Considered to be equal	Data from Traffic Division	Duration of sub-activities (excavation, PCC etc) is calculated and delay during each activity is calculated and added up.

	Which tool is used in your organization to calculate user delay costs?	How is the unit value of travel time calculated?	Is local travel and intercity travel valued equally?	What is the value of travel time for the following types of vehicles:
Colorado	Custom Developed Excel Sheet/ Software: "Workzone-RUC" which integrates elements from QueWZ, Quickzone, and the Highway Capacity Manual.	Using Average Wage in State	Yes	**Local Travel:** a. Personal passenger car travel: $17/hr, Reference Year 1999 b. Business passenger car travel: $17/hr, Reference Year 1999 c. Single Unit Trucks: $35/hr, Reference Year 1999 d. Combination Unit Trucks: $36.5/hr, Reference Year 1999 **Intercity Travel:** Same as Local Travel
Indiana	Custom Developed Excel sheet/ software: Developed by Purdue University, which is based on FHWA RealCost.	Other: From Colorado DOT research results	Yes	**Local Travel:** a. Personal passenger car travel: $17/hr, Reference Year 2004 b. Business passenger car travel: same c. Truck Drivers: $35/hr, Reference Year 2004 **Intercity Travel:** Same as Local Travel
Louisiana	Custom Developed Excel Sheet/ Software: Spreadsheet/program developed using FHWA Manual SA-98-079	FHWA Manual	Yes	**Local Travel:** a. Personal passenger car travel: $14.83/hr, Reference Year 2005 b. Business passenger car travel: $23.75/hr, Reference Year 2005 c. Trucks: $28.58/hr, Reference Year 2005 **Intercity Travel:** Same as Local Travel
Maryland	Custom Developed Excel Sheet/ Software: FHWA's RealCost	Other: Utilize FHWA's policy and software application with updates for inflation provided by the Transportation component of the CPI.	Yes	**No Information Provided**
Michigan	Custom Developed Excel Sheet/ Software: CO3 http://www.ricarr.com/Papers/CO3%20Materials/CO3%20Abstract.html	Other: FHWA publication "Life-Cycle Cost Analysis in Pavement Design"	Yes	**Local Travel:** a. Personal passenger car travel: $14.83/hr, Reference Year 2005 b. Business passenger car travel: $14.83/hr, Reference Year 2005 c. Trucks: $26.17/hr, Reference Year 2005 **Intercity Travel:** Same as Local Travel
New Jersey	Custom Developed Excel Sheet/ Software: NJDOT Road User Cost Manual	Using values from NCHRP report 133	Yes	**Local Travel:** a. Personal passenger car travel: $15.21/hr, Reference Year 2006 b. Business passenger car travel: $15.21/hr, Reference Year 2006 c. Trucks: $25.35/hr, Reference Year 2006 **Intercity Travel:** Same as Local Travel
Washington State	FHWA Real Cost Version 2.2 CA4PRS	Using Values from HERS, Using values from NCHRP report 133, Using NCHRP Research Project 7-12 (MicroBENCOST), USDOT Office of Secretary of Transport Directive, AND Composite of all	Yes	**Local Travel:** a. Personal passenger car travel: $10-13, Reference Year 1996 b. Business passenger car travel: $10-13, Reference Year 1996 c. Truck Drivers: $17-24, Reference Year 1996 **Intercity Travel: S**ame as Local Travel
Quebec	Other: Method used in the FHWA REALCOST software	**No Information Provided**	Yes	See REALCOST

	Are vehicle operating costs (increased costs of operating vehicles) considered in the pavement type selection process?	What are the values for vehicle operating costs for the following different types of	What is the source from which the Vehicle Operating Cost values are attained/ derived?	3Are crash costs (Increased costs on account of crashes) considered in the pavement type selection process?
Colorado	Yes	Passenger Cars: $0.6944/Vehicle-hour Single Unit Trucks: $0.7713/Vehicle-hour Multiple Unit Trucks: $0.8283/Vehicle-hour	For the various speeds and types of vehicles, we used NCHRP Report 133 Table 5 and updated it to June 1999. The program can adjust these values to the current date by updating the Consumer Price Index.	No
Indiana	Yes	Passenger Cars: $0.8312/hour (idling cost) Single Unit Trucks: $0.9217/hour (idling cost) Multiple Unit Trucks: $0.9898/hour (idling cost) Note: Vehicle stopping costs depends on the speed.	FHWA guidelines	No
Louisiana	Yes	-	FHWA Manual SA-98-079 (Table 3.17) updated with 2005cpi	No
Maryland	Yes	Passenger Cars: $11.50 Single Unit Trucks: $18.50 Multiple Unit Trucks: $22.50	FHWA and we update for inflation provided by the Transportation component of the CPI	No
Michigan	Yes	Passenger Cars: $0.445/mile Single Unit Trucks: $1.18/mile Multiple Unit Trucks: $1.18/mile	For cars, we use the standard mileage rate. For trucks, we use the costs in the Motor Carrier Annual Report for 2003, on a per mile basis, with driver wages and benefits removed.	No
New Jersey	Yes	Passenger Cars: $0.277/Mile, Reference Year 2006 Single Unit Trucks: $10.553/Mile, Reference Year 2006 Multiple Unit Trucks: $0.553/Mile, Reference Year 2006	NCHRP Report #133	No
Washington State	Yes	Passenger Cars: $10-13 / 1996 Single Unit Trucks: $17-20/ 1996 Multiple Unit Trucks: $21-24/ 1996	Life Cycle Cost Analysis in Pavement Design (FHWA-SA-98-079)	No
Quebec	No	-	See REALCOST	No

	What values are assigned to the following types of crashes?	How is the number of these crashes estimated?	Please describe the qualitative approach used to account for user costs in the pavement type selection process.	Why are user costs not included in the pavement type selection process by your organization?
Colorado	NA	NA	In order to ensure we get the best information for the program, we talk to the Project Engineer and designers assigned to the project we are analyzing. User cost has the same weight as construction costs. We do not reduce the value.	NA
Indiana	NA	NA	Many times, we looked at the user's cost and queue length to see if it is reasonable to include the user's cost "as a separate item" in the LCCA. The road network has to be taken into account, as in our experience with the I-65 in Indianapolis (Hyperfix), if we set up the traffic control properly, minimal disruptions occurred because the users chose different routes. Therefore, we use the user's cost only for qualitative comparison only to see "how disruptive" each pavement alternative will be.	It is included and calculated "quantitatively", but at the end only as a separate item for qualitative comparison.
Louisiana	NA	NA	NA	NA
Maryland	NA	NA	NA	NA
Michigan	NA	NA	NA	NA
New Jersey	NA	NA	NA	NA
Washington State	NA	NA	Accumulative cost caused by the hourly work zone traffic demands changing speeds, traversing, and being queued.	Users cost are considered.
Quebec	NA	NA	NA	NA

APPPENDIX 3: Questionnaire Survey
Responses: User Costs NOT Included in
Pavement Type Selection Process

	What are the types of pavements considered in the Pavement Selection Process by your organization?	Do you perform Life Cycle Cost Analysis (LCCA) while selecting the pavement type in a project?	In what size projects is LCCA performed? (indicate all that apply)	Which method of financial analysis is used in LCCA?
Ohio	HMA, PCC	Yes	An economic analysis is performed for any project greater than or equal to 4 lane miles (not including ramps or CD lanes) in length	Net Present Value
Arkansas	HMA, PCC	Yes	Large Projects	Net Present Value
Florida	HMA, PCC	Yes	Medium Projects, Large Projects, Mega Projects	Net Present Value
Illinois	HMA, PCC	Yes	All Projects LCCA is conducted for all new or reconstructed pavements with design traffic less than 35,000,000 ESALs. Pavements with design traffic greater than 35,000,000 ESALs are automatically constructed with CRCP and no LCCA is done.	Equivalent Uniform Annualized Cost
Minnesota	HMA, PCC	Yes	Varies LCCA is performed on all projects that go through pavement selection. Cost is not a consideration when determining when pavement selection is required. We do pavement type selection on ALL new and reconstruction projects 2 miles or longer for 2-lane roads and 30,000 sq.yds or larger for multi-lane roads regardless of cost.	Equivalent Uniform Annualized Cost
Montana	HMA, PCC	No	-	-
Nebraska	HMA, PCC, In-Place Recycling	Yes	All New Build Construction	Future Value
Oklahoma	HMA, PCC	No	-	-
Texas	HMA, PCC	No	-	-
Wisconsin	HMA, PCC	Yes	All Projects	Net Present Value
Alberta	HMA, PCC (Very seldom - only constructed 1st PCCP this year)	Yes	All Projects	Net Present Value
British Columbia	HMA	No	-	-
Ontario	HMA, PCC, For low volume facilities with <500 AADT, Typically use surface treatment	Yes	Medium Projects: Project cost up to $1-5 Million, Large Projects: Project cost up to $5-25 Million, Mega Projects: Project cost up to $25-50 Million	Net Present Value

	What is the analysis period in LCCA?	What discount rate is currently being employed in LCCA?	Do you consider inflation rate in LCCA?	Do you consider the cost of controlling traffic during rehabilitation in LCCA?
Ohio	HMA: 35 yrs PCC: 35 yrs	3%	N ODOT uses a real discount rate	N
Arkansas	HMA: 35 yrs PCC: 35 yrs	3.80%	N	N
Florida	HMA: 40 yrs PCC: 40 yrs	4%	No	Y Standard Estimating procedures are used.
Illinois	HMA: 40 yrs PCC: 40 yrs	3%	No	N
Minnesota	HMA: 50 yrs PCC: 50 yrs	3.5% We adjust the discount rate annually to the real interest rate on a 30-year treasury bond as published by the Federal Office of Management and Budget (OMB)	No	N We did consider traffic control costs and time when we looked into user costs. However, our current policy is to not include user costs in the pavement selection process.
Montana	NA	NA	NA	NA
Nebraska	HMA: 50 yrs PCC: 50 yrs	3.08%	No	N
Oklahoma	NA	NA	NA	NA
Texas	NA	NA	NA	NA
Wisconsin	HMA: 50 yrs PCC: 50 yrs	5%	No	No
Alberta	HMA: 30 yrs PCC: 30 yrs	4%	No	No
British Columbia	NA	NA	NA	NA
Ontario	HMA: 50 yrs for freeways; 30yrs for non freeways PCC: 50 yrs	5%	Y Inflation is included in the discount rate	No

	While conducting LCCA, when is major rehabilitation work scheduled for HMA and PCC type pavements?	What type of maintenance and rehabilitation activities are considered in LCCA?	For which types of roadways is LCCA carried out?
Ohio	**HMA:** 12 - 1.5" mill and fill of travel lanes 22 - 3.25" full with overlay with ~ 1" milling 34 - 1.5" mill and fill of travel lanes **PCC:** 22 - 4% full depth repairs, diamond grind 32 - 2% full depth repair, 3.25" AC overlay	Scheduled Major Rehabilitation	Interstate Urban Highways Rural Highways Arterials
Arkansas	**HMA:** 12 - Inlay or Overlay 20 - INLAY OR OVERLAY & UPDATE TO CURRENT STANDARDS 30 - INLAY OR OVERLAY **PCC:** 15 - PATCHING, GRINDING, JOINT REHAB 25 - PATCHING, RUBBLIZATION AND/OR OVERLAY & UPDATE TO CURRENT STANDARDS	Scheduled Major Rehabilitation Other: ROUTINE MAINTENANCE EVERY 5TH YEAR	Interstate
Florida	**HMA:** 14 - Mill and Resurfacing 28 - Mill and Resurfacing **PCC:** 20 - Rehab, Grind, Reseal 30 - Rehab, Grind, Reseal or Overlay	Scheduled Major Rehabilitation	Interstate Urban Highways Rural Highways Arterials
Illinois	This depends on the type of pavement and the traffic level. See pages 54-7 (1) – 54-7 (9) of Chapter 54 of our BDE Manual for details. IDOT's web site is http://www.dot.il.gov/ Once on the site, click on "Doing Business", found on the left side of the page. Under "Manuals-Memorandums-Rules", select "Bureau of Design and Environment Manuals & Memorandums". Then click on "Bureau of Design & Environment Manual". You can select Chapter 54 and then locate the pertinent pages noted above.	Annual Routine Maintenance Scheduled Major Rehabilitation	Interstate Urban Highways Rural Highways Arterials Side Streets

	While conducting LCCA, when is major rehabilitation work scheduled for HMA and PCC type pavements?	What type of maintenance and rehabilitation activities are considered in LCCA?	For which types of roadways is LCCA carried out?
Minnesota	**HMA:** For HMA design with Low Design ESALs (7 million or less) 6 years Type of Work: Rout & Seal Cracks 10 years Type of Work: Surface Treatment 20 years Type of Work: Mill & Overlay 23 years Type of Work: Rout & Seal Cracks 27 years Type of Work: Surface Treatment 35 years Type of Work: Mill & Overlay 38 years Type of Work: Rout & Seal Cracks 43 years Type of Work: Surface Treatment The surface treatment is either a chip seal or micro-surfacing, depending on the traffic volume (AADT). If the 20-year projected AADT is 10,000 or less the surface treatment is a chip seal. For HMA design with High ESALs 7 years Type of Work: Crack Fill 15 years Type of Work: Mill & Overlay 20 years Type of Work: Crack Fill 27 years Type of Work: Mill & Overlay 32 years Type of Work: Crack Fill 40 years Type of Work: Mill & Overlay **PCC:** 17 years Work: Joint Reseal and Minor CPR (partial depth repairs) 27 years Work: Minor CPR and some full depth repairs 40 years Work: Major CPR (full depth repairs & Diamond grinding	As discussed in #8	Other: All State Highways
Montana	NA	NA	NA
Nebraska	**HMA:** 20 - 4" Overlay 35 - 4" Overlay **PCC:** 35 - 4" Overlay	Annual Routine Maintenance Scheduled Major Rehabilitation	Other: New Build
Oklahoma	NA	NA	NA
Texas	NA	NA	NA
Wisconsin	**HMA:** 18 - Overlay or mill and overlay 30 - Overlay or mill and overlay 42 - Overlay or mill and overlay **PCC:** 25 - Repair or repair and grind 33 - Repair or repair and grind 41 - Repair, or repair and grind, or repair and overlay	Other: Regular ("every few years") maintenance	Interstate Urban Highways Rural Highways Arterials

	While conducting LCCA, when is major rehabilitation work scheduled for HMA and PCC type pavements?	What type of maintenance and rehabilitation activities are considered in LCCA?	For which types of roadways is LCCA carried out?
Alberta	**HMA:** 18 - Rehab Overlay **PCC:** 20 - Grinding Various - Crack re-sealing	Annual Routine Maintenance - Only for PCCP vs. ACP not for just ACP options Scheduled Major Rehabilitation	All roads
British Columbia	NA	NA	NA
Ontario	**FOR FREEWAYS:** **HMA (SMA)**: 21 - Mill 50mm and Overlay 50mm 34 - Mill 50mm and Overlay 50mm 46 - Mill 50mm and Overlay 50mm **HMA (DFC):** 19 - Mill 80mm and Overlay 80mm 31 - Mill 80mm and Overlay 80mm 42 - Mill 80mm and Overlay 80mm **PCC**: 18 - Diamond grinding & minor CPR 28 - Major CPR, Joint Seal, & Diamond Grinding 38 - 80mm hot mix overlay	Scheduled Major Rehabilitation Other: (Maintenance schedule for freeways only) **For SMA:** Route & seal at year: 3, 9,15,19, 24, 28, 31, 37, 41, 44, and 49 Mill & patch at year: 9, 15, 19, 28, and 41 **For DFC:** Route & seal at year: 3, 9,15,22, 27, 34, 38, 45, and 48 Mill & patch at year: 9, 15, 27, 38, and 48	Interstate Urban Highway Rural Highway Arterials (Note: The major rehabilitation schedules and maintenance and rehab activities listed above are formalized for FREEWAYS ONLY).

	How would you characterize the role played by LCCA in pavement type selection process in your organization?	Please explain the Role of LCCA in Pavement Type Selection Process briefly:	Is a sensitivity analysis performed while comparing various pavement type alternatives?	Is a salvage value (Remaining Life) included in the Life Cycle Cost Analysis?
Ohio	Pavement type selection is based on LCCA Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.	If the life cycle cost of one alternative is more than 10% cheaper than all other alternatives, the lowest life cycle cost alternative is selected. If two or more alternatives are within 10% life cycle cost, the decision is based on subjective analysis of secondary factors	No	No
Arkansas	Subjective Analysis of Factors	PROVIDES THE ENGINEER A MEANS TO EVALUATE INITIAL INVESTMENT VERSUS LIFETIME PERFORMANCE	No	BOTH CONCRETE AND ASPHALT SALVAGE
Florida	Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.	Tool to estimate relative costs of the alternate pavement systems.	No	No
Illinois	Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.	In Illinois, pavement design alternatives for new or reconstructed pavements are evaluated based on a life-cycle cost analysis. If the difference in life-cycle costs between pavement alternatives is greater than 10%, the alternative with the lowest life-cycle cost is selected for construction. However, if the difference in life-cycle costs is 10% or less, selection is determined by a committee that considers the factors found in Appendix B of the 1993 AASHTO Guide for Design of Pavement Structures.	No	No
Minnesota	Pavement type selection is based exclusively on LCCA	Whichever pavement type has the lowest LCCA is the one chosen. If the district disagrees with the decision they can appeal to the Assistant Commissioner for a variance. However, variances are rarely granted.	No	For the PCC option it is assumed that the final concrete rehab, done in year 40, will still have 5 years (33%) of its life left so only 67% of the cost of the final rehab is included.

	How would you characterize the role played by LCCA in pavement type selection process in your organization?	Please explain the Role of LCCA in Pavement Type Selection Process briefly:	Is a sensitivity analysis performed while comparing various pavement type alternatives?	Is a salvage value (Remaining Life) included in the Life Cycle Cost Analysis?
Montana	NA	NA	No	NA
Nebraska	Final Decision is based on a subjective analysis of factors such as LCCA, initial construction costs, constructability issues, district preference of materials, environmental issues etc.	Required to do a cost comparison by state legislature and maintain a copy in project files. It is a piece of decision process as shown in question 11.	No	Y Salvage Value
Oklahoma	NA	NA	NA	NA
Texas	NA	NA	NA	NA
Wisconsin	Pavement Type Selection is based exclusively on LCCA.	A minimum of 2 structurally-equal alternative pavement designs are considered (at least one HMA and one concrete). These designs are run through the LCCA process (considering rehabilitations and maintenance over the 50 year period). The pavement designer has a 5% cost leeway in final selection.	No	Based on life remaining beyond the 50 year LCCA period
Alberta	Pavement type selection is based Exclusively on LCCA	Alberta doesn't typically consider PCCP pavements (only for high trafficked roadways such as ring roads) LCCA is used for all pavement rehab decision to compare overlay vs. mill and inlay vs. in-place options etc.	No	Typically just the remaining life as a direct ratio of predicted life and the remaining percent of cost discounted to present value
British Columbia	NA	NA	NA	NA

	Is there a percentage difference in Life Cycle Costs at which two alternatives are considered equivalent?	In the case that two pavement type alternatives are considered equivalent, the pavement type selection is based on:	How would you characterize the analysis of user costs in the pavement type selection process?
Ohio	Yes, 10%	Local Conditions (sub-grade, weather, traffic, drainage, etc.), Type of Adjacent Pavement Engineering Judgment, Other Factors	User Costs are considered
Arkansas	No	Local Conditions, Type of Adjacent Pavement, Engineering Judgment	User Costs not currently considered but may be included in future
Florida	No	Engineering Judgment	User Costs not currently considered but may be included in future
Illinois	Yes 10%	the factors found in Appendix B of the 1993 AASHTO Guide for Design of Pavement Structures as discussed on page 54-7(11) of the BDE Manual.	User Costs are not currently considered but will definitely be considered in the future (currently methods / approaches being studied)
Minnesota	N	Local Conditions, Type of Pavement in adjacent area, Other: District preference. However I don't think we have ever had a "tie" in the LCCA cost.	User Costs not currently considered but may be included in future. We did a study to determine whether we should include user costs. The conclusion was that for now, we will not include them. They did not affect the outcome that much. Even though we do not include user costs in our pavement selection process we did consider it a few years ago. The answers below pertain to the way we calculated user costs for that study.
Montana	NA	NA	User Cost not currently considered but may be included in the future.

	Is there a percentage difference in Life Cycle Costs at which two alternatives are considered equivalent?	In the case that two pavement type alternatives are considered equivalent, the pavement type selection is based on:	How would you characterize the analysis of user costs in the pavement type selection process?
Nebraska	N	Local Conditions, Type of Adjacent Pavement, Engineering Judgment	User costs are not currently considered and there are no plans of incorporating them in the future.
Oklahoma	NA	NA	User Costs not currently considered but may be included in future
Texas	NA	NA	User Costs not currently considered but may be included in future.
Wisconsin	Yes	Local Conditions, Type of Adjacent Pavement, Engineering Judgment, Other: Reasons can vary	User Costs not currently considered but may be included in future
Alberta	Yes 5%	Engineering Judgment Lowest Initial Cost	User Costs not currently considered but may be included in future. (except where we have looked at PCCP vs. ACP and included lane rental costs which reflect user delay costs, and these are included in the LCCA – therefore the rest of the questions were not answered)
British Columbia	NA	NA	NA
Ontario	NA	Other: Alternative Bids for freeway pavements	User Cost is not currently considered but may be included in future.

	How are user costs accounted for in the pavement type selection process used by your organization?	Please describe the qualitative approach used to account for user costs in the pavement type selection process.	Why are user costs not included in the pavement type selection process by your organization?
Ohio	Qualitatively	ODOT considers user delay as a secondary factor	User costs are difficult to quantify. ODOT's maintenance of traffic policy minimizes user costs for all alternatives. Unlike agency costs, user cost savings are not a direct benefit to the department.
Arkansas	NA	NA	AT THIS TIME WE HAVE NOT DEVELOPED A MEANS BY WHICH ROAD USER COSTS CAN BE INCORPORATED INTO OUR LCCA.
Florida	Qualitatively	The FDOT goes to night work when day work would cause queues to build up, so quantitative user delay costs are minimal. Subjective consideration is given to the discomfort the public goes through in construction zones.	The FDOT goes to night work when day work would cause queues to build up, so quantitative user delay costs are minimal
Illinois	NA	NA	Illinois last revised their LCCA more than 10 years ago. At the time, methodologies to consider user costs were not well documented.
Nebraska	NO	-	Uniform method/values to assess user costs have not been established.
Oklahoma	NA	NA	NA

	How are user costs accounted for in the pavement type selection process used by your organization?	Please describe the qualitative approach used to account for user costs in the pavement type selection process.	Why are user costs not included in the pavement type selection process by your organization?
Minnesota	Quantitatively, but independent of Life Cycle Cost Analysis		Mn/DOT conducted a study to examine the feasibility of calculating RUC for pavement type determination projects. RUC were calculated for three projects. The Work Group found that the process was very time consuming and complex. We were relatively confident in our ability to model rural traffic for this type of analysis. However the Work Group did not have the resources to model traffic on high-volume, signalized arterials. With three analyses completed, the Work Group did not analyze enough projects to make a recommendation as to whether RUC should be included in the pavement type selection process. However, possible next steps included: • Hire a consultant to analyze additional projects, including more complicated projects that would require traffic modeling, including the effects on detour routes. • Continue to analyze road-user costs on a limited basis, for example: o When the cost estimates are less than 5% apart. o Under specific traffic and roadway conditions, such as high volumes
Montana	Qualitatively	Montana used flexible pavements on most roads. Rigid Pavements are sometimes used on high volume intersections or high volume urban roads. The District Administrator chooses which pavement type to use. Usually, rigid pavements are used because of it's rut resistance in areas where we have historically had asphalt rutting problems. Less often, rigid pavement is used because the DOT wants to build the road and not have to go in for periodic maintenance because this impacts commuters and adjacent business owners.	Most of Montana's roads are low volume roads in rural areas so impacts to the traveling public are minimal. Also, Montana does not have a set policy to use user costs, making it difficult to use user costs in LCCA.

	How are user costs accounted for in the pavement type selection process used by your organization?	Please describe the qualitative approach used to account for user costs in the pavement type selection process.	Why are user costs not included in the pavement type selection process by your organization?
Texas	NA	NA	There has not been a great deal of interest in evaluating pavement type selection based on LCCA analysis. One reason is that it has never been required. Another reason is that our Districts work in a very decentralized capacity - they know what they like and use what they like. This may eventually change, especially now with our increased use of HMA perpetual pavements versus rigid pavements.
Wisconsin	NA	NA	NA
Alberta	NA	NA	NA
British Columbia	NA	NA	NA
Ontario	NA	NA	User costs have not been included in the Ministry's LCC model. Although it is recognized that traffic delays, road conditions and vehicle operating costs result in costs for the user, they are not borne directly by the Ministry and are difficult to quantify. Although user cost models are available, they typically are not calibrated to the traffic conditions and environment of a single jurisdiction. Moreover, they are generally too complex for use in routine program delivery projects. The Ministry feels that user costs could be considered in pavement selection, but it may not be appropriate to include them in the overall LCC as they tend to overwhelm all other costs. User costs could be considered in a Benefit/Cost Analysis.

APPPENDIX 4: Case Study 1: RealCost Output

RealCost Input Data

1. Economic Variables	
Value of Time for Passenger Cars ($/hour)	$21.00
Value of Time for Single Unit Trucks ($/hour)	$39.00
Value of Time for Combination Trucks ($/hour)	$39.00

2. Analysis Options	
Include User Costs in Analysis	Yes
Include User Cost Remaining Service Life Value	Yes
Use Differential User Costs	Yes
User Cost Computation Method	Calculated
Include Agency Cost Remaining Service Life Value	Yes
Traffic Direction	Both
Analysis Period (Years)	35
Beginning of Analysis Period	2004
Discount Rate (%)	3.5

3. Project Details and Quantity Calculations	
State Route	WAR-75-3.40
Project Name	WAR-75-3.40 Pavement Type Selection
Region	
County	Warren
Analyzed By	Tony Geara
Mileposts	
Begin	3.40
End	12.20
Length of Project (miles)	8.80
Comments	Case Study (from ODOT reports) - Covering Alternatives 1 & 2

4. Traffic Data	
AADT Construction Year (total for both directions)	88,350
Cars as Percentage of AADT (%)	78.0
Single Unit Trucks as Percentage of AADT (%)	22.0
Combination Trucks as Percentage of AADT (%)	
Annual Growth Rate of Traffic (%)	3.0
Speed Limit Under Normal Operating Conditions (mph)	65
No of Lanes in Each Direction During Normal Conditions	3
Free Flow Capacity (vphpl)	1982
Rural or Urban Hourly Traffic Distribution	Urban
Queue Dissipation Capacity (vphpl)	1818
Maximum AADT (total for both directions)	288,000
Maximum Queue Length (miles)	1.5

Alternative 1: Rubblize and Roll

Initial Construction	@ 0 years: Remove the existingasphalt, rubblize and roll the existing reinforced concrete pavement and overlay with 12-1/2" of item 880 Asphalt Concrete (7-year warranty). 15% removal is required to meet elevation of mainline bridges and provide 16'-6" clearance under overhead dridges, assuming bridges are not jacked.	
Agency Construction Cost ($1000)	$19,532.97	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	824	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	12.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$315,664	4%
WZ Speed Change Delay	$319,162	4%
WZ Reduced Speed Delay	$7,022,385	92%
Queue Stopping Delay	$0	0%
Queue Stopping VOC	$0	0%
Queue Added Travel Time	$0	0%
Queue Idle Time	$0	0%
Total Cost	$7,657,211	100%

Rehabilitation #1	@ 12 years: 1.5" overlay with planing (mainline Only)... (@ 3.5% discount rate included)	
Agency Construction Cost ($1000)	$1,053.94	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	28	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	10.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$15,293	4%
WZ Speed Change Delay	$15,463	4%
WZ Reduced Speed Delay	$340,222	92%
Queue Stopping Delay	$0	0%
Queue Stopping VOC	$0	0%
Queue Added Travel Time	$0	0%
Queue Idle Time	$0	0%
Total Cost	$370,978	100%

Alternative 1

Rehabilitation #2	@ 22 years: 3.25" overlay with planing (full width of mainline and shoulders), 1% patching planed surface (percent of planned area)... (@ 3.5% discount rate included)	
Agency Construction Cost ($1000)	$2,033.93	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	142	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	12.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

Cost Component	Cost	Percent
WZ Speed Change VOC	$67,460	1%
WZ Speed Change Delay	$68,207	1%
WZ Reduced Speed Delay	$2,537,608	31%
Queue Stopping Delay	$175,329	2%
Queue Stopping VOC	$116,496	1%
Queue Added Travel Time	$4,989,339	62%
Queue Idle Time	$141,782	2%
Total Cost	$8,096,220	100%

Rehabilitation #3	@ 34 years: 1.5" overlay with planing (mainline Only)... (@ 3.5% discount rate included)	
Agency Construction Cost ($1000)	$494.46	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	28	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	1.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	($1,748)	0%
WZ Speed Change Delay	($1,767)	0%
WZ Reduced Speed Delay	$925,799	14%
Queue Stopping Delay	$58,944	1%
Queue Stopping VOC	$39,165	1%
Queue Added Travel Time	$5,560,143	83%
Queue Idle Time	$158,003	2%
Total Cost	$6,738,539	100%

Alternative 2

Initial Construction		@ 0 years: Remove the existing asphalt, place 1" asphalt bond breaker layer and overlay with 10" of Item 884 Portland Cement Concrete (7-year Warranty). 13.5% removal is required to meet elevation of mainline bridges and provide 16'-6" clearance under overhead bridges, assuming bridges are not jacked.
Agency Construction Cost ($1000)	$23,205.69	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	515	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	22.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$197,290	4%
WZ Speed Change Delay	$199,476	4%
WZ Reduced Speed Delay	$4,388,991	92%
Queue Stopping Delay	$0	0%
Queue Stopping VOC	$0	0%
Queue Added Travel Time	$0	0%
Queue Idle Time	$0	0%
Total Cost	$4,785,757	100%

Rehabilitation #1	@ 22 years: Diamond grinding (mainline plus one foot of shoulder), full depth repair 4% of mainline surface area	
Agency Construction Cost ($1000)	$1,202.87	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	115	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	10.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$54,633	1%
WZ Speed Change Delay	$55,238	1%
WZ Reduced Speed Delay	$2,055,105	31%
Queue Stopping Delay	$141,991	2%
Queue Stopping VOC	$94,345	1%
Queue Added Travel Time	$4,040,662	62%
Queue Idle Time	$114,823	2%
Total Cost	$6,556,798	100%

Rehabilitation #2	@ 32 years: 3.25" asphalt overlay, full depth repair 2% of mainline surface area	
Agency Construction Cost ($1000)	$1,605.88	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	74	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	3.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

Cost Component	Cost	Percent
WZ Speed Change VOC	($4,619)	0%
WZ Speed Change Delay	($4,670)	0%
WZ Reduced Speed Delay	$2,446,754	14%
Queue Stopping Delay	$155,781	1%
Queue Stopping VOC	$103,508	1%
Queue Added Travel Time	$14,694,665	83%
Queue Idle Time	$417,578	2%
Total Cost	$17,808,997	100%

Alternative 3 : FLEXIBE REPLACEMENT

Initial Construction	@ 0 years: Remove the existing pavement and place 14.5" of Itam 880 Asphalt Concrete (7-year Warranty) on 6" of Item 304 Aggregate Base.	
Agency Construction Cost ($1000)	$23,961.34	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	1088	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	12.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$416,800	4%
WZ Speed Change Delay	$421,418	4%
WZ Reduced Speed Delay	$9,272,275	92%
Queue Stopping Delay	$0	0%
Queue Stopping VOC	$0	0%
Queue Added Travel Time	$0	0%
Queue Idle Time	$0	0%
Total Cost	**$10,110,492**	**100%**

Rehabilitation #1	@ 12 years: 1.5" overlay with planing (mainline Only)... (@ 3.5% discount rate included)	
Agency Construction Cost ($1000)	$1,053.94	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	28	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	10.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$15,293	4%
WZ Speed Change Delay	$15,463	4%
WZ Reduced Speed Delay	$340,222	92%
Queue Stopping Delay	$0	0%
Queue Stopping VOC	$0	0%
Queue Added Travel Time	$0	0%
Queue Idle Time	$0	0%
Total Cost	$370,978	100%

Rehabilitation #2	@ 22 years: 3.25" overlay with planing (full width of mainline and shoulders), 1% patching planed surface (percent of planed area)... (@ 3.5% discount rate included)	
Agency Construction Cost ($1000)	$2,033.93	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	142	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	12.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$67,460	1%
WZ Speed Change Delay	$68,207	1%
WZ Reduced Speed Delay	$2,537,608	31%
Queue Stopping Delay	$175,329	2%
Queue Stopping VOC	$116,496	1%
Queue Added Travel Time	$4,989,339	62%
Queue Idle Time	$141,782	2%
Total Cost	$8,096,220	100%

Rehabilitation #3	@ 34 years: 1.5" overlay with planing (mainline Only)... (@ 3.5% discount rate included)	
Agency Construction Cost ($1000)	$494.46	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	28	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	1.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	($1,748)	0%
WZ Speed Change Delay	($1,767)	0%
WZ Reduced Speed Delay	$925,799	14%
Queue Stopping Delay	$58,944	1%
Queue Stopping VOC	$39,165	1%
Queue Added Travel Time	$5,560,143	83%
Queue Idle Time	$158,003	2%
Total Cost	$6,738,539	100%

Alternative 4: RIGID REPLACEMENT

Initial Construction		
	@ 0 years: Remove the existing pavement and place 14.5" of Item 884 Portland Cement Concrete (7-year Warranty) on 6" of Item 304 Aggregate Base.	
Agency Construction Cost ($1000)	$32,014.84	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	929	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	22.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$355,889	4%
WZ Speed Change Delay	$359,832	4%
WZ Reduced Speed Delay	$7,917,228	92%
Queue Stopping Delay	$0	0%
Queue Stopping VOC	$0	0%
Queue Added Travel Time	$0	0%
Queue Idle Time	$0	0%
Total Cost	$8,632,948	100%

Rehabilitation #1	@ 22 years: Diamond grinding (mailine plus one foot of shoulder), full depth repair 4% of mailine surface area... (@ 3.5% discount rate included)	
Agency Construction Cost ($1000)	$1,202.87	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	115	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	10.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$54,633	1%
WZ Speed Change Delay	$55,238	1%
WZ Reduced Speed Delay	$2,055,105	31%
Queue Stopping Delay	$141,991	2%
Queue Stopping VOC	$94,345	1%
Queue Added Travel Time	$4,040,662	62%
Queue Idle Time	$114,823	2%
Total Cost	$6,556,798	100%

Rehabilitation #2	@ 32 years: 3.25" asphalt overlay, full depth repair 2% of mailine surface area... (@ 3.5% discount rate included)	
Agency Construction Cost ($1000)	$1,605.88	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	74	
No of Lanes Open in Each Direction During Work Zone	2	
Activity Service Life (years)	3.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	8.80	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1390	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	($4,619)	0%
WZ Speed Change Delay	($4,670)	0%
WZ Reduced Speed Delay	$2,446,754	14%
Queue Stopping Delay	$155,781	1%
Queue Stopping VOC	$103,508	1%
Queue Added Travel Time	$14,694,665	83%
Queue Idle Time	$417,578	2%
Total Cost	$17,808,997	100%

APPPENDIX 5: Case Study 2: RealCost Output

RealCost Input Data

1. Economic Variables	
Value of Time for Passenger Cars ($/hour)	$21.00
Value of Time for Single Unit Trucks ($/hour)	$39.00
Value of Time for Combination Trucks ($/hour)	$39.00

2. Analysis Options	
Include User Costs in Analysis	Yes
Include User Cost Remaining Service Life Value	Yes
Use Differential User Costs	Yes
User Cost Computation Method	Calculated
Include Agency Cost Remaining Service Life Value	Yes
Traffic Direction	Both
Analysis Period (Years)	35
Beginning of Analysis Period	2007
Discount Rate (%)	3.1

3. Project Details and Quantity Calculations	
State Route	LAK-2-3.32 - One LANE CLOSURE
Project Name	
Region	
County	
Analyzed By	Tony Geara
Mileposts	
Begin	3.32
End	7.60
Length of Project (miles)	4.28
Comments	Case Study #3 (from ODOT reports) - Covering the two Alternatives

4. Traffic Data	
AADT Construction Year (total for both directions)	78,940
Cars as Percentage of AADT (%)	96.0
Single Unit Trucks as Percentage of AADT (%)	4.0
Combination Trucks as Percentage of AADT (%)	
Annual Growth Rate of Traffic (%)	3.0
Speed Limit Under Normal Operating Conditions (mph)	65
No of Lanes in Each Direction During Normal Conditions	2
Free Flow Capacity (vphpl)	1490
Rural or Urban Hourly Traffic Distribution	Urban
Queue Dissipation Capacity (vphpl)	1818
Maximum AADT (total for both directions)	192,000
Maximum Queue Length (miles)	1.5

Alternative 1

Initial Construction	@ 0 years	
Agency Construction Cost ($1000)	$7,481.58	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	160	
No of Lanes Open in Each Direction During Work Zone	1	
Activity Service Life (years)	12.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	4.28	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$51,411	8%
WZ Speed Change Delay	$42,095	7%
WZ Reduced Speed Delay	$515,637	85%
Queue Stopping Delay	$0	0%
Queue Stopping VOC	$0	0%
Queue Added Travel Time	$0	0%
Queue Idle Time	$0	0%
Total Cost	$609,142	100%

Alternative 1

Rehabilitation #1	@ 12 years	
Agency Construction Cost ($1000)	$569.48	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	10	
No of Lanes Open in Each Direction During Work Zone	1	
Activity Service Life (years)	10.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	4.28	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$1,417	0%
WZ Speed Change Delay	$1,161	0%
WZ Reduced Speed Delay	$53,555	11%
Queue Stopping Delay	$13,892	3%
Queue Stopping VOC	$10,311	2%
Queue Added Travel Time	$378,552	80%
Queue Idle Time	$12,125	3%
Total Cost	**$471,013**	**100%**

Alternative 1

Rehabilitation #2	@ 22 years	
Agency Construction Cost ($1000)	$1,175.02	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	37	
No of Lanes Open in Each Direction During Work Zone	1	
Activity Service Life (years)	12.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	4.28	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$5,389	0%
WZ Speed Change Delay	$4,413	0%
WZ Reduced Speed Delay	$194,271	11%
Queue Stopping Delay	$53,432	3%
Queue Stopping VOC	$39,661	2%
Queue Added Travel Time	$1,386,147	80%
Queue Idle Time	$44,400	3%
Total Cost	**$1,727,714**	**100%**

Alternative 1

Rehabilitation #3	@ 34 years	
Agency Construction Cost ($1000)	$290.93	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	10	
No of Lanes Open in Each Direction During Work Zone	1	
Activity Service Life (years)	1.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	4.28	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$1,457	0%
WZ Speed Change Delay	$1,193	0%
WZ Reduced Speed Delay	$52,506	11%
Queue Stopping Delay	$14,441	3%
Queue Stopping VOC	$10,719	2%
Queue Added Travel Time	$374,634	80%
Queue Idle Time	$12,000	3%
Total Cost	$466,950	100%

Alternative 2

Initial Construction	@ 0 years	
Agency Construction Cost ($1000)	$8,305.04	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	118	
No of Lanes Open in Each Direction During Work Zone	1	
Activity Service Life (years)	22.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	4.28	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$37,915	8%
WZ Speed Change Delay	$31,045	7%
WZ Reduced Speed Delay	$380,282	85%
Queue Stopping Delay	$0	0%
Queue Stopping VOC	$0	0%
Queue Added Travel Time	$0	0%
Queue Idle Time	$0	0%
Total Cost	$449,242	100%

Alternative 2

Rehabilitation #1	@ 22 years	
Agency Construction Cost ($1000)	$695.06	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	35	
No of Lanes Open in Each Direction During Work Zone	1	
Activity Service Life (years)	10.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	4.28	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$5,098	0%
WZ Speed Change Delay	$4,174	0%
WZ Reduced Speed Delay	$183,770	11%
Queue Stopping Delay	$50,544	3%
Queue Stopping VOC	$37,518	2%
Queue Added Travel Time	$1,311,220	80%
Queue Idle Time	$42,000	3%
Total Cost	$1,634,324	100%

Alternative 2

Rehabilitation #2	@ 32 years	
Agency Construction Cost ($1000)	$911.77	
User Work Zone Costs ($1000)		
Work Zone Duration (days)	30	
No of Lanes Open in Each Direction During Work Zone	1	
Activity Service Life (years)	3.0	
Maintenance Frequency (years)		
Agency Maintenance Cost ($1000)		
Work Zone Length (miles)	4.28	
Work Zone Speed Limit (mph)	55	
Work Zone Capacity (vphpl)	1490	
Time of Day of Lane Closures (use whole numbers based on a 24-hour clock)		
Inbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		
Outbound	Start	End
First period of lane closure	0	6
Second period of lane closure	20	24
Third period of lane closure		

User Cost Output:

Cost Component	Cost	Percent
WZ Speed Change VOC	$4,370	0%
WZ Speed Change Delay	$3,578	0%
WZ Reduced Speed Delay	$157,517	11%
Queue Stopping Delay	$43,324	3%
Queue Stopping VOC	$32,158	2%
Queue Added Travel Time	$1,123,903	80%
Queue Idle Time	$36,000	3%
Total Cost	$1,400,849	100%