

**ECONOMIC IMPACT OF WORK ZONE TRAVEL TIME DELAYS**

**PHASE I**

**FINAL REPORT**

**SUBMITTED**

**IDAHO TRANSPORTATION DEPARTMENT**

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## TABLE OF CONTENTS

<b>INTRODUCTION</b> .....	1
Calculating User Time Delay U of I Model.....	2
Adapting the U of I Model for Work Zone Time Delays .....	3
<b>FREEWAY CAPACITY AND USER COST MODELS</b> .....	4
Highway Capacity Manual (HCM) .....	4
Queue and User-Cost Evaluation of Work Zones (QUEWZ) .....	4
Economic Analysis of Roadway Occupancy for Maintenance And Rehabilitation (EAROMAR) .....	5
The Ohio Model.....	6
<b>USER WORK ZONE COSTS</b> .....	9
Vehicle Operating Cost.....	9
Travel Time Costs.....	10
Dollar Amount .....	11
Cost of Comfort and Convenience.....	11
Value of Motorists' Time .....	11
<b>SUMMARY</b> .....	12
<b>CONCLUSIONS AND RECOMMENDATIONS</b> .....	13
<b>REFERENCES</b> .....	15
<b>APPENDIX (Example Problem Ohio Model)</b> .....	16

## **INTRODUCTION:**

The Idaho Department of Transportation (IDT) is interested in the development of a computer model that can calculate an estimate of user costs of travel time delays due to work zones. The IDT hopes that such a computer model could generate a benefit/cost ratio that will aid in the decision making process regarding future highway construction projects. The project is similar to a computer program previously developed for the IDT by the University of Idaho (U of I) that calculated the economic impact of time delays induced by winter road conditions.

This report will review the method and model used in calculation the economic impact of winter maintenance time delays and its possible adaption to work zone time delays. Then will analyze the models developed by other researchers, states and the Federal Highway Administration that have the best potential for application to the work zone economic impact estimation in Idaho. These models must have methods to:

- (1) Calculate the time delay to road users induced by a given construction or road maintenance project
- (2) Translate that time delay into a dollar amount (user costs).

The conversion into a dollar amount represents the amount of money that highway users would lose as a result of any vehicle time delay in a work zone.

## Calculating User Time Delay U of I Model

The model used to calculate the time delay caused by winter condition and the type of winter maintenance for the U of I Model, was based on a study *Economic Impact of Winter Road Maintenance on Road Users*<sup>1</sup>, conducted by Rashad Hanbali in 1994. The U of I Model uses an equation for calculating total travel time based on vehicle speed statistical distribution on various highway types from two lane roadways to interstates with various levels winter maintenance. The statistical vehicle speed parameters for winter roadway conditions and the level of winter maintenance were determined from a field study in Utah. The U of I Model used these speed parameters with the most recent ADT from ITD's Traffic Survey Database to calculate total travel time for a given segment of highway. The actual equations used are:

$$T_1 = (DI / (V_1)) * ADT * 60$$

$$T_2 = (DI / (V_2)) * ADT * 60$$

$$\text{Travel time difference} = T_1 - T_2$$

Where:  $T_1$  = Total travel time (minutes)

$V_1$  = The random velocity for a vehicle on a specific section of highway with one level of winter maintenance.

$V_2$  = The random velocity through the same segment of highway with a different winter maintenance level.

DI = Highway segment considered (miles)

ADT = Average Daily Traffic

60 = Conversion factor for hours to minutes

Since these equations contain a random variable with a known distribution, simulation techniques were used to determine the average user time delay differences between two levels of winter maintenance.

## **Adapting the U of I Model for Work Zone Time Delays**

The equations used in the winter maintenance model were based on vehicle speed distributions over highways with different winter maintenance conditions. IDT's Traffic Survey Database has information that could be used to determine normal traffic mean speed, variance and volume in hourly intervals for approximately 80 percent of rural highway locations for non-winter conditions<sup>2</sup>. For the remaining 20 percent of the highway locations, daily volume information is available. The speed statistics could be estimated using a predictive equation developed by Oppenlander<sup>3</sup>. These predictive equations only establish the base travel time for normal highway conditions. To predict the user time delay for work zones, similar speed statistics must be estimated. Also, time delay calculations for traffic control measures that cause a queue would have to be incorporated.

## **FREEWAY CAPACITY AND USER COST MODELS**

The major effect work zones have on traffic flow is reduced capacity. Capacity values for normal travel for most roadways are available. However, the authors could not find any studies that estimated work zone capacities for other than freeways. For any roadway, if its capacity exceeds demand, delays are small. When demand exceeds capacity queues may form and the subsequent delays significant. Most models that predict user delays due to work zones use three capacity estimates:

- (1) *Normal Capacity* the maximum number of vehicles per hour (vph) that could be handled on the freeway under normal conditions.
- (2) *Reduced Capacity* the capacity of the freeway in the work zone when no work is in progress.
- (3) *Work Zone Capacity* the capacity of the work zone with M&R work actually in progress.

### **Highway Capacity Manual (HCM)**

Highway Capacity Manual (HCM)<sup>4</sup> 1994 contains information about highway capacities including a compendium of freeway work zone capacity studies and is one of the best sources for work zone freeway capacities. The manual indicates that work zone capacities depend on the kind of work being done, the equipment used, and the location of the crews with respect to moving traffic. The manual also has values for normal freeway traffic capacity.

### **Queue and User-Cost Evaluation of Work Zones (QUEWZ)**

QUEWZ is a computer program developed by Krammes, Marsden and Dudek<sup>5</sup>. The program is designed to analyze the flow of traffic through freeway work zones and estimate the queue lengths and additional road use costs that would result from alternative work zone configurations and schedules. The program model is designed for analysis of work zones on freeways with maximum six lanes in each direction. Traffic control was generally limited to two

major strategies:

*Single Lane Closure (SLC)* when one line in one direction is closed and the traffic in the opposite direction is relatively unaffected

*Two-Lane Two Way (TLTWO)* when a roadway is closed and the traffic is crossed over the median, and TLTWO is maintained.

Three capacity values are used for the model analysis, normal, restricted and work zone.

- (1) *normal capacity*, the model uses 2000 vehicles per hour per lane (vphpl) as the default value or the user could input site specific normal capacity values,
- (2) *restricted capacity*, the model uses 90% of normal as the default value (1800 vphpl) or gives the option to input site specific capacity values,
- (3) *work zone capacity*, the model again gives the option of inputting site specific values or using a default value suggested by previous studies.

### **Economic Analysis of Roadway Occupancy for Maintenance and Rehabilitation**

#### **( EAROMAR)**

The EAROMAR Model<sup>6</sup> was designed to predict life-cycle roadway costs for freeway operations. R&M costs, reconstruction costs, user costs of vehicle operation, travel time and accidents are considered. Since the model tries to predict such a wide variety of costs, the data need to drive the model is considerable and it is complicated to use. The EAROMAR uses a normal capacity of 2000 vphpl but allows for capacity adjustments due to grade, lane width and other site-specific factors.

## **The Ohio Model**

The one of most recent attempts to develop user travel time delays and costs for freeways was in a report *User Cost Models for Pavement Maintenance and Rehabilitation in Highway Work Zones* by Arudi, Minkarah and Pant<sup>7</sup>. The Ohio Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration, sponsored this research. This report gave a very detailed review of available literature on user travel delay models and user cost models. The study's objective was to estimate user delay costs and use this as a separate factor in ODOT's life cycle cost analysis. The authors after examining existing user cost models used a combination of parts of these models and additional information to calculate an estimate of user delay costs for freeways in Ohio. A computer program was developed using visual basic 4.0 that assists in the computation of these user costs for a range of M&R alternatives given information on traffic, the roadway, work zone characteristics, and the desired maintenance of a traffic scenario.

**Maintenance and Rehabilitation Ohio Model** The M&R alternatives chosen were the most likely ones for interstate pavement maintenance. A total of thirty three M&R items were included in the study ranging from *Wearing Course Removed* to *Crack/Seal Reinforced Concrete Pavement*. Production rates were estimated for each item. Combinations of M&R items could be formed that represented realistic maintenance strategies. From the production rates, an estimate of the total project duration could be determined for each alternative. The total project duration is one of the major factors in estimating user travel delays in this model as in all user time delay models.



**Traffic Control Ohio Model** After examining traffic control for interstate M&R projects in Ohio, the traffic control strategies allowed in this model could be grouped into *Single Lane Closure* and *Two-Lane Two-Way Operation*. User travel costs and M&R costs could be estimated by running the model with the chosen M&R alternative with either of the two traffic control strategies thereby giving a cost comparison between strategies.

**Normal Capacity Ohio Model** This study used a base capacity value of 2200 for normal conditions for freeways with two lanes in any one direction and 2300 for three or more lanes in one direction. These base values were adjusted for lane width and a truck capacity factor. The equation used for normal freeway capacity was:

$$C = C_{\text{base}} * W * T * N$$

Where:

$C_{\text{base}} = 2200$  or  $2300$  depending on the number of lanes

W = Lane width factor

T = Truck factor

N = Number of lanes in one direction

**Work Zone Capacity Ohio Model** For work zone capacity, the model is expressed by:

$$C = (1600 + I - R) * H * N$$

Where:

R = Adjustments factor for ramps

H = Heavy vehicle adjustment factor

N = Number of lanes open through the work zone

I = Work intensity factor.

The adjustment factor for heavy vehicle (trucks) can be determined by % of heavy vehicles and the roadway grade, the work intensity factor can be determined from tables found in the study and the ramp adjustment factor can be determined by the number and placement of ramps within the work zone.

**Speed Profiles Ohio Model** This model uses features from both the QUEWZ and the EAROMAR model to calculate average speeds for normal freeway conditions and work zone conditions for both queue and no-queue situations.

The speed-flow relationships used in developing the user cost models in this study are as follows:

$$S1=0.9*DS$$

DS = Design Speed

$$S2=30$$

$$S3=S1-S2$$

$$S4=(0.4*DS-10)*V/C \quad V=\text{Lane Volume} \quad C=\text{Normal Capacity}$$

$$S5=S3-S4$$

$$S6=0 \text{ (if } V/C \leq 0.93)$$

$$S6=[(V/C)-0.93]*S5/.07 \text{ (if } V/C \geq 0.93)$$

Governing speed due to road design,  $S_D=S1-S4-S6$

Governing speed due to speed limit,  $S_L=(0.9*\text{Speed Limit})-(3.6*V/C)$

Estimated free-flow average speed,  $\text{Speed} = \text{Minimum} (S_D, S_L)$

Minimum speed in work zone,  $SP_{\min} = SP_{\text{work zone}} - 2.3-25.7*(V/C_{\text{work zone}})^2$

If there is a queue,  $SP_{\min} = 0$

## **USER WORK ZONE COSTS**

The user costs associated with traveling through work zones include increases in operating costs, travel time costs and pollution costs. The increase in user cost is the difference between costs traveling through the work zone and costs traveling through the equivalent road segment under normal conditions.

### **Vehicle Operating Cost**

**QUEWZ Model** In most cases, the difference in operating costs between the work zone travel and normal travel is small. The QUEWZ Model considers costs for fuel, oil, tire consumption, and other vehicle costs as a single operating cost. This cost is computed for two scenarios:

- (1) When there is no queue generally the vehicles do not come to a complete stop;
- (2) When there is a queue and the vehicles come to a complete stop.

**Ohio Model** The Ohio Model used the QUEWZ Model approach for calculating the difference of operating cost for normal and work zone travel.

**U of I Model** The U of I model did not consider vehicle operating costs due to the small differences in cost due to speed changes and no queues

**EAROMAR Model** The EAROMAR model handles costs due to fuel and oil and tire consumption separately. EAROMAR uses regression equations based on data from Claffey and Winfrey<sup>8</sup>. This model gives a more detailed estimate of vehicle operating costs but requires significantly more input data.

## Travel Time Costs

Costs associated with increased travel time through a work zone are the largest user cost. This travel time delay could be due to the following reasons:

- (1) Reduced speed with and without a queue
- (2) Speed change cycles with and without a queue

QUEWZ calculates time delays from the speed-volume relationships mentioned in the previous section and computes the Total Hourly

Costs (THC) as follows:

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

Where:

CQUE = Cost of delay to queue

CDWZ = Cost of delay while going through the 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 with a queue

OC = Vehicle running cost

OCQ = Vehicle running cost with a queue

From traffic data and work zone capacities, the program computes hourly distribution of traffic by using speed models with and without a work zone. This step leads to the computation of excess travel time, delay due to queues and length of queue during each hour of the day.

Assuming a time value for a car and for a truck, the user delay costs are estimated.

## **Dollar Amount**

The issue of calculating a monetary amount associated with vehicle time delay has been the subject of several studies over the years. Typically, the three major factors taken into account while trying to determine the cost of time delays include: 1) the cost of comfort and convenience, 2) vehicle operating cost, and 3) the value of the motorists' time.

## **Cost of Comfort and Convenience**

Thomas and Thompson<sup>9</sup> define the cost of comfort and convenience, "as the amount of money that a driver will pay to avoid being delayed" (4). Although, the cost of comfort and convenience cannot be directly observed it is an important component of total cost of time delays nonetheless. The cost of comfort and convenience has been incorporated into several studies. Many of these studies have come to the similar conclusions as a monetary value. The U of I determined the cost of comfort and convenience from a graph created by Welch<sup>10</sup>. Both the QUEWZ and The Ohio Model do not assign a value to the cost of comfort and convenience.

## **Value of Motorists' Time**

The value of the driver's time is directly related to the amount of wages lost while being delayed. A study conducted in 1994 by Hanbali<sup>1</sup> found a conservative value for commuter's time in 1990 to be \$6.65 per hour (1). The following is Hanbali's equation for converting older values of time into modern dollar values:

$$VT = VT_0 * (CMB_0 / CMB_{199S})$$

Where:

VT = New value of driver's time

VT<sub>0</sub> = Previous known value of driver's time

CMB<sub>0</sub> = Previous value for the Cost of Market Basket

$CMB_{1998} = 1998 \text{ value for the Cost of Market Basket}$

This equation is based off the Gross National Product (GNP) deflator, "is constructed from a market basket that includes every item in the GNP" (4). This equation is incorporated into the U of I Winter Maintenance Model. The user then can have the updated (1999) value of travel time. QUEWZ and The Ohio Model user similar approaches for the value of user time delays. In the Ohio Model, a 1995 base time value of \$10.20 for a car and \$19.20 for a truck was used. These values could be brought to current values using the Consumer Price Index.

## **SUMMARY**

An extensive literature search was conducted on previous user cost studies and models for work zones. The search found studies and models that did predicted user costs for work zones **but only on freeway systems**. All models considered roadways with at least two lanes in each direction. The most relevant user cost models were selected for comparison with the U of I Winter Maintenance Model. Summaries of the methodologies used by the most recent models to determine user time delay and the subsequent calculation of user costs were presented along with traffic control strategies for the freeway work zone. A comparison between the methodologies used to determine vehicle time delays by the U of I Model and other user cost models was presented. A similar comparison was presented on the translation of time delays into monetary units.

## CONCLUSIONS AND RECOMMENDATIONS

- (1) Data necessary to determine statistical speed parameters used by U of I Model to calculate **normal** user travel time for most Idaho highway segments is available on the ITD's Traffic Survey Database.
- (2) **Work zone** statistical speed parameters are **not** available on ITD's database. The U of I Winter Delay Model could not be used to calculate user costs due to work zone delays without these parameters. Therefore it is not recommended to use this part of the U of I Winter Delay Model.
- (3) All the models investigated including the U of I Model used similar methodologies to translate user time delays into monetary units.
- (4) The Ohio Model seems to simulate Idaho Freeway conditions. If Idaho M&R projects were taking place on freeways with at least two lanes in each direction and traffic control was either SLC or TLTWO, the Ohio Model in its present form could be used to estimate work zone user costs.
- (5) Normal capacities and normal speed profiles for any Idaho Highways segment can be obtained or estimated. These values are necessary to establish a base travel time for a work zone segment.
- (6) The capacity analysis used by the QUEWZ for user travel delays should be adapted to work zones for highways with less than two lanes in each direction. The information necessary to use the QUEWZ in these situations would be an estimate of the work zone capacity given a traffic control scenario. This approach is more easily accomplished than attempting to obtain speed statistical parameters for work zone necessary to the U of I Model.



- (7) The major scope of work in Phase II would be developing estimates of capacities for work zones on two-lane highways verses traffic control. QUEWZ could then be used to minimize calculation time for user costs.
  
- (8) The QUEWZ computer model has been used by ITD personnel and by the project leader. Updated versions of the QUEWZ model, if available, will be used in Phase II . The basic language version of the Ohio Model has not been obtained. However, the research was funded by Federal Highway Administration in cooperation with the State of Ohio and copies should be available.

## List of References

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## OHIO MODEL EXAMPLE PROBLEM

Under the 1995 multi-lane resurfacing program, ODOT considered major rehabilitation of a 3.18 mile long pavement section on I-475. Project WOO-475-0.67 involves rehabilitation/replacement of the existing pavement. Five alternative rehabilitation/replacement strategies were selected for analysis.

Project: WOO-475-0.67 Length: 3.19 miles

ADT (1990): 30480 (assumed 35000); % Trucks: 17

### Alternate 1: Repair and Overlay

	Item Special	Sawing and Sealing Asphalt Concrete, Pavement Joints
3"	Item 446	Asphalt Concrete, Types I and II
6"	Item 301	Bituminous Aggregate Base
	Item 255	Rigid Repair
	Item 254	Pavement Planing

### Alternate 2: Rubblize and Roll

3"	Item 446	Asphalt Concrete, Types I and 11
11"	Item301	Bituminous Aggregate Base
	Item Special	Rubblize and Roll Existing Concrete Base
	Item 254	Pavement Planning

### Alternate 3: Unbonded Concrete Overlay

11"	Item 451	Reinforced Concrete Pavement
1"	Item 403	Asphalt Concrete Bondbreaker
	Item 254	Pavement Planing

### Alternate 4: Replace with Flexible Pavement

3"	Item 446	Asphalt Concrete, Types I and 11
13"	Item301	Bituminous Aggregate Base
	Item Special	Free Drainage Base
6"	Item 254	Aggregate Base

### Alternate 5: Replace with Rigid Pavement

12"	Item 451	Reinforced Concrete Pavement
4"	Item Special	Free Drainage Base
6"	Item 304	Aggregate Base

The researchers make the following assumptions:

Design Speed: 70 mph

Speed Limit: 65 mph

Work Zone Speed Limit: 45 mph

Number of Lanes: 4

Percent Grade: 0

Traffic Control: SLC

Each of these alternatives was designed for a design period of 20 years and a performance period of 35 years. Cost data was obtained by researching recently constructed projects in the same region of the state, and of approximately the same size. The construction and maintenance cost of these alternatives is presented in the table below. Based on this cost analysis, the ODOT recommended Alternate 2.

**Construction and Maintenance Costs of Alternate Strategies**

Strategy	Construction Cost	Future Maintenance Cost	Total
Alternate 1	\$3,185,538	\$2,562,952	\$5,748,490
Alternate 2	\$2,757,502	\$1,991,557	\$4,749,059
Alternate 3	\$4,076,585	\$740,482	\$4,817,067
Alternate 4	\$3,876,186	\$1,991,557	\$5,867,743
Alternate 5	\$5,184,960	\$673,978	\$5,858,938

Summary Input and Output for the Single Lane Closure Strategy		
	<b>INPUT DATA</b>	
<b>Project Name</b>	WOO-475-0.67	
<b>Freeway Name</b>	I-475	
<b>Input Filename</b>	E:\WOO_ALT2.WZM	
<b>Project Start Date</b>		
<b>Project End Date</b>		
<b>Design Speed</b>	65 mph	
<b>Speed Limit</b>	55 mph	
<b>Workzone Speed Limit</b>	45 mph	
<b>Grade</b>	0.00%	
<b>Work Zone Length</b>	3.19 miles	
<b>total Number of Lanes</b>	4	
<b>Number of Open Lanes</b>	2	
<b>Number of Temporary Lanes</b>	0	
<b>AADT</b>	30480	
<b>Percentage of Trucks</b>	17.00%	
<b>Functional Class</b>	Rural Interstate	

	<b><u>OUTPUT SUMMARY</u></b>	
<b><u>TYPE OF WORK</u></b>	<b><u>COST</u></b>	<b><u>DURATION</u></b>
<b>254-Pavement Planning - Rigid</b>	\$275, 206.37	26
<b>301-Bituminous Aggregate Bas</b>	437917.5	39
<b>446I-Asphalt Concrete</b>	69018.75	6
<b>446II-Asphalt Concrete</b>	96626.03	9
<b>Special-Rubb/Roll</b>	489606.95	45
<b>TOTALS</b>	1368375.6	125

### Hourly Distribution of User Costs and Queue Lengths

<b>Volume</b>	<b>Normal Capacity</b>	<b>Work Zone Capacity</b>	<b>Approach Speed</b>	<b>Work Zone Speed</b>	<b>Queued Traffic</b>	<b>Queue Length</b>	<b>Additional User Costs</b>
589.33	8800.00	4192.77	49.26	39.99	0.00	0.00	128.01
471.46	8800.00	4192.77	49.31	40.10	0.00	0.00	101.09
392.89	8800.00	4192.77	49.34	40.16	0.00	0.00	92.54
392.89	8800.00	4192.77	49.34	40.16	0.00	0.00	92.54
471.46	8800.00	4192.77	49.31	40.10	0.00	0.00	101.09
825.06	8800.00	4192.77	49.16	39.79	0.00	0.00	184.29
1492.97	8800.00	4192.77	48.89	39.22	0.00	0.00	365.81
2082.30	8800.00	4192.77	48.65	38.71	0.00	0.00	562.62
2043.01	8800.00	4192.77	48.66	38.75	0.00	0.00	548.17
2121.59	8800.00	4192.77	48.63	38.68	0.00	0.00	577.29
2200.17	8800.00	4192.77	48.60	38.61	0.00	0.00	607.29
2239.46	8800.00	4192.77	48.58	38.58	0.00	0.00	622.63
2239.46	8800.00	4192.77	48.58	38.58	0.00	0.00	622.63
2318.03	8800.00	4192.77	48.55	38.51	0.00	0.00	654.02
2514.48	8800.00	4192.77	48.47	38.34	0.00	0.00	736.84
2750.21	8800.00	4192.77	48.37	38.14	0.00	0.00	845.32
2907.37	8800.00	4192.77	48.31	38.00	0.00	0.00	923.80
2789.50	8800.00	4192.77	48.36	38.10	0.00	0.00	864.45
2200.17	8800.00	4192.77	48.60	38.61	0.00	0.00	607.29
1689.41	8800.00	4192.77	48.81	39.05	0.00	0.00	426.95
1414.39	8800.00	4192.77	48.92	39.29	0.00	0.00	342.46
1296.53	8800.00	4192.77	48.97	39.39	0.00	0.00	308.52
1060.80	8800.00	4192.77	49.07	39.59	0.00	0.00	244.26
785.77	8800.00	4192.77	49.18	39.83	0.00	0.00	174.67