

# CONSTRUCTION CONGESTION COST (CO<sup>3</sup>) TRAFFIC IMPACT AND CONSTRUCTION COST<sup>1</sup>

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**ABSTRACT:** The Construction Congestion Cost System (CO<sup>3</sup>) is an integrated set of tools to estimate impact of traffic maintenance contract provisions on congestion, road user cost, and construction cost. We use CO<sup>3</sup> to produce realistic budgets and select practical contracting methods that provide an acceptable balance between construction cost and congestion. This paper demonstrates computation of impacts associated with alternative methods of maintaining traffic during construction. The Routes Sheet computes equivalent average vehicle routes for complex diversion routes. The Input Sheet provides for documentation of vehicle and route inputs and computes user cost for individual trips through the work zone, diversions, and cancellations. The Traffic Sheet computes daily traffic impacts and user cost for each construction method. The Construction Sheet computes impact of different construction methods on construction costs. The Impact Sheet summarizes daily impacts and computes total project traffic impacts, road user costs, and construction costs for all alternatives. These tools provide practical information with which to select construction methods whose impacts are acceptable.

## 1 INTRODUCTION

The CO<sup>3</sup> System is a tool with which engineers can estimate the magnitude and impacts of traffic congestion, including its cost impact on road users, that can be expected during a construction project (Carr 1997). Its name comes from the first two letters of COnstruction COngestion COst, on which the system focuses. From project conception through drafting provisions for maintaining traffic, CO<sup>3</sup> provides a useful way for engineers to include construction congestion and its costs to users as an important variable in all project decisions.

CO<sup>3</sup> measures the impact of congestion in two basic ways: (1) variables such as delay, diverted vehicles, and backup measure different characteristics of congestion and (2) user cost provides a common unit of measure with which to sum traffic impacts and compare them with construction cost. User costs consist of direct costs of increased travel distance due to traffic diversions and indirect costs that measure the impact of traffic delays and trip cancellations caused by congestion. CO<sup>3</sup> helps us select among alternative methods of maintaining traffic during construction, and it helps us select contract period costs for contract provisions that provide incentives for reducing congestion impacts during construction. This paper demonstrates computation of impacts associated with alternative methods of maintaining traffic during construction. A fictitious example of 8 mi of overlay on US-X0 demonstrates various aspects of CO<sup>3</sup> applications. A fictitious example of 8 mi of overlay on US-X0 demonstrates various aspects of CO<sup>3</sup> applications.

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## **2 BACKGROUND**

CO<sup>3</sup> models the circular relationship between work zone demand and delay, in which diversions and cancellations are functions of delay, work zone demand is a function of diversions and cancellations, and delay is a function of work zone demand. A companion paper describes this basic CO<sup>3</sup> model (Carr 1998). It also identifies prior software that calculate traffic delay and user cost for construction decisions (“Alternative” 1978) (Morales 1986) (Krammes, Ullman, Memmott, and Dudek 1993). Not only does CO<sup>3</sup> extend prior methods in its model of construction congestion and user cost, but it also includes a broad, integrated set of tools for project decision-making. These tools also provide for practical implementation of incentive/disincentive based contract provisions, which have proven to be an excellent instrument for controlling project impacts (“Incentive” 1989) (“Traffic” 1992) (“Contract” 1997) (Jaraiedi, Plummer, and Aber 1995) (Herbsman, Chen, and Epstein 1995) (Herbsman 1995). This paper describes the CO<sup>3</sup> toolkit for basic project decisions. However, space constraints prevent inclusion of CO<sup>3</sup> tools for implementation of incentive/disincentive contract provisions.

CO<sup>3</sup> was developed with financial support from the Michigan Department of Transportation (MDOT) to allow it to reduce the impact of highway construction on Michigan travelers. CO<sup>3</sup> was tested during its development on several recent MDOT projects, and MDOT is now using it on all major projects.

## **3 CO<sup>3</sup> SOFTWARE**

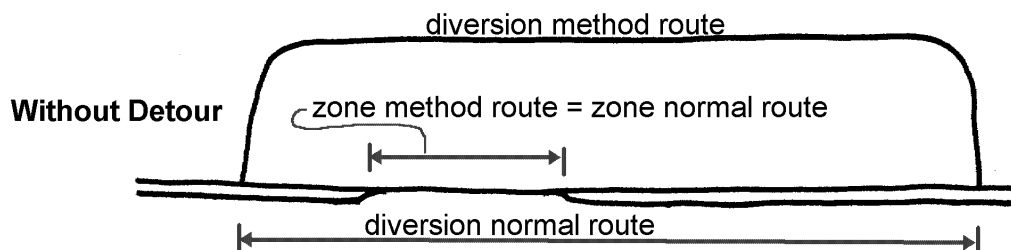
The CO<sup>3</sup> system is implemented in a Microsoft Excel spreadsheet. The spreadsheet contains extensive imbedded Visual Basic code, which we call the CO<sup>3</sup> Program. The software and CO<sup>3</sup> User Manual can be downloaded from the worldwide web at <http://grader.engin.umich.edu/>. The CO<sup>3</sup> computer program consists of the CO.xls file, which in Excel is called a “workbook”. The workbook contains “worksheets”, which we also call “sheets”. These sheets can have more than one module, which we often call a “view” when it is a separate item that can be printed separately as a report. Listed below is the subset of sheets and views that are described in this paper, with a short description of the purpose of each.

- Routes Sheet – Project input and calculation of travel data (1) for multiple alternative routes and (2) for complex routes (see Fig. 3, pg. 5).
- Input Sheet – Field input and documentation of project data and calculation of travel data to assist Traffic Sheet input and documentation of decreases to demand (see Fig. 4, pg. 7).
- Traffic Sheet
  - Summary View – Input and calculation and summarization of traffic impact and user cost for up to four traffic maintenance methods (See Fig. 5, pg. 10). All input to the Traffic Sheet is through the Summary View.
  - Overall View – Report of hourly traffic and user cost impact for the most recently calculated traffic maintenance method and direction (see Fig. 6, pg. 12).
- Construction Cost Sheet – Input of construction cost estimate for Standard Method of performing work and calculation of estimated project cost for alternative traffic maintenance methods (see Fig. 7, pg. 14).
- Impact Sheet – Summarization of daily user cost, total user cost, construction cost, and project cost impacts of alternative traffic maintenance methods (see Fig. 8, pg. 17).

## 4 PRIMARY VARIABLES

### 4.1 WORK ZONE AND DIVERSION ROUTES

Fig. 1 shows travel routes that are important to calculations of extra distance and time that may be required during construction, relative to normal travel when there is no work zone. We differentiate between a method route and a normal route for work zone travel and for diversion travel. Vehicles travel a method route while a construction method is being applied. The normal route is the comparable route vehicles travel when there is no construction. Therefore, diversion normal route = normal route between the points at which diverting vehicles leave and return to the normal route. Fig. 1 shows the routes when there is no detour, in which case work zone method route = work zone normal route. If there is a detour and no vehicles travel the normal route through the work zone, generally work zone method route > work zone normal route.



**Fig. 1 - Work Zone and Diversion Distances with No Detour**

The model requires input of distance and speed for four routes:

- work zone method travel = distance and average speed each vehicle will travel through the work zone during construction, or a required detour around the work zone, if present.
- work zone normal travel = distance and average speed each vehicle will travel if there is no construction, no work zone.
- diversion method travel = distance and speed of the average alternate route vehicles will select to avoid going through the work zone or a required detour around the work zone.
- diversion normal travel = distance and average speed each vehicle would travel if there were no work zone and the vehicle did not divert to an alternate route.

Work zone method travel distance = work zone normal travel distance, except when there is a detour, in which case work zone method travel distance is the length of the detour. We input estimates for speed here, except for work zone method travel speed, which is separately calculated from Speed Delay Input.

### 4.2 DELAY

A work zone can cause three types of delay:

- speed delay = difference in time to travel the method travel distance through the work zone (or around it if a detour is required) during construction and the normal time when there is no work zone..
- backup delay = time vehicles wait to enter the work zone when work and traffic maintenance conditions reduce capacity below design demand, and
- diversion delay = difference in time to travel the diversion travel distance around the work zone during construction instead of the normal time when there is no work zone.

Vehicles that travel through the work zone experience

$$\text{work zone delay} = \text{speed delay} + \text{backup delay} \quad (1)$$

whereas vehicles that divert around the work zone experience diversion delay.

### 4.3 ACTUAL DEMAND

Demand through the work zone (or detour) decreases when drivers divert to other routes or cancel trips to avoid the work zone conditions and possible delays associated with it. Actual demand in a period consists of vehicles that arrive at the work zone during the period, which is design demand minus vehicles that cancel trips or divert around the work zone (or detour). At any capacity, the decrease in traffic from diverted and canceled vehicles is modeled in four components for both cars and trucks:

- decrease (with no delay) = diverted (with no delay) + canceled (with no delay) traffic that occurs even in periods in which there is no significant delay at the work zone. This is expressed in percent.
- decrease (with delay) = diverted (with delay) + canceled (with delay) traffic that occurs due to delay at the work zone. This is expressed in percent decrease per minute of delay.

Therefore, demand = actual demand is a function of work zone delay:

$$\text{decrease (\%)} = [\text{decrease (with no delay) (\%)}] + [\text{decrease (with delay) (\% / min)}] * [\text{work zone delay (min)}] \quad (2)$$

where decrease (%) = per cent of design demand that diverts or cancels its trips. This is demonstrated in Carr (1998). Total decreases are the sum of diverted and cancelled cars and trucks,

## 5 ROUTES SHEET (ROUTES TAB)

### 5.2 GENERAL

The Routes Sheet calculates equivalent properties of normal and diversion routes that consist of more than one road or speed. Inputs that are unique to the Routes Sheet are briefly described here. The Routes Sheet is not needed for projects that do not have complex routes

Fig. 2 shows complex diversion routes for the US X0 example problem. The construction work zone moves a mile at a time over the 8 mi between ramps at Cedar and Diag. There are two diversion routes. We estimate 40% of diverting vehicles will take North Cedar (1 mi @ estimated average speed = 65 mph), Lex (9+3=12 @ 65), and Wax (1 @ 60) versus normal travel of 8+4=12 mi @ 75 mph on US X0. 60 % will take South Cedar (0.8 @ 65), Rib (7 @ 55), and Diag (1.5 @ 50) versus normal travel of 8 mi @ 75 mph on US X0. Fig. 3 shows the Routes Sheet for this example. Inputs to the Routes Sheet are shown in color on a computer monitor and in light gray here.

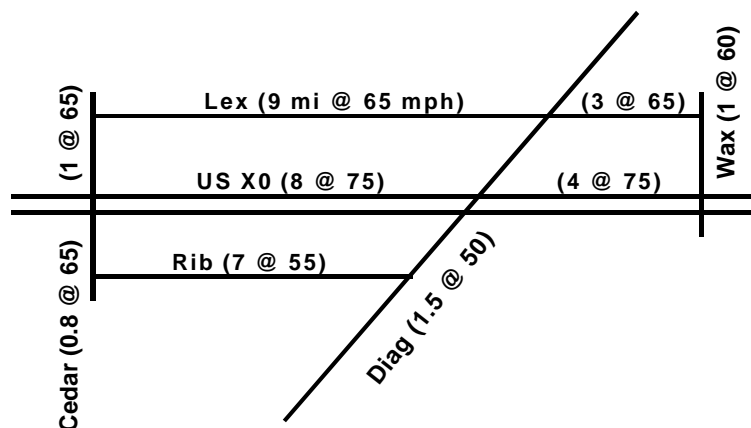


Fig. 2 Map of Example Routes

### 5.3 TRAFFIC TRAVELING DIFFERENT DISTANCES AND SPEEDS

For complex routes, the Routes Sheet calculates equivalent travel distance, speed, time based on the following general equations for average distance traveled per vehicle,  $L_{avg}$ ; average speed traveled per mile,  $S_{avg}$ ; and average time taken per vehicle,  $T_{avg}$ ,

$$L_{avg} = \frac{\text{total distance traveled}}{\text{total number of vehicles}} = \frac{\sum_i V_i L_i}{\sum_i V_i} \quad (3)$$

$$S_{avg} = \frac{\text{total distance traveled}}{\text{total time taken}} = \frac{\sum_i V_i L_i}{\sum_i V_i \frac{L_i}{S_i}} \quad (4)$$

$$T_{avg} = \frac{\text{total time taken}}{\text{total number of vehicles}} = \frac{\sum_i V_i \frac{L_i}{S_i}}{\sum_i V_i} = \frac{L_{avg}}{S_{avg}} \quad (5)$$

where  $V_i$  = number of vehicles traveling distance  $L_i$  at speed  $S_i$ .

From Eq. (3) to (5), the Routes Sheet calculates equivalent average normal travel = 9.6 mi @ 75 mph = 7.68 min. and equivalent average diversion travel = 11.18 mi @ 57.95 mph = 11.57 min. Therefore, the average vehicle that diverts will travel  $11.18 - 9.6 = 1.58$  mi further and take  $11.57 - 7.68 = 3.91$  min. longer than normal travel when there is not work zone.

Normal Travel						
Input				Calculated Values		
Route Name	% that Take Route	Distance (mi)	Speed (mph)	Travel Time (min)	Weighted Distance (mi)	Weighted Time (min)
US 16	40%	12	75	9.60	4.8	3.84
US 16	60%	8	75	6.40	4.8	3.84
				0.00	0	0.00
				0.00	0	0.00
				0.00	0	0.00
				0.00	0	0.00
				0.00	0	0.00
				0.00	0	0.00
Totals	1.00				9.60	7.68
Averages		9.6	75.00	7.68		
Method Travel						
Input				Calculated Values		
Route Name	% that Take Route	Distance (mi)	Speed (mph)	Travel Time (min)	Weighted Distance (mi)	Weighted Time (min)
N. Cedar	40%	1	65	0.92	0.4	0.37
Lex	40%	12	65	11.08	4.8	4.43
N. Wax	40%	1	60	1.00	0.4	0.40
				0.00	0	0.00
S. Cedar	60%	0.8	65	0.74	0.48	0.44
Rib	60%	7	55	7.64	4.2	4.58
Diag	60%	1.5	40	2.25	0.9	1.35
				0.00	0	0.00
Totals	3.00				11.18	11.57
Averages		11.18	57.95	11.57		
Differences		1.58	-17.05	3.89		

Fig. 3 Routes Sheet

## **6 INPUT SHEET**

### **6.1 GENERAL**

The Input Sheet provides a form that helps us identify and estimate values of variables that are important for input to the Traffic Sheet. It has two basic uses: (1) It provides an easy format for handwritten specification and documentation of input values, which can be done separate from a computer (an example is not shown here). (2) It provides for computer input, calculation, and documentation of project travel data for entry into the Traffic Sheet. This is shown in Fig. 4, for the example problem. Inputs are generally for both directions of travel.

Inputs to the Input Sheet are shown in color on the monitor and in light gray here. On the left end of each input row is a circled number, such as ①, which indicates the sequence in which data is normally input. Default values are indicated by ②. The general steps are the following: (1) Input general inputs related to project. (2) Input variables with values up to ③. (3) Calculate travel and user cost values. (4) Estimate remaining input values, based on calculations, for use in the Traffic Sheet.

### **6.2 VARIABLES**

This paper only contains brief descriptions of Input Sheet input variables, because they are described in detail elsewhere (Carr 1997, 1998-1, 1998-2). Design demand, trucks is the fraction of design demand that we estimate is trucks (versus cars). Values for user cost per hour and user cost per mile are generally the result of policy decisions of a transportation agency, to be applied to all projects. User cost per cancellation is estimated based on calculated travel and user cost values that are described below. Distance and speed input is taken directly from the Route Sheet for complex routes. We dispense with the Route Sheet and input directly into the Input Sheet for simple routes.

Capacity of the roadway is the number of vehicles per hour it can carry. Speed delay and diverted and cancelled trips occur only when a lane is closed, which reduces capacity. In our example, estimated lane-closed capacity is 1400 Vph (the threshold capacity at which speed delay and traffic decreases begin) when no work is being performed and 1200 Vph (the range capacity, which establishes speed delay and traffic decreases at all capacities below the threshold capacity) while work is being performed. Speed when demand is low, speed when demand = capacity, and canceled cars and trucks are estimated for both threshold and range capacities. The Input Sheet calculates differences in travel times and distances and related user cost for work zone conditions and for the diversion route. For example, speed delay under heavy traffic ( $D = C$ ) = \$0.14 per car and \$0.29 per truck when capacity = 1400 Vph and \$0.32 per car and \$0.67 per truck when capacity = 1200 Vph. At capacity = 1400 Vph user cost through the work zone equals user cost diverting around the work zone for cars when backup = 5.58 min and for trucks when backup = 7.00 min.

We estimate decrease to demand input based on knowledge of the travel needs and practices of those who use the road and work zone conditions. The right column provides a useful place to document calculations and reasons behind decisions.

PROJECT INPUT AND DOCUMENTATION			Project:	US X0 Overlay
METHOD INPUT		METHOD #		
method title				
VEHICLE INPUT		cars	trucks	
1	design demand (%)	85.0%	15.0%	
0	user cost per hour (\$/V hr)	\$12.00	\$25.00	Est.
0	user cost per mile, (\$/V mi)	\$0.30	\$1.00	default
4	user cost per cancellation, (\$/V)	\$0.80	\$2.00	about 2/3 diversion cost
ROUTE TITLES		US X0		Calculated on Route Sheet
DISTANCE AND SPEED INPUT		distance	speed	
1	work zone method travel	1.0	see delay	
1	work zone normal travel	1.0	75	
1	diversion method travel	11.2	57.9	
1	diversion normal travel	9.6	75	
SPEED DELAY INPUT		threshold	range	
2	capacity for speed delay (V/hr)	1400	1200	Est 1 lane capacity = 1400 Vph. Reduced to 1000 Vph during work.
3	speed (when D=0) (mph)	50	35	Est for low traffic
3	speed (when D=C) (mph)	40	25	Est for demand =>capacity
WORK ZONE TRAVEL		threshold	range	General Comments:
	normal travel time (min)	0.80	0.80	
	method travel time (when D=0) (min)	1.20	1.71	
	speed delay (when D=0) (min)	0.40	0.91	
	method travel time (when D=C) (min)	1.50	2.40	
	speed delay (when D=C) (min)	0.70	1.60	
WORK ZONE SPEED DELAY USER COST		threshold	range	
	car speed delay user cost (when D=0)	\$0.08	\$0.18	
	truck speed delay user cost (when D=0)	\$0.17	\$0.38	
	car speed delay user cost (when D=C)	\$0.14	\$0.32	
	truck speed delay user cost (when D=C)	\$0.29	\$0.67	
DIVERSION TRAVEL				
	normal travel time (min)	7.68		
	method travel time (min)	11.59		
	diversion delay (min)	3.91		
	extra diversion travel distance (mi)	1.6		
DIVERSION USER COST		cars	trucks	
	diversion delay user cost	\$0.78	\$1.63	
	diversion distance user cost	\$0.47	\$1.58	
	diversion user cost	\$1.26	\$3.21	
	backup delay balance (min)	5.58	7.00	
DECREASE TO DEMAND INPUT		threshold	range	
2	capacity for decreases to design demand (V/hr)	1400	1200	
6	canceled cars (with no delay) (%)		5.0%	Est none cancel during off hours. However, reputation causes cancellations @ work hours
6	canceled trucks (with no delay) (%)			
6	canceled cars (with delay) (%/min)	1.0%	1.0%	Est 10% cancel with 10 min of delay. More divert.
6	canceled trucks (with delay) (%/min)	0.5%	0.5%	Est 10% cancel with 20 min delay = 1/2 of car values
5	diverted cars (with no delay) (%)	5.0%	10.0%	
5	diverted trucks (with no delay) (%)		4.0%	
5	diverted cars (with delay) (%/min)	2.0%	2.0%	Est 20% divert with 10 min delay.
5	diverted trucks (with delay) (%/min)	1.0%	1.0%	
OTHER USER COST INPUT		cars	trucks	
	other user cost per vehicle (\$/V)	\$0.00	\$0.00	default
	user cost per diversion (\$/V)	\$1.26	\$3.21	
CAPACITY INPUT		normal	method	
1	total capacity each way (V/hr)			

Fig. 4 Input Sheet

## 7 TRAFFIC SHEET

### 7.1 GENERAL

The CO<sup>3</sup> Program computes period and daily values of traffic congestion and user cost due to construction. The Traffic Sheet is our connection to the primary CO<sup>3</sup> Program, which includes imbedded Visual Basic code. Through the Traffic Sheet, we compute and report values for one direction of travel and one method of maintaining traffic in each computer run, which we call a CO<sup>3</sup> run.

### 7.2 SUMMARY VIEW

#### 7.2.1 General

The Summary View is the core of CO<sup>3</sup>. It is the place that we input and calculate traffic impact and user cost, and it is the primary report on which we document input and output and from which we make decisions. The Summary View consists of the following elements, each of which is appropriately labeled in the view for easy identification:

- Input values:
  - For the project as a whole: title block, period length, traffic growth, vehicle input, and period input, and historical demand for each period in each direction. These can be taken from the Input Sheet, if it used.
  - For each traffic direction and maintenance method: method input, distance and speed, speed delay input, decrease to demand input, other user cost, and capacity for each period in each direction.
- Control buttons
  - Action buttons, which direct CO<sup>3</sup> to perform specific calculations or to print reports.
  - Navigation buttons, which take us to various locations in views
- Output values: design demand in each direction and summary output of traffic impact and user cost.

We generally use the Summary View in this same sequence. We input project information, we input method information, we calculate traffic delay and user cost values for each method, we move from one view to another to review results, and we print the Summary View and/or other view(s) to document input and report results.

The numerical values provide the basis of all calculations and are limited to non-negative, decimal numbers. Text values (e.g., “W” and “7A-5P”) provide descriptive information only (e.g., a description of a method). Thus, they have no effect on the outcomes of calculations. Input cells require values by keyboard entry in the case of numerical and text values, or by acceptance of a default value. Most input variables are briefly described above. Detailed descriptions are in Carr (1997) (1998).

We left-click the mouse on control buttons to bring to the screen a particular view of the Traffic Sheet or to perform a particular action. For example, we left-click on the bottom button to the right of **Overall** to go to the bottom third of the Overall View. Similarly, we left-click on “Summary” in **Print: Summary** to print the Summary View.

We click on the **Compute** button in a column of the Summary View to perform a complete CO<sup>3</sup> computer run on the Traffic Sheet for that column’s method and direction of traffic.

CO<sup>3</sup> has a validity check that determines whether any inputs have changed since the summary output was last calculated. This insures that the output we see was caused by the input we see. For example, we left-click on the button to the right of “Auto” to turn the automatic validity check on: **Auto: ON** or off: **Auto: OFF**. We left-click the button to the right of “Print” to vali-



date printed output, and we left-click the button to the right of “Now” to immediately check output validate.

### 7.2.2 Summary Output

Summary output consists of the following:<sup>3,4</sup>

- total user cost = all user cost = user cost of delays + user cost of decreases.
- user cost of delays = total user costs for speed delay and backup delay.
- user cost of decreases = total user costs for cancellations and diversions.
- maximum backup (V) = maximum number of vehicles that are backed up in any period.
- maximum backup length (lane mi) = lane miles of backup due to maximum backup = (maximum backup) \* (vehicle length in backup, default = 30 ft).
- maximum delay (min) = maximum delay of any vehicle in actual demand = maximum sum of backup delay and speed delay of any vehicle.
- total delay, except diversions (V hr) = speed delay and backup delay for vehicles in actual demand = total speed delay + total backup delay.
- average delay, except diversions (min) = average delay for vehicles in actual demand = (total delay, except diversions) / (total actual demand)
- total vehicles canceled (V) = total number of vehicles that cancel trips.
- total vehicles diverted (V) = total number of vehicles that divert around the work zone (or around detour).
- total decrease in demand (V) = (total vehicles canceled) + (total vehicles diverted) = (design demand) – (actual demand).
- % decrease in demand = fraction of design demand that cancels trips or diverts around work zone (or around detour) = (total decrease in demand) / (total design demand).
- delay per diverted vehicle (min) = delay time for each vehicle that diverts around work zone (or around detour).
- total diversion delay (V hr) = total delay time from diversions = (delay per diverted vehicle) \* (total vehicles diverted) / (60 min/hr).
- total delay, including diversions (V hr) = total delay for traffic through the work zone (or detour) and diversions = (total delay, except diversions) + (total diversion delay).
- average delay, including diversions (min) = average delay for vehicles that do not cancel = (total delay, including diversions) / [(actual demand) + (total vehicles diverted)].
- user cost / design demand = average user cost for all normal traffic = (total user cost) / (design demand)
- delay cost / actual demand = average delay cost for vehicles in actual demand = (user cost of delays) / (actual demand).
- validity of output = VALID if summary output shown was computed using the input shown and NOT VALID if one or more input values have been changed since the current summary output was computed.

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<sup>3</sup> demand decreases = cancelled and diverted vehicles

actual demand = design demand – demand decreases = vehicles that travel through the work zone (or detour).

<sup>4</sup> Backup occurs when actual demand exceeds capacity, and vehicles must wait to enter the work zone. Backup delay (min) is the length of time between a vehicle’s arrival at the backed-up queue and its reaching the front of the queue and entering the work zone.

Summary View

Copy This Sheet		period length (min)	60	PROJECT INFORMATION				REPORT INFORMATION			
Update		annual traffic growth (%)	3.00%	PROJECT TITLE US X0 Overlay				REPORT TITLE DETAILED USER COST REPORT			
		years of growth	2	PASTE VALUES C.S. 1234 JOB # 5678 START DATE 1-Jun-99				DIVISION District 4 REPORT BY R. I. Carr REPORT DATE 3-Apr-98			
VEHICLE INPUT				NOTES:							
		cars	trucks								
		design demand (%)	85.0%								
		user cost per hour (\$/V hr)	\$10.79								
		user cost per mile, (\$/V mi)	\$0.30								
		user cost per cancellation, (\$/V)	\$0.80								
METHOD INPUT				METHOD 1		METHOD 2		METHOD 3		METHOD 4	
method title				10 hr: 7A-5P		8 hr: 9A-5P		10 hr Night:8P-6A		2 crews, 7A-5P	
DISTANCE AND SPEED (mi) (mph)				distance	speed	distance	speed	distance	speed	distance	speed
work zone				1.0	see delay	1.0	see delay	1.0	see delay	2.0	see delay
normal travel				1.0	75.0	1.0	75.0	1.0	75.0	2.0	75.0
diversion				11.2	57.9	11.2	57.9	11.2	57.9	11.2	57.9
normal travel				9.6	75.0	9.6	75.0	9.6	75.0	9.6	75.0
SPEED DELAY				threshold	range	threshold	range	threshold	range	threshold	range
capacity for speed delay (V/period)				1400	1200	1400	1200	1400	1200	1400	1200
speed (when D=0) (mph)				50	35	50	35	50	35	50	30
speed (when D=C) (mph)				40	25	40	25	40	25	40	20
DECREASE TO DEMAND				threshold	range	threshold	range	threshold	range	threshold	range
capacity for decreases to design demand (V/period)				1400	1200	1400	1200	1400	1200	1400	1200
canceled cars (with no delay) (%)					5.0%		5.0%		5.0%		5.0%
canceled trucks (with no delay) (%)											
canceled cars (with delay) (%/min)				1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
canceled trucks (with delay) (%/min)				0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
diverted cars (with no delay) (%)				5.0%	10.0%	5.0%	10.0%	5.0%	10.0%	5.0%	10.0%
diverted trucks (with no delay) (%)					4.0%		4.0%		4.0%		4.0%
diverted cars (with delay) (%/min)				2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
diverted trucks (with delay) (%/min)				1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%
OTHER USER COST INPUT				cars	trucks	cars	trucks	cars	trucks	cars	trucks
other user cost per actual demand (\$/V)				\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
user cost per diversion (\$/V)				\$1.18	\$2.28	\$1.18	\$2.28	\$1.18	\$2.28	\$1.18	\$2.28
Paste Values				Compute	Compute	Compute	Compute	Compute	Compute	Compute	Compute
Summary	Go To: Summary	Overall	Traffic	User Cost	Combined	Print: This View	Summary	Overall	All	Setup	
PERIOD INPUT				backup at start (V)		0		0		0	
direction: West East				West East		West East		West East		West East	
period				capacity		capacity		capacity		capacity	
(hr) (V/period) (V/period) (V/period) (V/period)				(V/period) (V/period)		(V/period) (V/period)		(V/period) (V/period)		(V/period) (V/period)	
12 A				3500 3500		3500 3500		1200 1200		3500 3500	
1 A				3500 3500		3500 3500		1200 1200		3500 3500	
2 A				3500 3500		3500 3500		1200 1200		3500 3500	
3 A				3500 3500		3500 3500		1200 1200		3500 3500	
4 A				3500 3500		3500 3500		1200 1200		3500 3500	
5 A				3500 3500		3500 3500		1400 1400		3500 3500	
6 A				3500 3500		3500 3500		3500 3500		3500 3500	
7 A				1400 1400		3500 3500		3500 3500		1400 1400	
8 A				1200 1200		3500 3500		3500 3500		1200 1200	
9 A				1200 1200		1400 1400		3500 3500		1200 1200	
10 A				1200 1200		1200 1200		3500 3500		1200 1200	
11 A				1200 1200		1200 1200		3500 3500		1200 1200	
12 P				1200 1200		1200 1200		3500 3500		1200 1200	
1 P				1200 1200		1200 1200		3500 3500		1200 1200	
2 P				1200 1200		1200 1200		3500 3500		1200 1200	
3 P				1200 1200		1200 1200		3500 3500		1200 1200	
4 P				1400 1400		1400 1400		3500 3500		1400 1400	
5 P				3500 3500		3500 3500		3500 3500		3500 3500	
6 P				3500 3500		3500 3500		3500 3500		3500 3500	
7 P				3500 3500		3500 3500		3500 3500		3500 3500	
8 P				3500 3500		3500 3500		1400 1400		3500 3500	
9 P				3500 3500		3500 3500		1200 1200		3500 3500	
10 P				3500 3500		3500 3500		1200 1200		3500 3500	
11 P				3500 3500		3500 3500		1200 1200		3500 3500	
Total				32228 32191 34191 34151		61400 61400		66000 66000		61400 61400	
SUMMARY OUTPUT				10 hr: 7A-5P		8 hr: 9A-5P		10 hr Night:8P-6A		2 crews, 7A-5P	
direction				West East		West East		West East		West East	
total user cost				\$23,940 \$23,549		\$12,084 \$14,502		\$2,218 \$2,802		\$25,222 \$24,256	
user cost of delays				\$16,248 \$16,904		\$8,556 \$10,691		\$1,329 \$1,788		\$17,209 \$17,403	
user cost of decreases				\$7,692 \$6,645		\$3,528 \$3,812		\$890 \$1,014		\$8,013 \$6,854	
maximum backup (V)				399 321		217 247		85 135		368 294	
maximum backup length (lane mi)				2.3 1.8		1.2 1.4		0.5 0.8		2.1 1.7	
maximum delay (min.)				21.5 17.7		11.1 10.0		5.9 8.4		22.8 19.1	
total delay, except diversions (V hr)				1506 1567		793 991		123 166		1595 1613	
average delay, except diversions (min)				3.3 3.3		1.5 1.9		0.2 0.3		3.5 3.4	
total vehicles canceled(V)				2167 1865		966 1049		219 255		2261 1926	
total vehicles diverted (V)				4618 4002		2155 2322		570 643		4805 4124	
total decrease in demand (V)				6786 5867		3121 3371		789 898		7066 6050	
% decrease in demand				19.8% 17.2%		9.1% 9.9%		2.3% 2.6%		20.7% 17.7%	
delay per diverted vehicle (min)				3.9 3.9		3.9 3.9		3.9 3.9		3.9 3.9	
total diversion delay (V hr)				301 261		140 151		37 42		313 269	
total delay, including diversions (V hr)				1,807 1,827		933 1,142		160 208		1,908 1,881	
average delay, including diversions (min)				3.4 3.4		1.7 2.1		0.3 0.4		3.6 3.5	
user cost / design demand				\$0.70 \$0.69		\$0.35 \$0.42		\$0.06 \$0.08		\$0.74 \$0.71	
delay cost / actual demand				\$0.59 \$0.60		\$0.28 \$0.35		\$0.04 \$0.05		\$0.63 \$0.62	
Auto: ON Print: ON Now: OK validity of output				VALID VALID		VALID VALID		VALID VALID		VALID VALID	

Fig. 5 Summary View of Traffic Sheet

## 7.3 OVERALL VIEW

### 7.3.1 General

The Overall View is second only to the Summary View in importance, because it alone shows the traffic impact and user cost results for each period for one method and direction. In addition, it shows the input data on which the results are based and summary output. Therefore, the Overall View provides a complete report of input values and the detailed and summarized output for the most recent computer run.

### 7.3.2 CO<sup>3</sup> Computer Runs

The sequence of each CO<sup>3</sup> computer run is the following:

1. We left-click the mouse on the **Compute** button for a method and direction column on of Summary View.
2. The CO<sup>3</sup> Program (using Visual Basic code) does the following
  - a. copies appropriate input values for that method and direction from the Summary View to the Overall View
  - b. reads the input into the CO<sup>3</sup> Program; computes values of delays, backups, and traffic decreases for each period; and outputs values into the Overall View.
3. The spreadsheet then calculates the following:
  - a. values of user cost for each period, based on period output from the CO<sup>3</sup> Program
  - b. summary output values, which are reported on the Overall View and Summary View
  - c. validity check for input and summary output for all methods and directions, if “Auto” button is ON.

### 7.3.3 Period Output

Variables that have not been explained earlier or that are not self evident are described below:

- backup eop (V) = end of period backup = number of vehicles that is backed up at the end of the period and start of the next period = actual demand that has arrived in this period and previous periods that is waiting to enter the work zone (or detour) at the end of this period.
- backup length eop (lane mile) = end of period backup length = (backup eop) \* (vehicle length in backup, default = 30 ft).
- maximum delay (min) = maximum delay of any vehicle in actual demand that arrived at the work zone during the period, which includes backup delay and speed delay.
- total period delay (V hr) = speed delay and backup delay for vehicles in actual demand = (total period backup delay) + (total period speed delay).
- average backup delay (min) = average backup delay of all vehicles in actual demand.
- average speed delay (min) = average speed delay of all vehicles in actual demand.
- average delay (min) = (average backup delay) + (average speed delay).
- user cost / design demand (\$/V) = average user cost for all vehicles that would normally arrive during the period = (period user cost) / (period design demand).
- delay cost / actual demand (\$/V) = average delay cost for vehicles in actual demand = (delay cost) / (actual demand).
- decrease cost cars (\$) = total user cost due to canceled cars and diverted cars.
- delay cost cars (\$) = total user cost due to backup delay and speed delay of cars.
- decrease cost (\$) = total user cost due to canceled cars, canceled trucks, diverted cars, and diverted trucks = (decrease cost cars) + (decrease cost trucks).

- delay cost (\$) = total user cost due to backup delay and speed delay = (delay cost cars) + (delay cost trucks).
- user cost (\$) = total user cost due to construction = (decrease cost) + (delay cost).

**Overall View**

period length (min) annual traffic growth (%) years of growth			60 3.00% 2			PROJECT INFORMATION			REPORT INFORMATION					
PROJECT TITLE			US X6 Overlay Example			REPORT TITLE			DETAILED USER COST REPORT					
VEHICLE INPUT			cars trucks			Control Section			DIVISION					
design demand (%)			85.0% 15.0%			JOB #			REPORT BY					
user cost per hour (\$/V hr)			\$10.79 \$10.79			START DATE			REPORT DATE					
user cost per mile, (\$/V mi)			\$0.30 \$1.00			1-Jun-99			District 4 R. I. Carr 4/3/98					
user cost per cancellation, (\$/V)			\$0.80 \$2.00			NOTES:								
METHOD INPUT					METHOD 1			SUMMARY OUTPUT						
method title					10 hr: 7A-5P			traffic method						
DISTANCE AND SPEED (mi) (mph)					distance speed			direction West						
work zone					method travel			total user cost						
normal travel					1.0 75			\$23,940						
diversion					method travel			user cost of delays						
normal travel					11.2 58			\$16,248						
threshold range					9.6 75			user cost of decreases						
SPEED DELAY					threshold range			maximum backup (V)						
capacity for speed delay (V/period)					1400 1,200			399						
speed (when D=0) (mph)					50 35			maximum backup length (lane mi)						
speed (when D=C) (mph)					40 25			2.3						
DECREASE TO DEMAND					threshold range			maximum delay (min.)						
capacity for decreases to design demand (V/period)					1400 1200			21.5						
canceled cars (with no delay) (%)								total delay, except diversions (V hr)						
canceled trucks (with no delay) (%)								1,506						
canceled cars (with delay) (%/min)					1.0% 1.0%			average delay, except diversions (min)						
canceled trucks (with delay) (%/min)					0.5% 0.5%			3.3						
diverted cars (with no delay) (%)					5.0% 10.0%			total vehicles canceled(V)						
diverted trucks (with no delay) (%)								2,167						
diverted cars (with delay) (%/min)					2.0% 2.0%			total vehicles diverted (V)						
diverted trucks (with delay) (%/min)					1.0% 1.0%			6,418						
								total decrease in demand (V)						
								6,786						
								% decrease in demand						
								19.8%						
								delay per diverted vehicle (min)						
								3.9						
								total diversion delay (V hr)						
								301						
								total delay, including diversions (V hr)						
								1,807						
								average delay, including diversions (min)						
								3.4						
								user cost / design demand						
								\$0.70						
								delay cost / actual demand						
								\$0.59						
OTHER USER COST INPUT					cars trucks									
other user cost per vehicle (\$/V)					\$0.00 \$0.00									
user cost per diversion (\$/V)					\$1.18 \$2.28									
direction:	West	backup at start (V):			0	backup	total	average	average	average		user cost	delay cost	
period	capacity	hist. demand	design demand	actual demand	backup eop (V)	length eop (lane-mile)	period delay (V hr)	backup delay (min)	speed delay (min)	delay (min)		/ design demand (\$/V)	/ actual demand (\$/V)	
(hr)	(V/period)	(V/period)	(V/period)	(V/period)										
12 A	3500	365	388	388	0	0.00	0.00	0	0.00	0.00		\$0.00	\$0.00	
1 A	3500	267	283	283	0	0.00	0.00	0	0.00	0.00		\$0.00	\$0.00	
2 A	3500	169	179	179	0	0.00	0.00	0	0.00	0.00		\$0.00	\$0.00	
3 A	3500	133	141	141	0	0.00	0.00	0	0.00	0.00		\$0.00	\$0.00	
4 A	3500	279	296	296	0	0.00	0.00	0	0.00	0.00		\$0.00	\$0.00	
5 A	3500	909	965	965	0	0.00	0.00	0	0.00	0.00		\$0.00	\$0.00	
6 A	3500	1754	1861	1,861	0	0.00	0.00	0	0.00	0.00		\$0.00	\$0.00	
7 A	1400	2468	2619	1,799	399	2.26	21.53	292	8.86	0.90	9.76	\$1.56	\$1.75	
8 A	1200	3248	3446	1,120	318	1.81	21.53	364	17.92	1.60	19.52	\$1.91	\$3.51	
9 A	1200	1825	1936	1,002	121	0.69	17.51	210	10.97	1.60	12.57	\$1.72	\$2.26	
10 A	1200	1380	1464	1,080	1	0.00	7.63	83	3.03	1.60	4.63	\$0.91	\$0.83	
11 A	1200	1490	1581	1,247	47	0.27	3.97	58	1.20	1.60	2.80	\$0.63	\$0.50	
12 P	1200	1711	1815	1,276	124	0.70	7.79	125	4.28	1.60	5.88	\$1.08	\$1.06	
1 P	1200	1524	1617	1,130	54	0.31	7.79	114	4.44	1.60	6.04	\$1.10	\$1.09	
2 P	1200	1361	1443	1,139	0	0.00	4.29	53	1.19	1.59	2.78	\$0.63	\$0.50	
3 P	1200	1419	1505	1,218	18	0.10	2.54	42	0.47	1.59	2.06	\$0.51	\$0.37	
4 P	1400	1857	1970	1,598	217	1.23	8.84	140	4.66	0.61	5.27	\$0.99	\$0.95	
5 P	3500	2575	2732	2,732	0	0.00	3.71	24	0.52	0.00	0.52	\$0.09	\$0.09	
6 P	3500	2292	2432	2,432	0	0.00	0.00	0	0.00	0.00	0.00	\$0.00	\$0.00	
7 P	3500	1730	1836	1,836	0	0.00	0.00	0	0.00	0.00	0.00	\$0.00	\$0.00	
8 P	3500	1578	1674	1,674	0	0.00	0.00	0	0.00	0.00	0.00	\$0.00	\$0.00	
9 P	3500	825	876	876	0	0.00	0.00	0	0.00	0.00	0.00	\$0.00	\$0.00	
10 P	3500	603	640	640	0	0.00	0.00	0	0.00	0.00	0.00	\$0.00	\$0.00	
11 P	3500	466,088	494	494	0	0.00	0.00	0	0.00	0.00	0.00	\$0.00	\$0.00	
TOT	61,400	32,228	34,191	27,405				1,506			AVG	\$0.70	\$0.59	
MAX	3500	3248	3446	2732	399	2.26	21.53	364	17.92	1.60	19.52	\$1.91	\$3.51	
MIN	1200	133,168	141	141	0	0.00	0.00	0	0	0.00	0.00	\$0.00	\$0.00	
period	canceled cars	canceled trucks	diverted cars	diverted trucks	decrease to cars (V/period)	decrease to trucks (V/period)	total period decrease (V/period)	decrease cost cars (\$)	decrease cost trucks (\$)	delay cost cars (\$)	delay cost trucks (\$)	decrease cost (\$)	delay cost (\$)	user cost (\$)
(hr)	(V)	(V)	(V)	(V)	(V/period)	(V/period)	(V/period)	(V/period)	(V/period)	(V/period)	(V/period)	(V/period)	(V/period)	(V/period)
12 A	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
1 A	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
2 A	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
3 A	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
4 A	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
5 A	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
6 A	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
7 A	217	19	546	38	763	57	820	\$816	\$126	\$2,567	\$588	\$942	\$3,155	\$4,097
8 A	718	50	1,436	122	2,154	172	2,326	\$2,264	\$378	\$2,719	\$1,210	\$2,643	\$3,929	\$6,572
9 A	289	18	578	48	867	66	934	\$912	\$146	\$1,759	\$506	\$1,058	\$2,266	\$3,324
10 A	120	5	240	19	360	24	384	\$378	\$53	\$737	\$163	\$431	\$900	\$1,331
11 A	105	3	210	16	315	19	334	\$331	\$43	\$519	\$110	\$374	\$629	\$1,003
12 P	168	8	336	27	503	35	538	\$529	\$77	\$1,099	\$251	\$607	\$1,350	\$1,956
1 P	152	7	303	24	455	32	487	\$478	\$70	\$998	\$229	\$549	\$1,227	\$1,776
2 P	95	3	191	15	286	18	304	\$301	\$40	\$470	\$99	\$340	\$569	\$910
3 P	90	2	181	14	271	16	287	\$285	\$36	\$374	\$78	\$321	\$451	\$772
4 P	88	8	260	16	348	23	372	\$377	\$51	\$1,256	\$258	\$428	\$1,514	\$1,942
5 P	0	0	0	0	0	0	0	\$0	\$0	\$219	\$39	\$0	\$257	\$257
6 P	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
7 P	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
8 P	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
9 P	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
10 P	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
11 P	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
TOT	2,043	125	4,280	338	6,323	463	6,786	\$6,671	\$1,022	\$12,716	\$3,531	\$7,692	\$16,248	\$23,940
MAX	718	50	1,436	122	2,154	172	2,326	\$2,264	\$378	\$2,719	\$1,210	\$2,643	\$3,929	\$6,572
MIN	0	0	0	0	0	0	0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

**Fig. 6 Overall View of Traffic Sheet**

## **8 CONSTRUCTION COST SHEET**

### **8.1 GENERAL**

In the Construction Cost Sheet we estimate and document project cost for alternative ways of maintaining traffic and changes in construction they require. We can then enter construction project cost, along with user cost, in the Impact Sheet, to compare user cost and construction cost of each alternative, to help us select the best project alternative.

In the Construction Cost Sheet, we estimate the cost of each alternative based on the difference in its cost and the project cost of the Standard Case. The Standard Case is the typical method of construction, for which we generally estimate cost of construction, as a basis for making typical project decisions. Generally, this is the construction method we would use if we had no special concerns regarding user cost. Therefore, it usually provides us a well understood basis for estimating differences in construction cost for alternative methods.

Our estimates of portions of the total cost are generally quite rough, and we tend to round-off to the closest 10% or 5%. Labor is generally the most important, because (1) labor is a large portion of the cost and (2) it is generally the most sensitive cost. Equipment is generally the next most important, for its size and sensitivity. Material is a large cost, but it usually is not highly sensitive to changes in traffic maintenance alternatives.

We are particularly interested in determining the hours each day and number of days that traffic will be maintained under construction conditions, because this is the basis for determining user cost per day and total user cost. We call these “lane-closed hours per day” and “lane-closed days”, because the most common manner of maintaining traffic during construction and maintenance is to close the lane in which work is performed.

CO<sup>3</sup> uses a difference method as its basic approach to estimating construction cost for alternative construction methods. In this approach, we first estimate the contract cost and lane-closed days for the Standard Case, using conventional methods by which an engineer generally does its cost and duration estimating. We then estimate values of variables in the Standard Case cost that will be affected by changes in the alternatives. Then we input corresponding values for each alternative. The Construction Cost Sheet then calculates the estimated lane-closed days and project cost for each alternative. We can copy output values from the Construction Cost Sheet to the Impact Sheet, which provides us a combined summary of traffic impact, user cost, and construction cost for each method of maintaining traffic.

Inputs to the Construction Cost Sheet are shown in color on the monitor and in light gray here. The general steps are the following:

- Input values for the Standard Case.
- Input values for alternative methods of maintaining traffic.
- Calculate estimated construction costs for alternative methods.

General Input variables include the following:

- contract cost (\$) = contract cost for lane-closed work. Input is determined by conventional cost estimating procedures
- lane-closed days (day)= number of days a lane will be closed, estimated from past experience.
- lane-closed days per work day = ratio of number of lane-closed days to number of days in which work is performed. This accounts for any difference the days that traffic is maintained and the days work is performed. Default = 1.
- lane-closed hours per day (hr/day)= number of hours a lane is closed each day that lane(s) is closed.

- relative productivity = estimated ratio of productivity of a method to productivity using Standard Case. By definition, relative productivity using Standard Case = 1.

CONSTRUCTION COST SHEET		Project: US X0 Overlay			
CONSTRUCTION COST		Standard Case	Alternative 1	Alternative 2	Alternative 3
General Input	method	10 hr day shift	8 hr day shift	10 hr night shift	10 hr day, 2 crews
contract cost (\$)		\$600,000	NA	NA	NA
lane-closed days (day)		16	NA	NA	NA
lane-closed days per work day		1.00	1.00	1.00	1.00
lane-closed hours per day (hr/day)		10	8	10	24
relative productivity		1	1	0.95	0.95
<b>Labor Cost</b>					
labor cost %		30%	NA	NA	NA
fixed mobilization (standard crew hr)		0.00	0.00	0.00	0.00
shifts per day		1.00	1.00	1.00	1.00
crews per shift		1.00	1.00	1.00	2.00
workers per crew (relative)		1.00	1.00	1.00	1.00
productive hours per shift (hr)		8.00	6.00	8.00	8.00
paid hours per shift (hr)		10.00	8.00	10.00	10.00
% premium time		0%	0%	0%	0%
premium cost (\$PT/\$ST)		1.40	1.40	1.40	1.40
workers (relative)		1.0	1.0	1.0	2.0
work days (day)		16.0	21.3	16.8	8.4
lane-closed days (day)		16.0	21.3	16.8	8.4
productive hours, total (hr)		128.0	128.0	134.7	67.4
worker production hours, total (relative)		128.0	128.0	134.7	134.7
paid hours, total (relative)		160.0	170.7	168.4	168.4
cost per paid hour (relative)		1.00	1.00	1.00	1.00
labor cost index		1.00	1.07	1.05	1.05
labor cost (\$)		\$180,000	\$192,000	\$189,474	\$189,474
labor cost difference (\$)		na	\$12,000	\$9,474	\$9,474
<b>Equipment Cost- Relative Based</b>					
equipment cost %		20%	NA	NA	NA
relative number of items		1.0	1.0	1.0	2.0
equipment fixed cost/item, relative					
equipment fixed cost, relative (\$)		\$0	\$0	\$0	\$0
equipment cost/day/item, relative					
equipment cost (\$ (day based)*		\$0	\$0	\$0	\$0
equipment cost/hr/item, relative		1.0	1.0	1.0	1.0
equipment cost (\$ (hr based)*		\$120,000	\$120,000	\$126,316	\$126,316
equipment cost, relative (\$)		\$120,000	\$120,000	\$126,316	\$126,316
equipment cost difference, relative (\$)		na	\$0	\$6,316	\$6,316
<b>Equipment Cost - Total Based</b>					
relative number of items				1.0	
equipment fixed cost/item, total					
equipment fixed cost, total (\$)		\$0	\$0	\$0	\$0
equipment cost/day/item, total				\$1,000	
equipment cost, total (\$ (day based)*		\$0	\$0	\$16,842	\$0
equipment cost/hr/item, total					
equipment cost, total (\$ (hr based)*		\$0	\$0	\$0	\$0
equipment cost, total (\$)		\$0	\$0	\$16,842	\$0
equipment cost difference, total (\$)		na	\$0	\$16,842	\$0
<b>Material Cost</b>					
material cost (\$)				\$5,000	
material cost difference (\$)		na	\$0	\$5,000	\$0
<b>Traffic Maintenance Cost</b>					
traffic maintenance fixed cost (\$)					
traffic maintenance daily cost (\$/day)					
traffic maintenance hourly cost (\$/hr)					
traffic maintenance total cost (\$)		\$0	\$0	\$0	\$0
traffic maintenance cost difference (\$)		na	\$0	\$0	\$0
<b>Other Contract Cost</b>					
other % cost (%)				2.00%	
other fixed cost (\$)					
other daily cost (\$/day)					
other hourly cost (\$/hr)					
other total cost (\$)		\$0	\$0	\$12,753	\$0
other total cost difference (\$)		na	\$0	\$12,753	\$0
<b>Agency Cost</b>					
agency % cost (%)					
agency fixed cost (\$)					
agency daily cost (\$/day)					
agency hourly cost (\$/hr)					
agency total cost (\$)		\$0	\$0	\$0	\$0
agency cost difference (\$)		na	\$0	\$0	\$0
<b>Total Construction Cost</b>					
contract cost (\$)		\$600,000	\$612,000	\$650,384	\$615,789
contract cost difference (\$)		na	\$12,000	\$50,384	\$15,789
project cost (\$)		\$600,000	\$612,000	\$650,384	\$615,789
project cost difference (\$)		na	\$12,000	\$50,384	\$15,789
<b>Summary</b>					
lane-closed hours per day (hr/day)		10	8	10	24
lane-closed days (day)		16.0	21.3	16.8	8.4
labor cost (\$)		\$180,000	\$192,000	\$189,474	\$189,474
project cost (\$)		\$600,000	\$612,000	\$650,384	\$615,789

Fig. 7 Construction Cost Sheet

## 8.2 LABOR COST

Labor cost is generally the most sensitive to differences in construction methods, because the ways in which we most often change construction methods is to work a different number of hours per day or week, to work a different set of hours, to change the work tasks, or to change the number of workers or crews. All of these can significantly impact construction cost. Therefore, the most important elements in the Construction Cost Sheet relate to differences in labor cost.

Variables we estimate include the following:

- labor cost % = estimated fraction of contract cost that is labor cost related to work performed with lane(s) closed, including fixed mobilization.
- fixed mobilization (standard crew hr)= fixed number of standard crew hours or work required while lane is not closed, that are to be included in labor cost. Default = 0.
- workers per crew (relative)= relative number of workers per work crew. Default = 1.
- productive hours per shift = number of hours in which actual productive work performed during each shift. Generally, productive hours per shift = (lane-closed hours per day) – (daily mobilization and demobilization time while lane is closed).
- paid hours per shift = number of hours for which workers are paid each shift.
- % premium time = percent of paid hours that is considered “overtime” for payroll purposes and for which “overtime” pay will be paid. Default = 0.
- premium cost (\$PT/\$ST) = ratio of premium time pay per hour (\$PT) to standard time pay per hour (\$ST).

CO<sup>3</sup> calculates the following from input for the Standard Case (standard) and alternative methods (alternative):

- workers (relative) = relative number of workers per day = (shifts per day) \* (crews per shift) \* (workers per crew).
- work days = number of days on which work is performed while lane is closed  

$$= (\text{standard work days}) * \left( \frac{\text{standard relative productivity}}{\text{alternative relative productivity}} \right) * \left( \frac{\text{standard workers}}{\text{alternative workers}} \right) * \left( \frac{\text{standard productive hours per shift}}{\text{alternative productive hours per shift}} \right)$$
- lane-closed days (day) = number of days with lane(s) closed = (lane-closed days per work day) \* (work days).
- productive hours, total (hr) = total number of hours in which actual productive work is performed = (shifts per day) \* (productive hours per shift) \* (work days)
- worker production hours, total (relative) = number of worker-hours of productive work that is performed = (work days) \* (workers) \* (productive hours per shift)
- paid hours, total (relative) = total number of hours for which workers are paid = (paid hours per shift) \* (workers) \* (work days) + (fixed mobilization)
- cost per paid hour (relative) = relative labor cost of each hour that is paid = (premium cost – 1) \* (% premium time) + 1
- labor cost index = labor cost relative to the labor cost of the Standard Case  

$$= \left( \frac{\text{alternative paid hours, total}}{\text{standard paid hours, total}} \right) * \left( \frac{\text{alternative cost per paid hour}}{\text{standard cost per paid hour}} \right)$$

- labor cost (\$) = labor cost for this construction method. Standard labor cost = (standard labor cost %) \* (standard contract cost). Alternative labor cost = (alternative labor cost index) \* (standard labor cost)
- labor cost difference (\$) = difference between labor cost of alternative method and labor cost of standard case = (alternative labor cost) – (standard labor cost)

### **8.3 EQUIPMENT COST**

Equipment cost can differ significantly for different methods of construction, including different working hours, and we estimate these differences in the two equipment cost sections of the Construction Cost Sheet. If we do not estimate equipment cost will significantly differ for the construction methods we are estimating, we simply leave each variable in its default condition. For most variables, default = blank = 0.

The best individual approach to modeling equipment cost for lane closure work will depend on the equipment used, which depends on the nature of the work. For this reason, two basic equipment costing methods are included:

- Relative based method, which is the default method. This approach to equipment cost estimating parallels the approach used for labor cost.
- Total based method, in which we identify specific items of equipment and their costs

### **8.4 TOTAL CONSTRUCTION COST AND SUMMARY**

This calculates and reports the overall results of the Construction Cost Sheet, which consists of the contract cost and project cost of each alternative and the magnitude of their differences from the Standard Case. Therefore, this is the “bottom line” of the impact of different methods of construction and traffic maintenance on construction cost.

- contract cost (\$) = estimated total contract cost. For each alternative, contract cost = (Standard Case contract cost) + (labor cost difference) + (equipment cost difference, relative) + (equipment cost difference, total) + (material cost difference) + (traffic maintenance cost difference) + (other contract cost difference).
- contract cost difference (\$) = difference between the contract cost of an alternative and the Standard Case contract cost = (alternative contract cost) – (Standard Case contract cost).
- project cost (\$) = total cost of construction, including agency cost = (contract cost) + (agency cost).
- project cost difference (\$) = difference between the project cost of an alternative and the Standard Case project cost = (alternative project cost) – (Standard Case project cost).

The Summary provides a short summary of the most important variables calculated on the Construction Cost Sheet, which have been described above. They are collected here so they can quickly be viewed together and they can be directly copied into the Impact Sheet.

## **9 IMPACT SHEET**

The Impact Sheet, also called the Impact Summary Sheet, reports daily user cost, total user cost, construction cost, and total project cost including user cost for different methods of maintaining traffic. Its purpose is to show in one place a summary of traffic, user cost, and construction cost so we can understand the overall impact of each method of maintaining traffic. For each method on the Traffic Sheet we input into the upper portion (not shown here) of the Impact Sheet (1) summary output for each direction from the Traffic Sheet Summary View and (2) summary output for the appropriate method from the Construction Sheet. This portion is not normally printed.



The lower portion is the part that is normally printed as a report, as shown in Fig. 8, and much of its output is not reported elsewhere. Its values are calculated from input into the upper portion.

SUMMARY OF IMPACTS		Project: US X0 Overlay			
DAILY USER COST	traffic method	10 hr: 7A-5P	8 hr: 9A-5P	10 hr Night:8P-6A	2 crews, 7A-5P
total user cost, daily (\$)		\$23,744	\$13,293	\$2,510	\$24,739
user cost of delays, daily (\$)		\$16,576	\$9,623	\$1,558	\$17,306
user cost of decreases, daily (\$)		\$7,169	\$3,670	\$952	\$7,433
total delay, except diversions, daily (V hr)		1,536	892	144	1,604
total vehicles canceled, daily (V)		2,016	1,007	237	2,093
total vehicles diverted, daily (V)		4,310	2,238	606	4,464
total decrease in demand, daily (V)		6,326	3,246	843	6,558
total diversion delay, daily (V hr)		281	146	39	291
total delay, including diversions, daily (V hr)		1,817	1,038	184	1,895
TOTAL USER COST					
total user cost (\$)		\$379,906	\$283,584	\$42,270	\$208,330
user cost of delays (\$)		\$265,209	\$205,299	\$26,244	\$145,735
user cost of decreases (\$)		\$114,697	\$78,285	\$16,026	\$62,595
maximum backup (V)		399	247	135	368
maximum backup length (lane mi)		2.3	1.4	0.8	2.1
maximum delay (min.)		21.5	11.1	8.4	22.8
total delay, except diversions (V hr)		24,579	19,027	2,432	13,506
average delay (min)		3.3	1.7	0.3	3.5
total vehicles canceled (V)		32,261	21,493	3,995	17,629
total vehicles diverted (V)		68,963	47,752	10,211	37,595
total decrease in demand (V)		101,223	69,245	14,206	55,224
% decrease in demand		18.5%	9.5%	2.5%	19.2%
average delay per diverted vehicle (min)		3.9	3.9	3.9	3.9
total diversion delay (V hr)		4,491	3,110	665	2,448
total delay, including diversions (V hr)		29,070	22,137	3,097	15,955
average delay, including diversions (min)		3.4	1.9	0.3	3.5
average user cost / design demand (\$/V)		\$0.69	\$0.39	\$0.07	\$0.72
average delay cost / actual demand (\$/V)		\$0.60	\$0.31	\$0.05	\$0.63
CONSTRUCTION COST		method	10 hr day shift	8 hr day shift	10 hr night shift
lane-closed hours per day (hr/day)			10	8	10
lane-closed days (day)			16.0	21.3	16.8
labor cost (\$)			\$180,000	\$192,000	\$189,474
project cost (\$)			\$600,000	\$612,000	\$650,384
TOTAL PROJECT COST			\$979,906	\$895,584	\$692,654
					\$824,119

**Fig. 8 Impact Sheet**

Each method's values for daily user cost are sums of values for the two directions. Values for total user cost are the daily user cost values multiplied by lane-closed days. Construction cost is the same reported in the summary at the bottom of the Construction Cost Sheet. The bottom line of the analysis is described by total project cost = (total user cost) + (project cost). For example, for 7A-5P, total project cost = (379,906) + (600,000) = \$979,906.

### 10 EXAMPLE PROJECT

We estimate the standard method a contractor would use to overlay US X0 is to work 10 hr days, from 7:00 am to 5:00 pm, four days a week, each taking 1 hr to close the work zone lane and 1 hr to re-open it, which leaves 8 hr of productive overlay work per day. We estimate construction will take 16 days and \$600,000 to overlay both directions. We also estimate lane-closed capacity = 1200 Vph and 1400 Vph when overlay work is being performed and when it is not. We call this Method 1.

Summary output shows total user cost is about \$24,000 per day (\$23,940 westbound, \$23,549 eastbound). Therefore, user cost is about  $(\$24,000 / \text{day}) * (16 \text{ day}) = \$384,000$ , which is almost two-thirds construction cost. Peak rush hours are 8A-9A and 5P-6P, and we note in the Overall View in Fig. 6 that westbound peak user cost for a 7A-5P workday is \$6,572 for 8A-9A. Therefore, we identify three alternative methods to analyze in the hope of finding a method that has lower user cost. These are:

Method 2 = Work 9A-5P = 8 hr, which fits between morning and rush hours but reduces overlay time to 6 hr per day. This reduces user cost to about \$13,000 / day. The Construction Sheet shows lane-closed days increases by 5.3 days to 21.3, and construction cost by

\$12,000. The Impact Sheet shows total user cost is reduced by about  $380,000 - 284,000 = \$96,000$ , so total project cost is reduced about  $96,000 - 12,000 = \$84,000$ . Each added construction dollar reduces user cost by  $96 / 12 = \$8.00$ .

Method 3 = Work 8P-6A at night = 10 hr. This reduces user cost to about \$2,500 / day, which is no longer significant. We estimate nightwork reduces relative productivity to 0.95, and it will require lighting equipment, it will increase cost of materials, and it will increase the 20% of contract cost that is not labor, equipment, or material by 10%. Therefore, user cost is reduced by about  $379,000 - 42,000 = \$337,000$  at a construction cost increase of about  $650,000 - 600,000 = \$50,000$ . Each added construction dollar reduces user cost by  $337 / 50 = \$6.74$ .

Method 4 = Work 7A-5P = 10 hr with 2 crews, each crew the same size as the Standard Case. Two crews working contiguous sections increase the work zone distance to 2 mi. We estimate on the Traffic Sheet that this will decrease traffic speed when demand is high, because there will be double the asphalt material deliveries over double the distance. On the Construction Sheet we estimate that doubling crews (including equipment) will decrease relative productivity to 0.95. Construction cost is increased about  $616,000 - 600,000 = \$16,000$ , but lane-closed days is reduced from 16 days to 8.4. The Impact Sheet shows that two crews increase daily user cost by about \$1,000, but reduction in construction time decreases user cost by about  $379,000 - 208,000 = \$171,000$ . Each added construction dollar reduces user cost by  $171 / 16 = \$10.69$ .

We now have sufficient information to compare methods. The Standard Method has major impact, which we would very much like to avoid. Three alternative methods significantly reduce user cost at a reasonable increase in construction cost. Contract provisions in the form of financial incentives and disincentives related to lane-closure hours can implement these methods. This paper does not provide sufficient space to treat this in any detail. However, hourly lane-closure incentives/costs to contractors that are a significant fraction of the user costs shown in the Overall View of Fig. 6 will lead bidding contractors toward implementation of the alternative construction methods discussed in this example.

If work is done at night, user cost is insignificant. However, impacts on adjacent landowners in particular must be considered in determining the practicality of night construction. The DOT can implement nightwork on this project by either (1) requiring night work in contract documents or (2) through lane-closure incentives/costs in contract provisions that make nightwork more competitive than daywork. Of course, if nightwork is expected, the DOT should increase its budgeted construction cost to about \$650,000.

If work is to be done during the day, starting work after 9A or increasing the number of crews per workday will each significantly reduce user cost. It is practical to implement these through hourly (or quarter-hour) lane-closure incentives/costs that make alternative methods such as these more competitive than the Standard Case. The DOT should increase its budgeted construction cost to about \$615,000 in conjunction with implementing lane-closure contract provisions. Each bidding contractor will select a construction method, including lane-closure hours, in a manner that is in line with DOT policy. The contractor with the lowest responsible bid will have planned its work in the manner that best balances DOT preferences for investment of public money. After contract execution, lane-closure contract provisions will continue to channel the contractor to an acceptable balance between its costs and public user cost throughout the construction process.

## **11 CONGESTION IMPACT GUIDELINES**

### **11.1 SUMMARY OF CONGESTION IMPACT COMPUTATIONS**

We can summarize the CO<sup>3</sup> approach to computing construction congestion cost.

- We use the Route Sheet to calculate equivalent values for input into the Summary View if we need to consider multiple alternate routes, or if the alternate route is complex,.
- We use the Input Sheet to estimate and record project variables that impact traffic impact and user cost, particularly for the method of traffic maintenance by which the work would typically be done, which we often call the Standard Method or Standard Case.
- We enter values in the Summary View of the Traffic Sheet for the Standard Method and compute traffic and user cost impact for each day of construction. Generally, we print the Overall View for each computer run. This allows us to study the impact in detail, to understand traffic impact for each hour of a day's construction. If the traffic and user cost impacts are acceptable, we can stop our study here. However, we might still go a little further, to see if some small adjustments might reduce impacts even further.
- We identify alternative methods of maintaining traffic during construction and for each we estimate and enter values in the Summary View and we compute and study their impacts.
- If we expect the different methods of maintaining traffic can impact construction contract cost, we use the Construction Cost Sheet.
- We copy traffic, user cost, and construction cost impacts from the Summary View(s) and Construction Cost Sheet(s) to the Impact Sheet to calculate overall daily traffic and user cost impact for each day of construction and total traffic, user cost, and construction cost for the complete project.
- We add what we learn from our CO<sup>3</sup> study of the project to other knowledge of project needs, and we select a traffic maintenance and construction method that has a good, acceptable, practical balance among construction needs and costs and traffic and user cost impact.

### **11.2 SENSITIVITY ANALYSIS**

Sensitivity analysis is calculation of differences in output due to differences in input. In formal sensitivity analysis, we input different values of input variables into our calculations to determine the impact that changes in input have on output and decisions. We can apply sensitivity analysis to any quantitative variables. Most typically, we change one variable or one set of related variables at a time to understand its impact. Even more important is our informal sensitivity analysis, in which we sit back and think through the relationships among variables, we identify possible inaccuracies, and we predict their impact on our decisions. This allows us to view CO<sup>3</sup> input and output and decisions from the perspective of the overall project, so we develop a realistic view of project behavior and make reasonable and practical project decisions.

### **11.3 CONCLUSIONS**

CO<sup>3</sup> is a tool with which we can improve our project decisions. It estimates the impact of different traffic maintenance and construction methods, and it can be applied at the first stages of project consideration when a project is still ill defined. CO<sup>3</sup> accuracy is a function of the accuracy of its input estimates, some of which may be quite rough, such as the effect of delays on traffic behavior. We should not be overly concerned with the absolute accuracy of CO<sup>3</sup>, because its purpose is not to provide precise estimates but to provide for good decisions. We expect its estimates of traffic behavior and user cost and construction cost are no better than  $\pm 10\%$ , which is sufficiently accurate for good engineering decisions. We use CO<sup>3</sup> to shape a project in a form that will

save miles of daily backups and hundreds of thousands (even millions) of dollars of user cost at an acceptable cost and will support reasonable and safe driver behavior. These broad decisions depend on a better understanding of project behavior, not on precise values of sensitive information.

## **APPENDIX 1 – References**

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