Construction Related User Delay Costs – The Case of the Crowchild Trail Bridge Rehabilitation in Calgary

Cory J. Wilson, B.Sc.

Department of Civil Engineering,
University of Calgary,
2500 University Dr. N.W.
Calgary T2N 1N4

Lynne Cowe Falls, M.A.Sc.
Department of Civil Engineering,
University of Calgary,
2500 University Dr. N.W.
Calgary T2N 1N4
403-220-5505
403-282-7026
lcowefal@ucalgary.ca
(Corresponding author)

Paper prepared for presentation at the
Pavements – Long-life Pavements
Of the 2003 Annual Conference of the
Transportation Association of Canada
St. John’s Newfoundland and Labrador

ABSTRACT
User delay costs are a well-known, major component of life cycle cost analysis. On major urban roadways where user delay can be substantial due to high volumes, user delay costs are often managed contractually through either night work or, in the case of bridge deck rehabilitation, the imposition of road/lane rent or bonus/penalties. This is particularly the case when bridge deck rehabilitation and/or complete reconstruction are required.

Using the Crowchild Trail North Bridge deck rehabilitation project, completed in 2002, this paper examines the user costs associated with delays created by the work zones in an attempt to quantify those costs. Actual travel time data was used to calculate the cost to the driving public on a crucial arterial route over the Bow River in Calgary. Because this bridge is in a dense urban environment, an attempt was made to understand the impact of consumer surplus on user costs as a result of re-routing of traffic during the construction.

INTRODUCTION

Calgary is a rapidly growing city and as a result the number of vehicles on our road networks is continually increasing. With these higher demands comes the need for more roads and more substantial rehabilitation and maintenance projects. At the present time, Calgary is struggling to keep up with the number of roadwork projects required to improve the traffic characteristics of the city. The large number of new construction projects reduces the funds that could otherwise be diverted into maintenance and rehabilitation. In other words, new projects are competing with rehabilitation projects for the capital allocated by the government for roadwork. Under the new transportation plan, Calgary can expect to see an increase in the number of construction projects being undertaken over the coming years.

With the increase in construction projects comes an increase in the number of work zones established to conduct the work. These work zones often reduce the capacity of a roadway or at a minimum, lower the traverse speed through the area [1]. If this is the case, then users can be expected to experience longer travel times and higher levels of frustration. Reasonable efforts must be made to reduce the negative impacts on users, while at the same time providing the most cost effective strategy.

The cost of a roadwork's construction project can be broken down into two parts. First, there are the direct costs associated with the construction. This includes costs such as the materials used and the use of machinery and labor. The second cost component of construction projects is the indirect cost incurred by the users of the roadway. If the work zone established reduces the capacity or speed of a section of roadway, then users will experience longer travel times. The indirect costs associated with a delay result from the additional time that the vehicle is in operation and the personal loss of time for the passengers. Since user costs are not a direct cost to those in charge of construction, but rather an indirect cost to society, they are often overlooked.

Many people and organizations have addressed the topic of construction related user costs. The Federal Highway Administration (FHWA) has developed a 12-step process by which to determine the potential user costs created by a work zone. The FHWA outlines how to get from base year data to the user costs created by a particular work zone established at a given time and over a given duration.

Using the Crowchild Trail North Bridge deck rehabilitation project completed in 2002, this report examines the user costs associated with delays created by work zones in an attempt to quantify these costs. First, some background on user costs, including the method that the FHWA uses to calculate user costs, will be presented and then a case study will be conducted to calculate the actual costs incurred during a major rehabilitation project. Due to a lack of data, the study has several limits:

1) Only user delay costs will be examined for the case study,
2) Loss in opportunity costs for the vehicles and their passengers are included and,
3) Vehicle operating costs and crash costs will not be considered.

LIFE CYCLE COST ANALYSIS (LCCA)

LCCA is a technique used to determine the overall cost of a project by considering both the present and future costs. It is important to consider all of the costs that may be incurred throughout the life of the project. By considering all the costs that will be incurred in the long run, a net present worth can be established. A net present worth is the cost in present dollars considering initial costs and future costs taking into account inflation.

In the context of this paper, it is important to consider the maintenance / rehabilitation costs of a roadway and the additional user costs created when these work zones are in operation. The frequency and duration of these work zones throughout the life of the roadway are important to consider when determining the present economic worth of a project.

It is also important to consider all possible competing alternatives for any construction project. A LCCA provides a means of comparing alternative concepts over the life span of a project. This ensures that the most cost effective option for the project is selected.

USER COSTS

Construction related user costs are calculated in an attempt to accurately account for the costs associated with roadway rehabilitation or maintenance delays. User costs are the increased Vehicle Operating Costs (VOC), delay, and number of crashes that are attributed to the construction [FHWA 1998]. The user costs associated with such construction delays are a function of many factors, which will determine how normal operating conditions will be affected by construction. These include: time of day that the work zone is operational, days of the week that the work zone is operational, duration of the work zone, frequency of the work zone, characteristics of the work zone (i.e. Length, posted speed, number of lanes, etc.), traffic volume of the roadway, capacity of the roadway and operating characteristics of the traffic.

User costs have three main components: Vehicle Operating Costs (VOC), delay and crash costs. VOCs are the increased vehicle operating costs (such as, gas, tire wear, etc.) that are a direct result of construction delays. VOC's can be broken down further into Speed Change VOC which is the additional VOC associated with decelerating from the user's initial speed down to the work zone speed and then accelerating back up to the approach speed, Stopping VOC, which is the additional VOC associated with coming to a complete stop and then accelerating back to the approach speed and, Idling VOC, which is the additional VOC associated with progressing through a queue, usually characterized by a stop and go motion until the entire queue has been traversed. [FHWA 1998] Delay is the personal loss of time experienced by the user of a roadway during reduced or constricted flow. A user's time is valuable and should therefore be considered as an indirect cost. There are three main types of delays that occur due to construction. Speed Change Delay, which is the additional time required to decelerate from an initial approach speed down to the work zone speed and then back up to the approach speed, Reduced Speed Delay, which is the additional time required to traverse the work zone at a lower posted speed. It depends on the difference between the approach speed and the work zone speed, as well as the total distance of the work zone. Stopping Delay, which is the additional time required to come to a complete stop and then accelerate back up to the approach speed. Queue

Delay, which is the additional time required to progress through a queue. [FHWA 1998] Crash Costs are incurred when, as a result of alteration of the roadway characteristics in the work zone, crashes occur. If a work zone is linked to an increased rate of accidents, then the costs associated with those accidents are a component of user costs.

WORK ZONES

A work zone is defined in the Highway Capacity Manual [TRB 1994] as "an area of a highway where maintenance and construction operations impinge on the number of lanes available to traffic or affect the operational characteristics of the traffic flowing through the area."

Traffic flow through a work zone can fall under two different classifications:

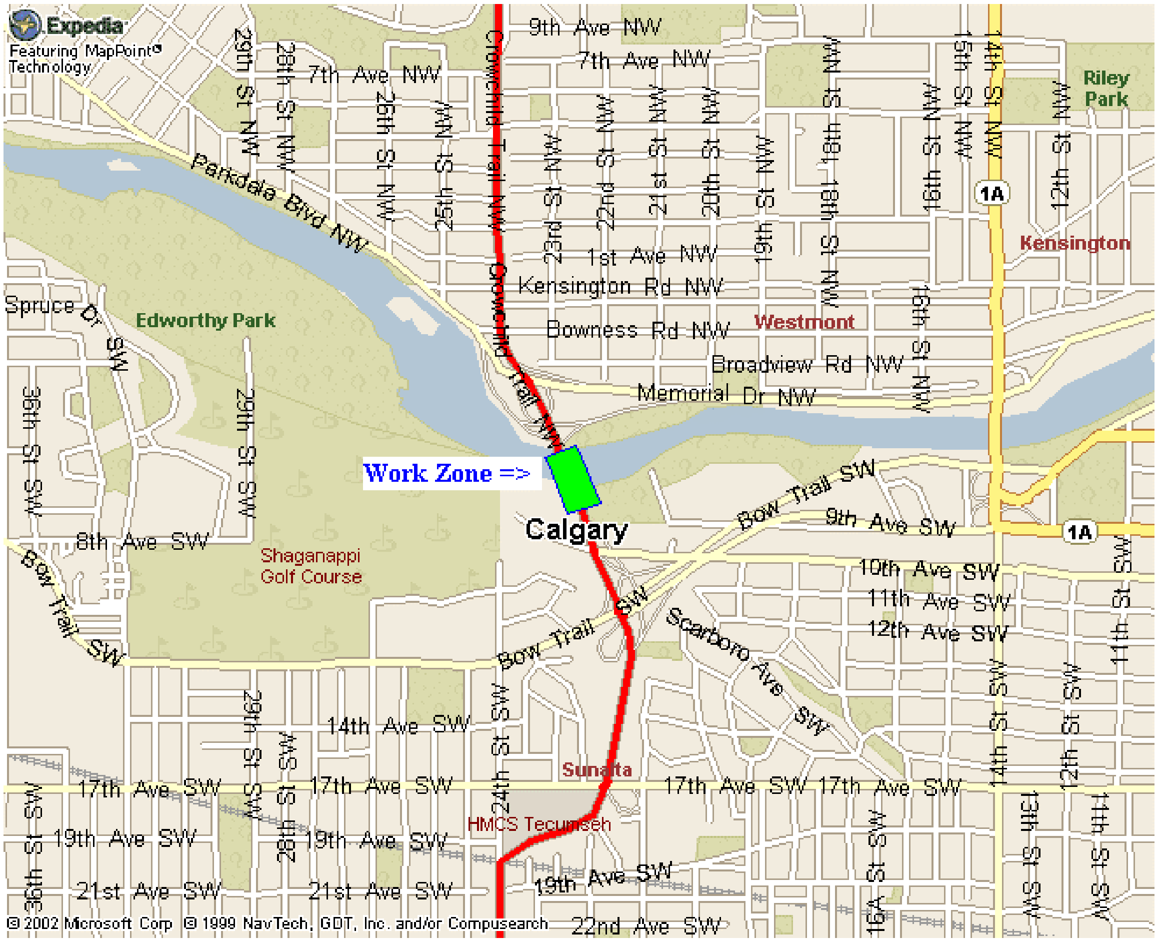
- **Free flow –** In a free flow situation, the traffic traveling through a work zone will only experience a reduction in speed. The reduction in speed may be a result of a lower posted speed limit or due to a reduced capacity. Although movement through the work zone will be slower, no queuing will form as a result.
- **Forced flow –** If the capacity of the work zone is reduced to a level below the traffic volume, then forced flow conditions will occur. In this situation, a queue will develop at the entrance of the work zone. This queue will continue to grow until the capacity exceeds the demand, or in other words, the traffic leaves faster than it arrives. The stop and go driving experienced during forced flow can greatly increase the vehicle operating costs for a user.

CONSUMER SURPLUS

Consumer surplus is found when a consumer values an item more than it is worth. The difference between the individual's perception of the value and its actual value is known as consumer surplus. Consumer surplus is an important issue in roadworks because it is important to consider how many people have detoured a work zone in an attempt to improve their commute. It would be inaccurate to assume that all users maintained the same route regardless of the construction. Many users will seek out alternate routes that they feel are more practical.

CROWCHILD TRAIL BRIDGE REHABILITATION

Crowchild Trail is a north-south arterial link located on the west side Calgary, Alberta. As part of the Trans-Canada Highway (it turns into Hwy 1A approximately 3km from the Bow River), this major arterial is a major access point for students traveling to the University of Calgary from the south side of the city. During the summer of 2002, the northbound deck of Crowchild Trail Bridge over the Bow River in Calgary underwent substantial rehabilitation which provided an opportunity to measure the actual user delay encountered during construction and calculate the construction related user delay costs.



Source: **[www.Expedia.ca]**

Figure 1 Map of Crowchild Trail

The rehabilitation of the bridge was conducted in three stages as illustrated in Figure 2. [Calgary 2002]:

Stage 1 – The ramp from westbound Bow Trail to northbound Crowchild Trail and the ramp from westbound 10th Avenue to northbound Crowchild Trail were closed to traffic (Appendix A, Figure A1).

Stage 2 – Northbound Crowchild traffic was reduced to one lane (Appendix A, Figure A2). Figure 3.1 illustrates the work zone during Stage 2 of the construction.

Stage 3 - The 10th Avenue and Bow Trail ramps are reopened to traffic. The ramp from northbound Crowchild Trail to eastbound Memorial Drive was closed (Appendix A, Figure A3).

Although the three stages exhibit very different geometric designs, they all had 10 ft. lane widths and a posted speed limit of 50 km/hr throughout the rehabilitation.

DATA COLLECTION

Travel Time

In order to calculate the user delays attributed to the work zone, it was necessary to collect data on the traffic conditions during the construction. These values will then be compared to the normal conditions in the analysis section to determine the additional user costs.

Travel time required to traverse the work zone between two major arterials was recorded. Overpasses conveniently mark the start and end points of the work zone and to reduce data noise, a few variables were kept constant throughout the data collection. These variables were maintained so that the data analyzed will only reflect delays caused by the construction and not other factors.

- Driver – The same driver was used throughout construction. Every driver behaves differently when they are behind the wheel of a vehicle and by maintaining the same driver, there are no variations in traverse time due to driving habits.

- Vehicle – The same vehicle, a 1992 Oldsmobile Cutlass, was also used for all of the data collection during construction. This reduced any variations in traverse time that would occur using different vehicles with different performance characteristics.

- Behaviour – The driver collecting the data followed the same pattern of lane movements over the course of the data collection. Specifically, the driver was in the inside lane throughout the work zone, with no lane changes while in the work zone. As a result, the distance traveled was constant. In a forced flow situation, the time required to traverse a section of road in one lane might be different than the time required in an adjacent lane.

The travel times are presented in Table 1, below.

Table 1 Travel Times

Date	Time Of Day	Travel Time (min:sec)	Date	Time Of Day	Travel Time (min:sec)
DURING CONSTRUCTION			POST CONSTRUCTION		
27-May-02	08:14	4:10	04-Nov-02	08:38	1:21
28-May-02	08:25	7:33	05-Nov-02	10:29	1:16
29-May-02	08:19	8:36	06-Nov-02	08:42	1:17
30-May-02	09:22	2:52	07-Nov-02	10:16	1:16
31-May-02	09:00	3:11	08-Nov-02	08:40	1:17
01-Jun-02	10:52	1:41	13-Nov-02	08:34	1:18
03-Jun-02	08:42	3:09	14-Nov-02	10:25	1:19
03-Jun-02	17:45	8:10	15-Nov-02	09:27	1:19
04-Jun-02	08:18	3:12	18-Nov-02	08:35	1:22
04-Jun-02	16:12	4:10	19-Nov-02	10:27	1:17
17-Jun-02	08:15	8:20	20-Nov-02	08:42	1:19
18-Jun-02	10:55	3:10	21-Nov-02	10:33	1:17
18-Jun-02	19:30	2:50	22-Nov-02	08:37	1:23
19-Jun-02	08:25	3:15			
19-Jun-02	15:45	3:20			
20-Jun-02	08:18	3:00			
20-Jun-02	18:26	1:20			
27-Jun-02	17:48	3:00			
28-Jun-02		1:16			
02-Jul-02	08:27	1:21			
03-Jul-02	10:11	2:30			
04-Jul-02	08:05	3:00			
05-Jul-02	08:00	5:48			
Mean		**3:52**			**1:19**
Standard Deviation		**2:15**			**0:02**

To test for statistical analysis of the difference between the mean travel time during and post construction a student's t test was done. It found that there is a statistically significant difference between the two results at the 99% confidence level). The mean travel time for the construction period (May 27 – July 5) is 3min and 52 secs, while during the non-construction period (Nov.2 – Nov 22), the travel time is 1 min and 19 secs.

Traffic Volumes

Volumes of northbound traffic on Crowchild Trail are continuously monitored by the City of Calgary using a permanent traffic counter. The volumes recorded from January –November, 2002 were extracted and the data was subdivided into three classes to account for fluctuating traffic during the year. As Crowchild Trail is a major access route from the south of the city to the University of Calgary, the traffic volumes are reduced during the period from May until September, when classes are not in session. As such, the traffic volumes were grouped into three classes: pre-construction – summer volumes, construction and post-construction- winter volumes. The results are summarized in Table 2 and presented in Figure 2.

TABLE 2: Average Northbound Volumes

Construction Characteristics	Dates (2002)	Average Weekday Traffic Volume
Pre Construction	January 1 - April 1	47457
Post Construction	October 1 - October 31	47748
Stage 1	April 15 - July 15	31103
Stage 2	May 21 - June 22	24741
Stage 3	June 22 - July 26	34070
University Break	January 1 - January 6	37342
University Break	February 16 - February 24	42682
University Break	August 26 - September 9	42632

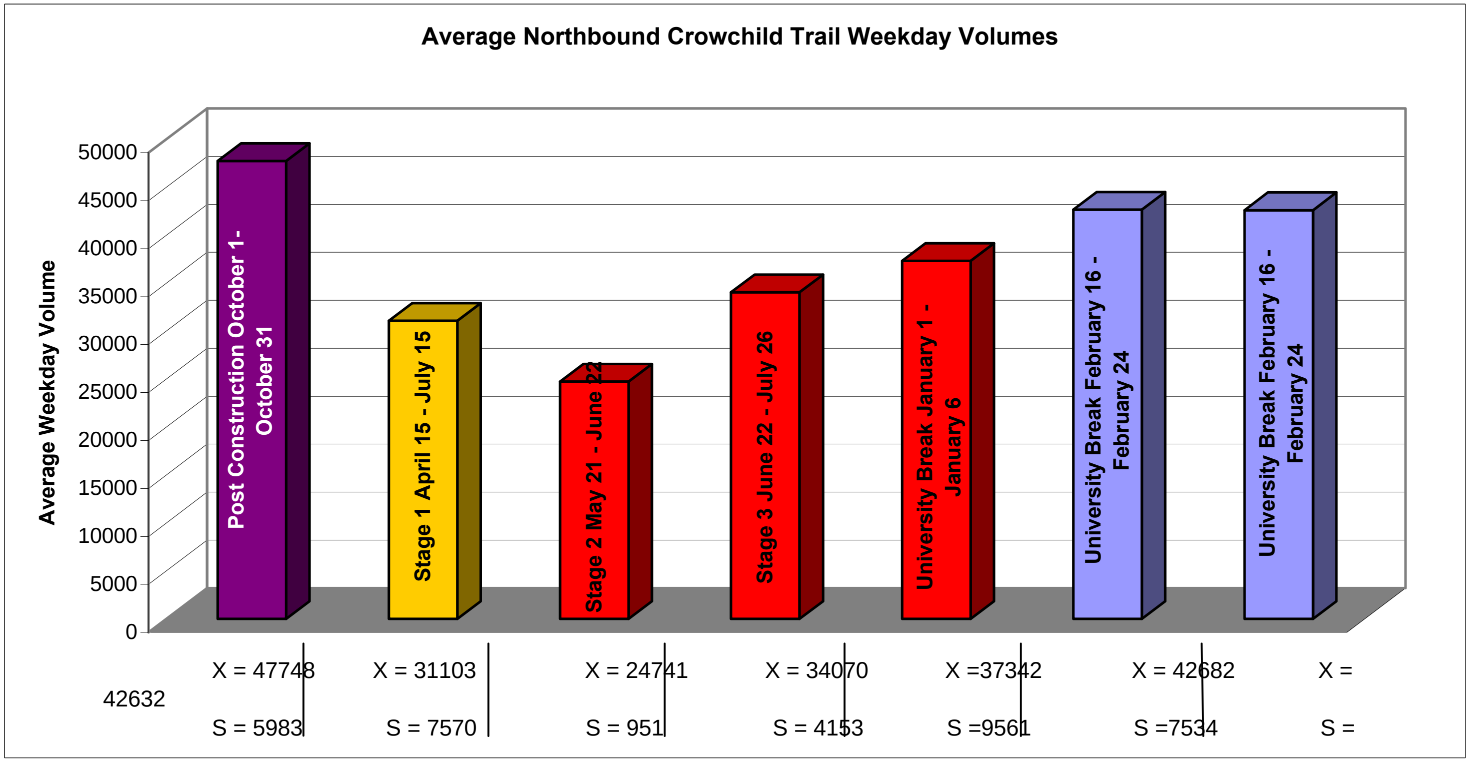


Figure 2 Average Northbound Weekday Volumes

ANALYSIS

Delay

The average delay created by the work zone can be determined by comparing the average travel time during the construction with the average travel time after the rehabilitation has been completed.

Average Delay = Travel time during construction –Travel time after construction

Average Delay = 3min 52 sec – 1min 19 sec

Average Delay = 2min 33 sec (153 seconds)

Stopping and Queue Delay

The data collected does not give an indication of the stopping delay or queue delay as a fraction of the total delay. However, comparing the posted work zone speed of 50km/hr to the average work zone speed can approximate stopping and queue delays. The average speed through the work zone can be calculated by using the following calculations.

$$\text{WZ Delay} = \frac{\text{WZ Length}}{\text{WZ Speed}} - \frac{\text{WZ Length}}{\text{Upstream Speed}}$$

$$\text{WZ Speed} = \frac{\text{WZ Length}}{\text{WZ Delay} + (\text{WZ Length} / \text{Upstream Speed})}$$

$$\text{WZ Speed} = \frac{1.4 \text{ km}}{0.0425 \text{ hr} + (1.4 \text{ km} / 70 \text{ km/hr})}$$

$$\text{WZ Speed} = 22.4 \text{ km/hr}$$

If the work zone was operating under free flow conditions, then the time required to traverse the section would be as follows:

Free flow traverse time = 1.4km / 50 km/hr = 0.028 hr = 100.8 seconds

However, since the average speed experienced through the site was found to be 22.4 km/hr., the lower average speed can be attributed to the presence of some stopping and queue delays.

Average traverse time = 1.4km / 22.4 km/hr = 0.0625 = 225 seconds

Therefore, the average time spent in a queue = 0.0625hr – 0.028hr = 0.0345 hr = 124.2 seconds. From the above calculations, it can be approximated that 55% of the travel time through the work zone was spent in a queue.

Detours

For the work zone under consideration, vehicles were not forced to detour. However, it is important to consider the users that detoured the work zone voluntarily. The daily traffic volumes recorded by the permanent traffic counters can give an indication of the users that detoured to avoid the work zone. By comparing the volumes during construction to the volumes when the work zone was not in operation, the number of vehicles that rerouted can be estimated.

User Detours = Normal Daily Traffic Volume - Work Zone Daily Traffic Volume

The value for the normal daily traffic volume will be taken as the average weekday daily volume experienced while university is not in session. This will give an indication of the volumes that would have been experienced had the work zone not been in operation over the summer.

Normal weekday daily traffic volume = (37,342 + 42,682 + 42,623) / 3 = 40,882 veh

Work zone daily traffic volume = (31,103 + 24,741 + 34,070) / 3 = 29,971 veh

User Detours = 40,882 - 29,971 = 10,911 vpd

CONSUMER SURPLUS

Most analyses of user delay costs [Tighe 2000a, 2000b] have been for rural roadways where consumer surplus is not factored into the analysis because of a lack of alternative routes. Drivers are forced through a detour provide by the contractor with no option. The argument can be made that in an urban setting, as a result of the work zone, capacity was reduced and increased travel times increased and, as such, there is a resulting loss in benefit to society of that route. This loss is offset by the fact that consumers, have a choice through selection of an alternative route which may or may not have the same or longer/shorter travel times. In the case of Crowchild Trail, travelers to the university had several routes to choose from and therefore it was important to determine what effect, if any, the construction had on the volumes. Consumer surplus in this case is determined through Figure 3 which compares the travel times and volumes experienced during and after the construction, as well as the resulting loss in consumer surplus.

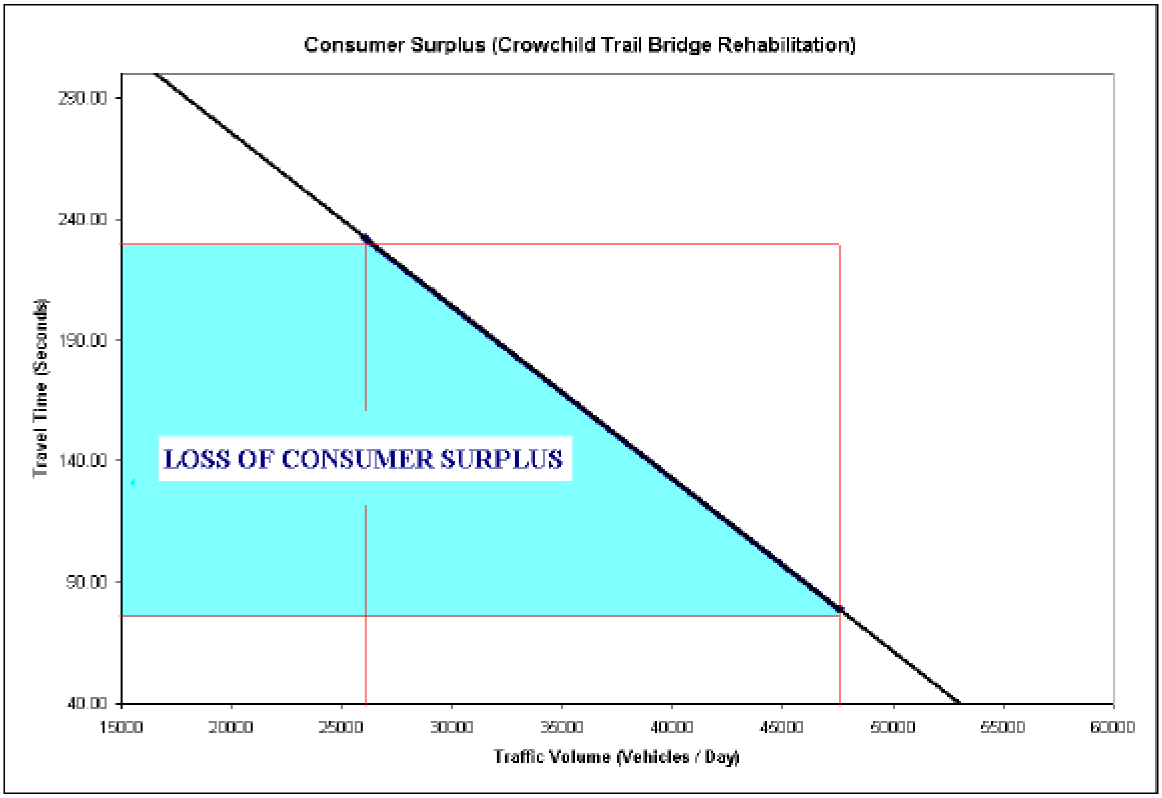


Figure 3 Consumer Surplus

Using Figure 3 the loss in consumer surplus can be estimated using the formula:

Consumer Surplus = ½ (Volume 2 + Volume 1)(Time 2 Time 1)

Consumer Surplus = ½(47569 veh. + 26092 veh.)(232sec 79sec)

Consumer Surplus = 5635066.5 Veh·Sec

Consumer Surplus = 1565.3 Veh·Hr

USER DELAY COSTS

The opportunity cost rates used were based on a flat rate per vehicle type. Clearly, within these vehicle classifications there will also be a wide range of opportunity costs. There are other factors to consider such as the number of passengers and the purpose of the trip. Using a flat rate assumption does not give an accurate account for the value of time for the vehicles progressing through the work zone. A more detailed investigation into the traffic distribution could produce a more accurate account for the opportunity costs

Due to a lack of information, the user costs associated with vehicle operating costs, crash costs, and vehicle detours will not be considered. Only the cost associated with user delays will be considered. Delay user costs are calculated by applying a value of time to the vehicles traversing the work zone:

User Cost = (Time of Travel / Vehicle) x (Number of Vehicles) x (Value of time)

Clearly, trucks and buses have higher opportunity costs than passenger cars and therefore, the vehicle distribution must be considered. Since the volume counts obtained for this report did not show vehicle classifications, an assumption was that 15% of the traffic consisted of trucks and buses. An assumption was also made for the opportunity costs. In this case, $14 / passenger car and $50 / truck or bus will be used. A sample calculation for user cost can be found below.

User Cost During University Break

$\text{User Cost}_{\text{(passenger cars)}}$ = (1min 19sec) x (40,882 veh)(85%) x ($14/hr) x 24hrs

= $10,676 / day

$\text{User Cost}_{\text{(trucks and buses)}}$ = (1min 19sec) x (40,882 veh)(15%) x ($50/hr) x 24hrs

= $6,728 / day

Total User Cost = $17,404 / day

To determine the additional user costs related to the work zone, the user costs experienced during the rehabilitation must be compared to the costs encountered when the work zone was not in operation. By examining the graph, the delay user cost resulting from the work zone can be calculated by subtracting the user cost during the university break from the average work zone user cost:

Delay User Cost = $34,593 – $17,404 = $17,189 / day

Table 3 and Figure 4 present the results of the analysis in text and graphical form. From this information, it can be estimated that with the work zone established it creates an additional $17,189 / day worth of user delay costs.

Table 3 User Delay Costs Per Day by Period

	Time (sec)	Volume (veh)	user cost (car)	user cost (truck)	Total
Pre Construction	79	47,457	$12,392.87	$7,810.63	$20,203.50
Post Construction	79	47,748	$12,468.86	$7,858.53	$20,327.38
University Break	79	40,882	$10,675.88	$6,728.50	$17,404.38
Stage 1	232	31,103	$23,852.55	$15,033.12	$38,885.66
Stage 2	254	24,741	$20,772.82	$13,092.11	$33,864.93
Stage 3	169	34,070	$19,032.83	$11,995.48	$31,028.31

Total User Delay Costs Stages 1-3 $103,778.90

Mean User Delay Stages 1-3 $34,592.97

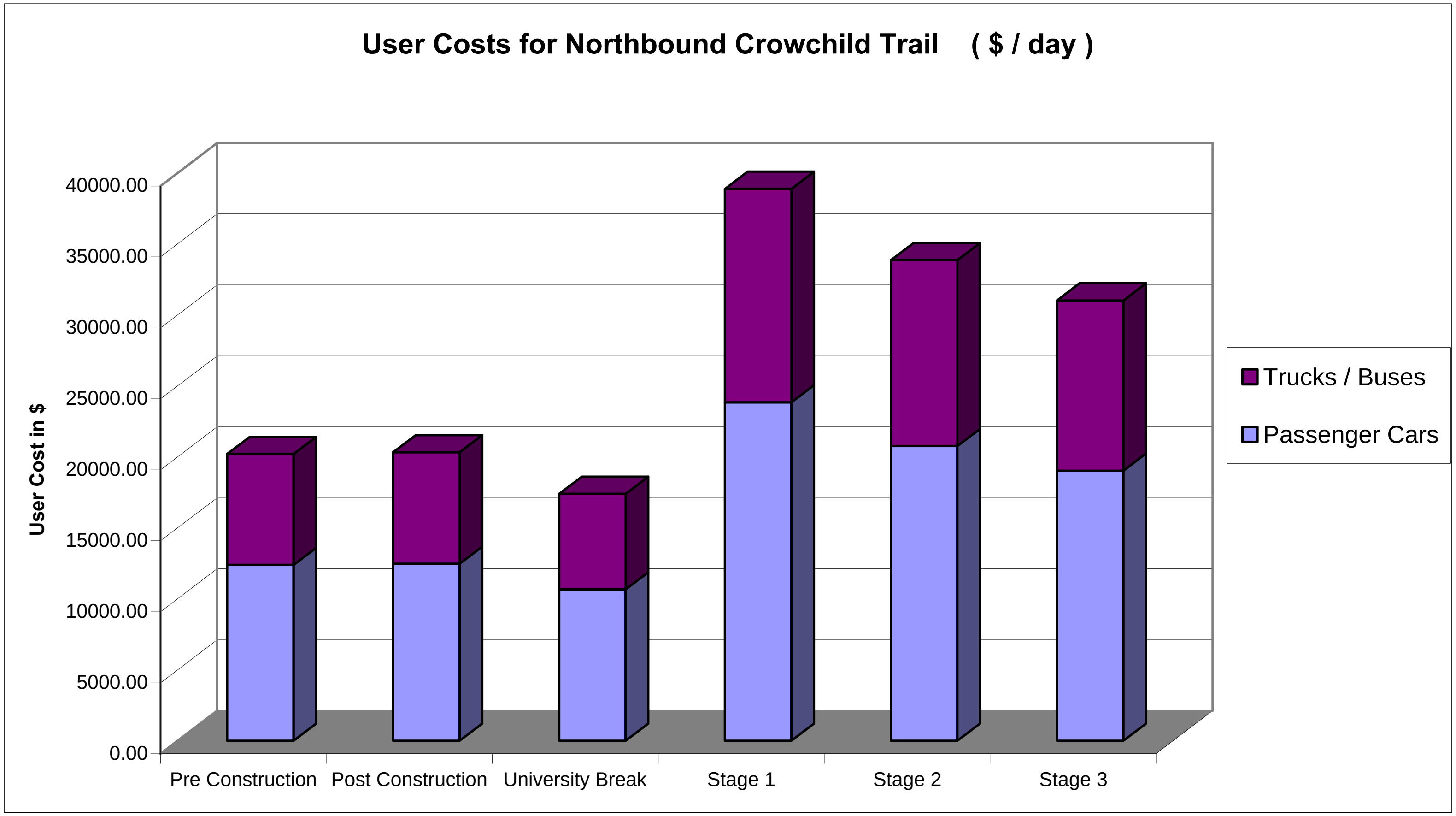


Figure 4 User Delay Costs per Day by Period

CONCLUSION

This paper has illustrated that construction, rehabilitation, or maintenance projects can have a significant impact on user costs. Work zones increase vehicle operating costs and delay the users of the network. These indirect costs to the users are often overlooked, as they do not affect the capital cost of the project.

The example of the Crowchild Trail Bridge rehabilitation provided a real life analysis of user costs. The user delay costs alone for the work zone studied were in the magnitude of $20,000 / day. Since the work zone was in operation for 96 days the total magnitude of the additional user delay costs is nearly 2 million dollars. If VOCs, crash costs, and the user costs associated with users that detoured are also considered, it can be seen that construction related user costs can summate to substantial amounts.

Although user costs are indirect, they can be a substantial burden to society and should not be overlooked. When developing a construction strategy, user costs should be considered just like any other cost. If this approach is taken, then user costs can be managed to ensure that they are kept to a minimum.

REFERENCES

[FHWA 1998] Federal Highway Administration. *Life-Cycle Cost Analysis in Pavement Design*. September 1998.

[TRB 1994] Transportation Research Board. “Highway Capacity Manual Third Edition.” Washington, D.C., 1994.

[Calgary 2002] http://www.gov.calgary.ab.ca/roads/capitalprojects/crowchild_bridge.html, access date October 7, 2002

[Tighe 2000a] Tighe, S.L., R. Haas, and C.M. Raymond. “User Cost Analysis of Traffic Staging Options for Resurfacing of Divided Highways in Ontario.” 2000.

[Tighe 2000b] Tighe, S.L., R. Haas, Z. He, and R. Al Assar. “Simplified User Delay Cost Model For Pavement and Bridge Life Cycle Analysis.” 2000.