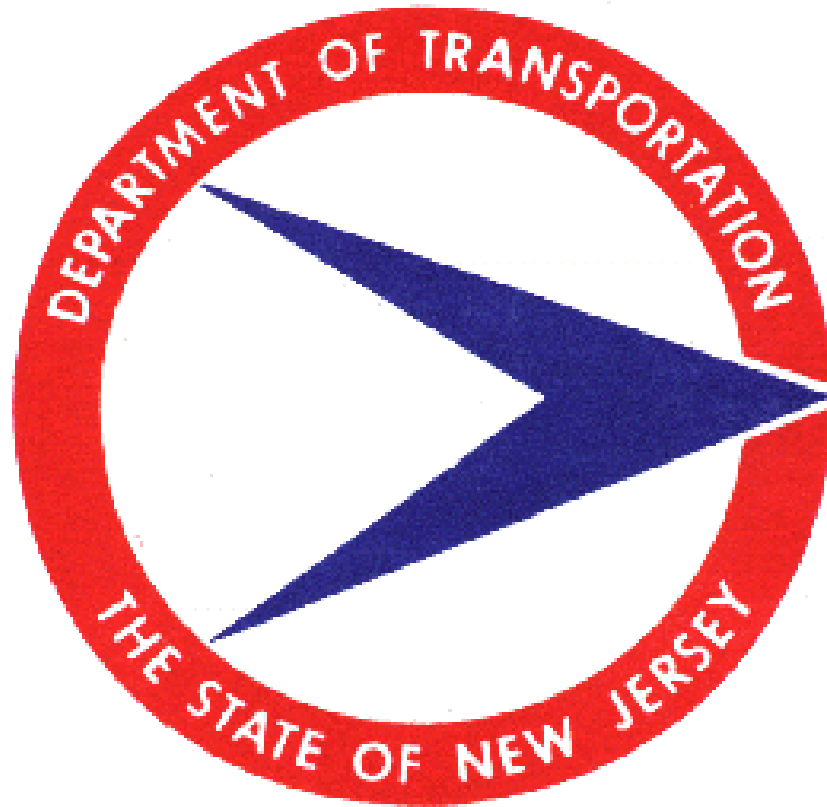**State of New Jersey**

Department of Transportation

Road User Cost Manual

Prepared by the

Road User Solutions Unit

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Section 1   Introduction

1.1 Overview

This manual provides guidelines and procedures to compute Road User Costs via a modeled approach that provides the analyst with consistent and quantifiable results. Road User Costs are directly related to the traffic demand, facility capacity, and the timing, duration and frequency of work zone induced capacity restrictions. The reliability of Road User Cost calculations is greatly dependent on good 24-hour traffic counts for weekday and weekend traffic and the percent of passenger cars and trucks in the traffic stream.

This manual will familiarize the analyst with work zone and traffic characteristics, explain the possible work zone related road user cost components that can occur, and provide a step by step procedure to determine road user costs. Example problems, default hourly traffic percentages, and computation worksheets are also provided to aid the analyst with the road user cost computations.

The road user costs incurred by the traveling public during project improvements can be extremely high. This manual provides a reasonable measurement of costs incurred by the traveling public to be paid in the form of Liquidated Damages, in lieu of timely performance by the contractor.

1.2 Purpose

Road User Costs in the work zone are added vehicle operating costs and delay costs to highway users resulting from construction, maintenance, or rehabilitation activity. They are a function of the timing, duration, frequency, scope, and characteristics of the work zone; the volume and operating characteristics of the traffic affected; and the dollar cost rates assigned to vehicle operations and delays.

As long as work zone capacity exceeds vehicle demand on the facility, road user costs are normally not a serious cost to the traveling public. Under such circumstances, the roadway operates under free flow conditions and road user costs are dominated by delay costs in traveling the work zone.

When vehicle demand on the facility exceeds work zone capacity, the facility operates under forced flow conditions and road user costs can be immense. Queuing costs can account for over 90% of road user costs with the majority of the cost being the delay time of crawling through long slow moving queues.

Designers should consider road user costs when determining the most appropriate construction staging and final design. This should be done early in the design process while there is still flexibility in the design. The optimal design will mitigate or avoid disruptions before they can be created. In addition to considering road user costs for the present construction needs, the analysis procedure provides the tools to determine future road user costs based on future construction needs. By understanding the major factors influencing road user costs, the designer can

take steps to minimize the effect of planned future rehabilitation activities on highway users.

Alternatives available to reduce work zone related road user costs include carefully selecting the preferred scheme and frequency of rehabilitation activities, restricting the allowable work hours to avoid queuing, adding capacity prior to the development of large traffic demands, accelerating contractor production rates to reduce the overall work zone duration, and utilizing alternative project delivery methods. For some projects, improvements could include enhanced mass transit services, improvements to other routes, coordination with other agencies, and public outreach.

The quantification of road user costs in both time and money provides the designer with a valuable decision making tool. The examples in this manual illustrate many practical and real life applications.

1.3 Benefits

Road User Costs play an important role in computing Liquidated Damages. The contractor's failure to complete a contract or reopen a lane of traffic on time results in damages in terms of delay and cost to the motoring public and the Department. The procedures in this manual will establish how to calculate and apply these damages. Desirably, these damages will never be imposed because it is preferable to avoid high road user costs by adhering to the completion dates and allowable work hours provided in the contract. The methods of computing liquidated damages have taken into account input by the Construction Industry and reflect that road user costs are in fact real, but difficult to accurately calculate given the many factors involved and the different variables that exist on a given day in the life of a construction project.

Road user costs can be used in Benefit/Cost ratios, Life Cycle Cost Analyses, and selecting the most appropriate project delivery method (Incentive/Disincentive, A+B Bidding, etc.). Road User Costs are not direct costs to the Department's budget, but they do directly affect the public it serves. This manual is an excellent tool in helping to determine the appropriate capital investment on a project.

1.4 Definitions

Work Zone is defined in the Highway Capacity Manual as an area of a highway in which maintenance and construction operations are taking place that impinge on the number of lanes available to traffic or affect the operational characteristics of traffic flowing through the area.

Road User Costs in the work zone are added vehicle operating costs, delay costs, and crash costs to highway users resulting from construction, maintenance, or rehabilitation activity.

1.5 Work Zone Characteristics

In order to calculate work zone related road user costs the characteristics of the work zone must be defined. Work zone characteristics of concern include such factors as work zone length, number and capacity of lanes open, duration of lane closures, timing (hours of the day and days of the week) of lane closures, posted speed, and the availability and traffic characteristics of alternative routes. The strategy for the maintenance of traffic should include any anticipated restrictions on contractor's or maintenance force's hours of operations or ability to establish lane closures.

Each work zone established over the analysis period can have different impacts on traffic flow and the associated user costs. Whenever characteristics of the work zone or the characteristics of the affected traffic change, a separate work zone must be defined and evaluated as a separate event.

The duration of a work zone (i.e. the overall length of time a facility or portion of a facility is out of service) can range from sporadic daily lane closures for maintenance to several months for bridge deck replacements.

1.6 Traffic Diversion

Traffic demand is generally determined based on the need to use the facility. Traffic volume during work zone operations may or may not be the same. Some portion of the traffic normally wanting to use the facility may divert to other routes when work zones are established.

Vehicles use a given facility because it offers, what the vehicle operators perceive to be, the least expensive combination of vehicle operating and time delay costs, consistent with safety requirements. When faced with restricted flow, or even the anticipation of restricted flow, vehicle operators who normally use a facility will exercise one of several options. The potential vehicle operator responses are categorized below.

Hang Toughers - This group continues to use the facility as they always have. They are primarily users with little, or no, option. They (1) must make the trip, (2) they must make it at a specific time, and (3) either don't know of or don't have alternative routes or modes to choose from. These users pay the full price of the work zone and have little effect on other facilities in the corridor. In rural areas, the predominate choice of through traffic will be to tough it out, as these users generally must make the trip and do not have available alternative routes unless formal detours are established.

Time Shifters - Time Shifters have the "luxury" to travel on the facility or other route at a different time, generally a time well outside of the restricted flow period. These users lessen their impact by sharing the impact with other vehicles by "invading" their time slot. These users also have little effect on other facilities in the corridor, but do impact hourly traffic distribution.

Detourees - Detourees either seek out and use alternate routes, or are forced to negotiate detours established by the highway agency. These operators also lessen their impact by sharing the impact with other vehicles by "invading" their routes. They tend to trade off anticipated time delay for additional travel distances and associated vehicle operating costs. In urban areas this could include users who switch modes. Detourees can have significant impact on overall road user costs of alternative routes.

Trip Swappers - Trip swappers have the "luxury" of totally abandoning the trip or seeking other destinations when the cost, in terms of time and money, becomes too great. Historically, this group consists primarily of shopping and social/recreational trip makers. While their behavior may diminish the road user costs impact in the work zone they adversely impact businesses along the route in question. More recent trends in people working out of the home and telecommuting may have a significant effect on work trips in the future.

In simple cases, where either work zone disruption is tolerable or alternative routes are limited, the estimated Average Daily Traffic (ADT) during the duration of the work zone can be anticipated to continue on the facility and the work zone analysis can be limited to the existing facility.

In more complex situations where existing traffic would face intolerable work zone disruptions, it is entirely possible that total travel demand and hourly distribution on the facility may change when the work zone is established. When demand changes, the road user cost analysis may have to expand beyond the existing facility and include road user costs on major alternative routes. When preliminary analyses of travel demand show that work zone related road user costs are unreasonably high, allowable work hours may need to be restricted, early contract completion incentives may be appropriate, or an alternative design may need to be considered.

1.7 Traffic Characteristics

Road user costs are directly dependent on the volume and operating characteristics of the traffic on the facility. Each construction, maintenance, and rehabilitation activity generally involves some temporary impact on traffic using the facility. The impact can vary from insignificant for minor work zone restrictions on low volume facilities to highly significant for major lane closures on high volume facilities.

The major traffic characteristics of interest for each work zone include such factors as the overall projected Average Daily Traffic (ADT) volumes, the associated 24-hour hourly traffic distributions, and the vehicle classification distribution within the traffic stream. Each of the major traffic characteristics is discussed in the sections that follow.

1.8 Average Daily Traffic (ADT)

Current weekday and weekend ADT volumes can be obtained from the traffic monitoring section. When using projected ADT volumes, it is generally assumed traffic patterns remain the same. However, consideration should be given as to whether traffic using the facility will continue to use the facility when work zones are established and traffic flow is restricted.

1.9 Hourly Traffic Distribution (By Direction)

The 24-hour hourly traffic distribution during work zone operations is essential to be able to compare the unrestricted demand on the facility with the facility's ability to carry that traffic through the work zone. On all routes, distinctions between weekday and weekend traffic hourly distributions are important. Furthermore, when work zones are proposed on recreational routes during seasonal peak periods, seasonal ADT traffic distribution is extremely important. The New Jersey Department of Transportation has developed average hourly traffic percentages for various functional classes of roadway which are provided in Table 3.1.

1.10 Vehicle Classifications

Road user costs are a composite of costs of all affected highway users. Highway users are not a homogeneous group. They include commercial and non-commercial vehicles ranging from motorcycles and passenger cars through multi-trailer trucks. The FHWA Traffic Monitoring Guide, Third Edition (February 1995) includes 13 different vehicle classifications which are shown in Figure 1.1. These different vehicle classes have different operating characteristics and associated operating costs. Further, the value of time differs between vehicle classes. As a result, road user costs need to be analyzed for each major vehicle class present in the traffic stream.
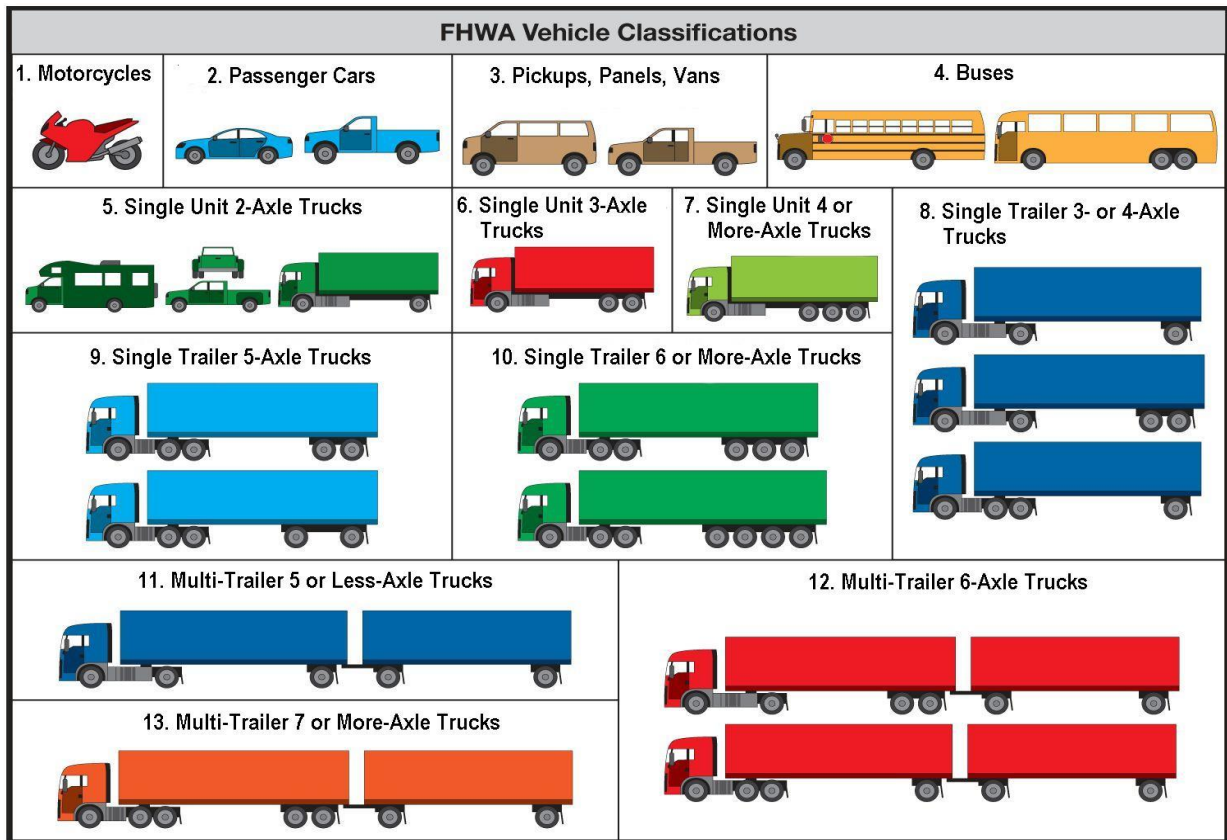
Figure 1.1

FHWA Vehicle Classifications

Road user cost analysis based on 13 vehicle classifications would be laborious and require extensive traffic data. For simplification and consistency with available traffic data, it is recommended to use **"Car"** (Classes 1-4) and **"Truck"** (Classes 5-13) classifications only.

Section 2   Components

Before addressing road user cost calculation procedures, it is helpful to understand the Road User Cost Components. There are a total of ten potential work zone related road user cost components that can occur. Three components are associated with a "Base Case" situation where traffic operates under "Unrestricted Flow" conditions. Four components are associated with a "Queue" situation where traffic operates under "Forced Flow" (Level of Service "F") conditions. Two components are associated with a "Circuity" situation where traffic is forced to utilize a detour to avoid a highway work zone, and the final component is associated with "Crash Costs". Each of the potential road user cost components is discussed in the sections that follow.

2.1   Unrestricted Flow

Work zones restrict traffic flow either by restraining the capacity of the roadway or, as a minimum, by posting lower speed limits. Figure 2.1 shows unrestricted flow conditions at a work zone. All traffic that flows through the work zone, at a minimum, must slow down while traveling through it and then accelerate back to normal operating speed. This is commonly referred to as a speed change and results in three work zone related road user cost components. The cost components associated with the unrestricted flow case in Figure 2.1 are described below.

Speed Change VOC (Vehicle Operating Cost) - This is the additional vehicle operating cost associated with decelerating from the unrestricted upstream approach speed to the work zone speed and then accelerating back to the unrestricted approach speed from the work zone speed after traversing the work zone.

Speed Change Delay - This is the additional time necessary to decelerate from the unrestricted upstream approach speed to the work zone speed and then to accelerate back to the unrestricted approach speed after traversing the work zone.

Work Zone Delay - This is the additional time necessary to traverse the work zone at the lower posted speed. This depends on the normal and work zone speed differential and length of the work zone.

If traffic volume remains below work zone capacity, the added road user costs are limited to the above three components and the analysis is relatively simple. In most cases delay times remain relatively low and represent more of a minor irritation and inconvenience than a serious problem.
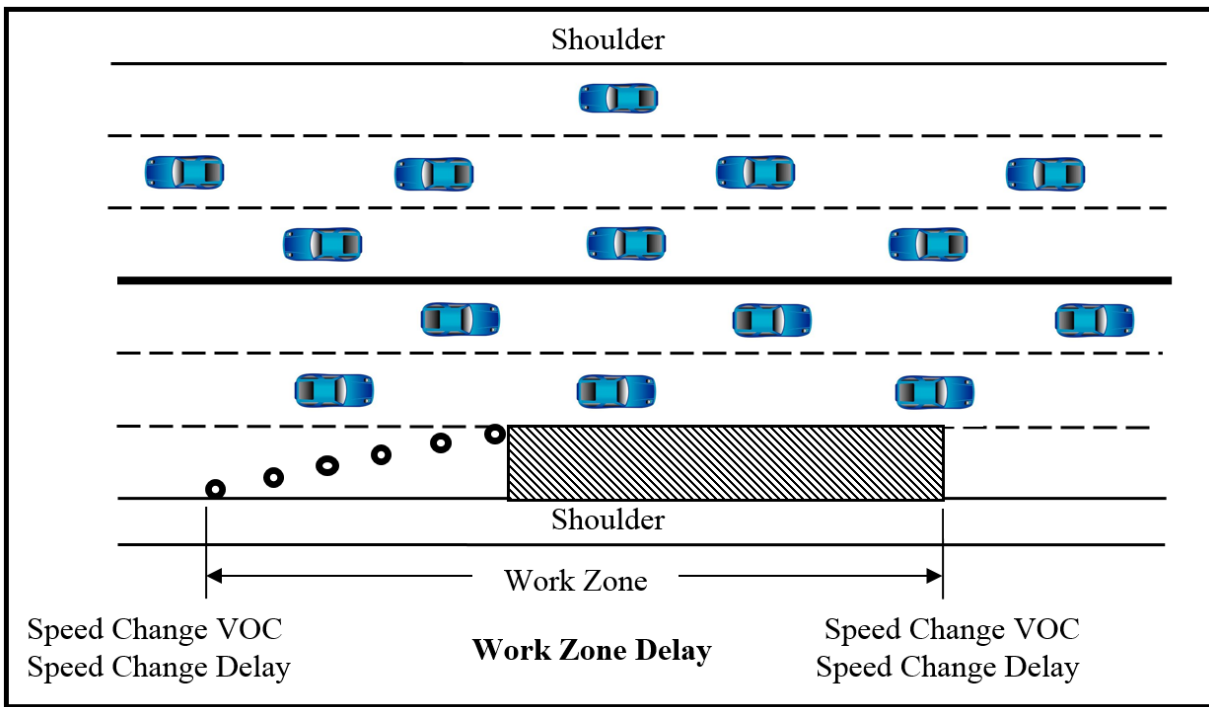
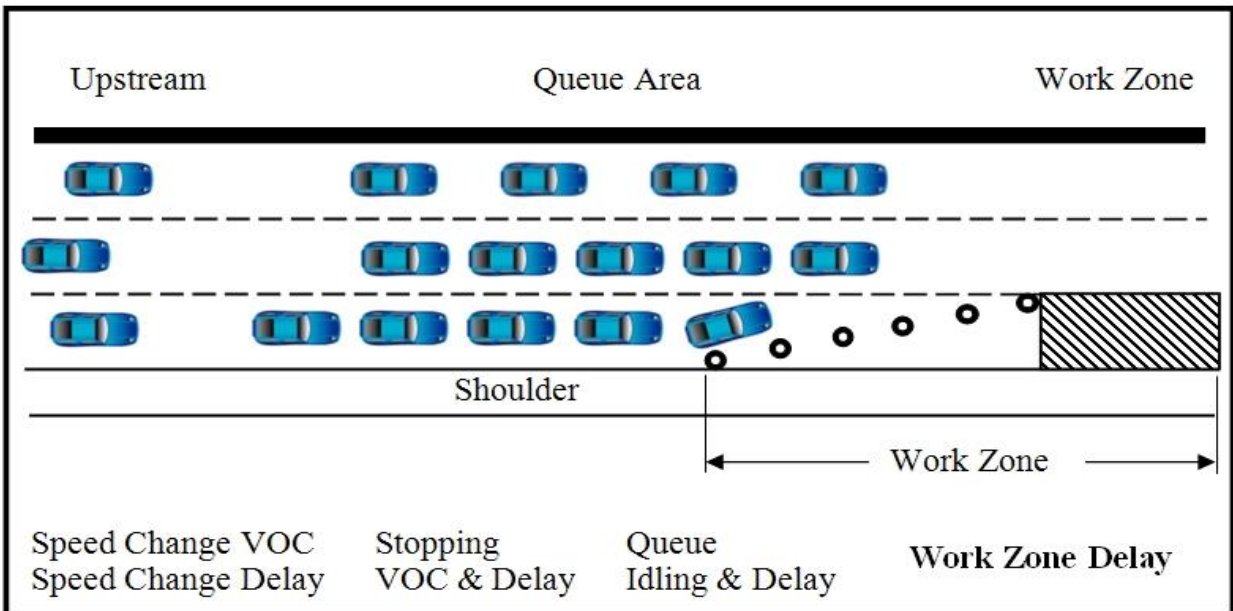**Figure 2.1**

Road User Cost Components (Unrestricted Flow)

Figure 2.2

Road User Cost Components (Forced Flow)

Department analyses have shown that the "Work Zone Delay" component accounts for approximately 90% of the total road user costs associated with the "Unrestricted Flow" situation. For simplification of calculations, it is recommended to only calculate the costs associated with the **Work Zone Delay** component.

2.2 Forced Flow (Level of Service "F")

When traffic demand exceeds work zone capacity, traffic flow breaks down and a queue of vehicles develops as shown in Figure 2.2. It is important to note that the queue does not form in the work zone itself, but in the upstream approach to the work zone. Once a queue develops, all approaching vehicles must stop at the approach to the work zone and creep through the length of the physical queue under forced flow conditions at significantly reduced speeds. As long as the traffic volume exceeds the work zone capacity, the length of the queue grows. When the traffic volume eventually falls below the work zone capacity, vehicles then leave the queue faster than they arrive and the length of the queue shrinks and eventually dissipates over time. When capacity is reduced on high traffic facilities, it is not uncommon for queues to develop in the morning peak traffic period, dissipate, and then redevelop in the afternoon peak traffic period.

Queuing situations impose four more work zone related road user cost components that are a direct result of the queue. They are in addition to the "Unrestricted Flow" added road user costs and only apply to vehicles that encounter a physical queue. The cost components associated with the forced flow case in Figure 2.2 are described below.

Stopping VOC - This is additional vehicle operating cost associated with stopping and accelerating back up to work zone speed.

Stopping Delay - This is additional time necessary to come to a complete stop (instead of just slowing to the work zone speed) and then accelerating back to the work zone speed.

Queue Delay - This is additional time necessary to creep through the queue under forced flow conditions.

Queue Idling VOC - This is the additional vehicle operating costs associated with "stop and go" driving in the queue. The operating costs include fuel, engine oil, maintenance, and depreciation.

Department analyses have shown that the "Queue Delay" and "Queue Idling VOC" components account for approximately 90% of the total road user costs associated with the "Forced Flow" situation. For simplification of calculations, it is recommended to only calculate the costs associated with the **Queue Delay** and **Queue Idling VOC** components.

The conceptual analysis presented in Figure 2.1 and Figure 2.2 is geared primarily to freeway conditions. Conceptual analysis of facilities with at-grade intersections would also incur speed change, stopping, delay, and idling costs, but at a much higher frequency due to intersection control devices and turning movements.

2.3 Circuity

Circuity is a term used to describe the additional mileage that users travel, either voluntarily or involuntarily, on a detour to avoid a highway work zone or queue situation. Circuity situations impose two more work zone related road user cost components that are a direct result of the detour. They can be in addition to or in lieu of the "Unrestricted Flow" and "Forced Flow" components. If traffic is forced to detour, the associated cost components are described below.

Circuity VOC - This is the additional vehicle operating cost associated with traveling the excess distance the detour imposes.

Circuity (Detour) Delay - This is the additional time necessary to travel the excess distance the detour imposes and this depends on the travel time and travel length differentials.

For simplification of calculations, it is recommended to only calculate the **Circuity VOC** and **Circuity Delay** components when a formal detour is established. For non-detour cases, it is assumed the traffic will remain on the roadway and travel the queue and/or work zone situations.

2.4 Crash Costs

Crash costs are a function of the crash rate for the work zone and for the facility in absence of work zones. Crash rates are typically based on the number of crashes per vehicle miles of travel. Crash rate is typically expressed as "crashes per million vehicle miles of travel (MVMT)" for roadway sections and "crashes per million entering vehicles (MEV)" for intersection locations.

Overall crash rates for the various functional classes of roadway are fairly well established. Crash rates for work zones, however, are not. Crashes that occur in work zone generated queues are not always classified as "Work Zone" crashes. It is also difficult to accurately quantify the work zone exposure rate (i.e., the length of the work zone and the hours and days the work zone queues are in place). Numerous studies indicate that the pre-work zone crash rate and severity (the number of fatal and nonfatal injury crashes) are likely to increase when there is a work zone in place.

The following operational and physical characteristics of a facility may influence the likelihood of crashes in work zones:

- Roadway functional class (freeway, arterial, collector)
- Location (urban, rural)
- Work zone configuration (length, speed, number of open lanes)
- Traffic Volume (daily, seasonal)
- Exposure period (number of days, nighttime versus daytime)
- Traffic management strategy (partial lane closure, crossover, detour)
- Traffic control strategy (flaggers, barriers, drums)

NJDOT Safety Programs currently utilize crash costs as part of a benefit / cost analysis to prioritize proposed crash countermeasures in order to mitigate identified crash patterns along existing roadway segments and at intersections. These costs historically increase approximately 8% per year.

The Department considers the human and financial factors associated with crash costs during the project development phase. However, due to the limited availability of work zone crash cost data, the inclusion of **Crash Costs** as part of the road user costs is **<u>not</u>** recommended.

Section 3   Computations

Once the individual work zones have been identified, each is evaluated separately. This is the point at which individual road user cost components are quantified and converted to dollar cost values. The following sections provide an approach for quantifying and costing the individual road user cost components encountered. The potential work zone related road user cost components were discussed in the previous section and are listed below.

1. Speed Change VOC
2. Speed Change Delay
3. **Work Zone Delay**
4. Stopping VOC
5. Stopping Delay

6. **Queue Delay**
7. **Queue Idling VOC**
8. **Circuity VOC**
9. **Circuity Delay**
10. Crash Costs

The road user cost components shown as bold are computed fairly accurately and account for the majority of the total road user costs. Computations for each bolded component will be discussed in detail in the following sections. NJDOT has developed an electronic workbook template consisting of five individual worksheets (in Microsoft Excel format) to aid in organizing and calculating the necessary road user cost information. The workbook can be found at http://www.state.nj.us/transportation/eng/documents/RUCM/. The workbook and examples used in this manual are calculated using English units of feet, miles and hours. Metric units must be converted to English units prior to using the workbook. It is recommended that this workbook be used for the actual computations.

3.1 Analysis of the Work Zone

The traffic demand and the capacity of individual work zones are important parts in calculating work zone related road user costs. Worksheet 3.1 has been developed to aid the analyst in comparing the traffic volume to the available capacity for each hour of the day. Worksheet 3.1 will provide the total affected traffic to be used in the computations and is discussed below.

Worksheet 3.1

Analysis of the Work Zone

Work Zone: _____ Normal Capacity: _____

Normal Speed (mph): _____ Percent Cars: _____ Work Zone Capacity: _____

Directional ADT: _____ Percent Truck: _____ Lanes Under Normal Operation: _____

3.1(A)	3.1(B)	3.1(C)	3.1(D)	3.1(E)	3.1(F)	3.1(G)	3.1(H)	3.1(I)	3.1(J)
Time Period (hour)	Hourly Traffic (%)	Vehicle Demand (vph)	Lanes Open (#)	Roadway Capacity (vph)	Queue Rate (vph)	Queued Vehicles (vph)	Work Zone Present? (Y or N)	Vehicles that Travel Work Zone (vph)	Vehicles that Travel Queue (vph)
12-1 AM									
1-2									
2-3									
3-4									
4-5									
5-6									
6-7									
7-8									
8-9									
9-10									
10-11									
11-12 PM									
12-1									
1-2									
2-3									
3-4									
4-5									
5-6									
6-7									
7-8									
8-9									
9-10									
10-11									
11-12									
TOTALS									

Work Zone

Provides all relevant information pertaining to each work zone operation such as the number of lanes closed, the direction of travel, the day(s) of the week and the hours the work zone is in place.

Normal Speed

The normal speed of the facility is the posted speed limit of the section operating in an unrestricted flow condition.

Directional ADT

The current or future directional ADT, based on the desired construction year, should be obtained from the traffic monitoring section.

Percent Cars &Trucks

Provide the percent of each vehicle class that is present in the traffic stream.

Normal / Work Zone Capacity

The appropriate capacity is related to the allowable lane closure schedule and each is discussed in the Roadway Capacity section.

Lanes Under Normal Operation

The lanes under normal operation are the available number of traffic lanes per direction when no roadway restrictions are present.

Time Period - *Column 3.1 (A)*

The time period generally is shown as one-hour intervals over a 24-hour period. Intervals less than one hour can be used and require that the hourly traffic distribution and roadway capacity be revised accordingly.

Hourly Traffic - *Column 3.1 (B)*

The hourly traffic percent distribution can be determined from traffic count data obtained from the traffic monitoring section. NJDOT has developed an electronic worksheet (in Microsoft Excel format) to aid in organizing and calculating the hourly traffic percent distribution. This worksheet also can be found at http://www.state.nj.us/transportation/eng/documents/RUCM/. If no count data is available to determine the hourly traffic percent, default hourly traffic percentages can be used. The NJDOT Traffic Monitoring Section has developed average hourly traffic percentages from counting station data for various roadway classes and are provided in Table 3.1 below.

Table 3.1

NJDOT Statewide Average Hourly Traffic Percentages

Hour	Interstates, Freeways, and Other Expressways			Principal Arterials			Major Arterials			Minor Arterials		
	AM Peak	PM Peak	BAL Peak	AM Peak	PM Peak	BAL Peak	AM Peak	PM Peak	BAL Peak	AM Peak	PM Peak	BAL Peak
12-1 AM	1.0	1.5	1.3	0.8	1.5	1.2	1.0	1.0	0.7	0.8	1.0	0.8
1-2	0.8	0.9	0.8	0.4	0.9	0.6	0.5	0.5	0.4	0.4	0.5	0.4
2-3	0.7	0.7	0.7	0.4	0.7	0.5	0.5	0.3	0.3	0.3	0.3	0.2
3-4	0.9	0.6	0.7	0.4	0.6	0.5	0.5	0.3	0.3	0.3	0.3	0.2
4-5	1.4	0.7	0.9	0.8	0.8	0.8	0.9	0.4	0.4	0.5	0.4	0.4
5-6	3.4	1.2	1.9	2.7	1.1	1.9	2.5	0.9	1.1	1.2	1.0	1.2
6-7	8.1	2.5	4.6	6.5	2.6	4.1	6.5	2.9	3.6	4.5	3.5	4.6
7-8	10.7	4.4	6.6	9.6	4.3	6.4	9.7	4.9	6.8	9.5	5.5	7.7
8-9	8.9	4.5	6.8	9.2	4.7	7.0	9.2	5.2	7.4	9.2	5.2	7.3
9-10	5.6	4.0	5.4	6.1	4.1	5.6	6.4	4.8	5.9	5.6	4.4	5.3
10-11	4.8	4.4	4.9	5.2	4.2	5.2	5.4	4.8	5.6	4.9	4.5	4.7
11-12	4.7	4.9	5.1	5.4	4.8	5.7	5.5	5.6	5.9	5.3	5.5	5.3
12-1 PM	4.6	5.3	5.2	5.4	5.2	5.8	5.5	6.1	6.2	6.1	6.2	5.8
1-2	4.6	5.4	5.2	5.4	5.4	6.0	5.6	6.0	6.1	5.8	5.8	5.8
2-3	5.0	5.9	5.6	5.5	6.2	5.9	5.7	6.5	6.6	6.0	6.3	6.2
3-4	5.5	7.5	6.5	6.0	8.0	6.3	5.8	7.9	7.3	6.9	7.7	7.4
4-5	6.2	9.2	7.4	6.1	9.7	6.5	6.0	9.2	7.5	6.9	9.7	8.0
5-6	6.3	9.2	7.5	6.2	9.7	6.8	5.9	8.9	7.3	6.7	9.2	7.1
6-7	4.7	7.4	6.1	5.0	7.2	5.9	4.5	7.1	6.0	5.4	6.7	6.1
7-8	3.5	5.7	4.6	4.0	5.4	5.0	3.6	5.1	4.7	4.2	5.1	4.9
8-9	2.7	4.6	3.9	2.9	4.3	4.1	2.9	3.8	3.4	3.5	4.0	3.6
9-10	2.5	4.0	3.4	2.5	3.6	3.6	2.5	3.3	2.9	2.6	3.2	3.1
10-11	2.0	3.1	2.8	2.1	2.8	2.7	2.1	2.6	2.1	2.0	2.2	2.3
11-12	1.4	2.4	2.1	1.4	2.2	1.9	1.3	1.9	1.5	1.4	1.8	1.6
Totals	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Vehicle Demand - *Column 3.1 (C)*

The hourly vehicle demand is calculated by multiplying the directional ADT by the hourly traffic percent distribution.

Lanes Open - *Column 3.1 (D)*

The number of lanes open on the facility varies directly with the allowable work zone lane closure hours provided in the contract.

Roadway Capacity - *Column 3.1 (E)*

Capacity is the maximum number of vehicles passing a point on the facility at established roadway conditions. In analyzing work zone related road user costs, there are three possible capacities that could be utilized and need to be determined. They include: (1) the capacity of the facility under normal operating conditions, (2) the capacity of the facility when the work zone is in place, and (3) the capacity of the facility to dissipate traffic from a queue condition. Each of these is discussed in turn.

(1) Normal Capacity

Normal Capacity is the maximum traffic volume a facility can handle under normal roadway conditions. Table 3.2 provides the ideal capacity a facility type can handle. Chapter 3 of the Highway Capacity Manual (HCM) points out that these capacities under ideal conditions must be adjusted for such real world factors as restricted lane widths, reduced lateral clearances, the presence of trucks and recreational vehicles, and the presence of a driver population unfamiliar with the area. The normal capacity of the facility is used during the non-work zone hours when all traffic lanes are open.

Table 3.2

Capacity By Facility Type

Facility Type	Ideal Capacity
Freeway – 4 lanes	2,200 Passenger Cars per hour per lane
Freeway – 6 or more lanes	2,300 Passenger Cars per hour per lane
Multilane Highway	2,200 Passenger Cars per hour per lane
Two-Lane Highway	1,400 Passenger Cars per hour per lane
Signalized Intersection	1,900 Passenger Cars per hour of green per lane

(Source: 1994 HCM Table 2-14)

(2) Work Zone Capacity

Capacity in the work zone can be estimated from research studies. Table 3.3 reflects average vehicle flow capacities at several real world work zones under several lane closure scenarios. These average capacities are 50% reliable. This means that the work zone capacity will be at least equal to the table value 50% of the time. On the other hand it also means the capacity of the work zone will be less than the table value 50% of the time. The recommended values in Table 3.3 are based on a freeway type of facility. These values can be adjusted to reflect other facility types and changes in reliability (as the reliability increases the capacity decreases). The appropriate work zone capacity would be used during the hours that lane restrictions are permitted.

Table 3.3

Measured Work Zone Capacities – Freeway Section

Number of Directional Lanes		Number of Studies	Average Capacity		Recommended Value (*) veh/lane/hour
Normal	Open		Vehicles per hour	vehicles per lane per hour	
3	1	7	1,170	1,170	1,200
2	1	8	1,340	1,340	1,300
5	2	8	2,740	1,370	1,400
4	2	4	2,960	1,480	1,500
3	2	9	2,980	1,490	1,500
4	3	4	4,560	1,520	1,500

(Source: 1994 HCM Fig. 6-11, Fig. 6-12, and Table 6.1)

(*) Value may be increased 100 vehicles per lane per hour when the work zone is protected with concrete construction barrier.

An alternating traffic (Flagging) work zone is utilized for low volume 2-lane roadways. A single lane is made available for alternating the traffic flow and is generally controlled by flagmen or temporary traffic signals. Table 3.4 reflects recommended flagging work zone capacities for a 2-lane roadway under several work zone length and cycle timing scenarios. Flagging work zones are generally up to a 1/2 mile in length and limited to a travel speed of 25 mph. The appropriate flagging work zone capacity would be used during the hours that lane restrictions are permitted.

Table 3.4

Flagging Work Zone Capacities

Flagging Zone Length (mile)	Flagging Operation Cycle Time (minutes)							
	1.0	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**
0.5			200	450	600	750	800	850
0.4			400	600	750	850	900	950
0.3		250	600	750	850	950	1000	1000
0.2		550	800	900	1000	1050	1050	1100
0.1	450	850	1000	1050	1100	1150	1150	1150

(3) Dissipation Capacity

Capacity during queue dissipation may be less than the capacity during normal conditions, even though the lanes are unrestricted. According to the Highway Capacity Manual, freeway queue departure rates range from as low as 1500 passenger cars per hour per lane (pcphpl) to as high as 2000 pcphpl. This effect ranges from a significant reduction in capacity of 25% to virtually no reduction at all. This implies that a separate and distinct temporary "dissipation capacity" may exist after a work zone is removed. The appropriate dissipation capacity would only be used during the hours all traffic lanes are open with a physical queue present.

Although a dissipation capacity may exist, in the case of a slow moving queue, it is recommended to use the normal capacity in lieu of the dissipation capacity as soon as the work zone is removed. However, in the case of traffic dissipating from a true stop condition such as a bridge opening, it is recommended to use a dissipation capacity that is 85% of the normal capacity (15% reduction).

Queue Rate - *Column 3.1 (F)*

The queue rate is the difference between hourly capacity of the facility and the unrestricted hourly demand (demand minus capacity) for each hour of the day. The queuing rate is the hourly rate at which vehicles accumulate to, or, if negative, dissipate from any queue that may exist. A physical queue develops when the queue rate is greater than zero.

Queued Vehicles - *Column 3.1 (G)*

The queued vehicles are those vehicles "backed up" in the queue at the end of each hour. Once a queue develops, the number of queued vehicles equals the queue rate at the end of the first hour. The next hours' queue rate is then added to the previous queued vehicles total until all the queued vehicles have been dissipated.

Work Zone Present? - *Column 3.1 (H)*

The hours of the day the work zone is present varies directly with the allowable work zone lane closure hours and construction staging provided in the contract.

Vehicles That Travel Work Zone - *Column 3.1 (I)*

Under unrestricted flow conditions, the number of vehicles that travel the work zone is generally the traffic demand on the facility during the hours the work zone is in place. Under forced flow conditions, the number of vehicles that travel the work zone is limited to the capacity of the work zone. In the case of a detour, the vehicles that travel the work zone are those vehicles that are forced to use the alternate route during the hours the detour is in effect.

Vehicles That Travel Queue - *Column 3.1 (J)*

A physical queue develops when demand exceeds capacity (i.e. queue rate greater than zero). All vehicles that approach the work zone when a physical queue exists must stop and work their way through the queue before entering the work zone. Traffic that arrives as the queue starts to develop will have a rather short queue to work through, while traffic arriving when the queue is fully developed will have a much longer queue to travel. On the other hand, vehicles arriving as the queue is dissipating will have a continually shrinking queue to deal with. It is important to note that since the facility is operating under forced flow condition, the hourly volume of vehicles traveling the queue is limited to the capacity of the work zone. This is because the only way out of the queue is through the work zone.

Once the analysis of the work zone has been completed, the 24-hour totals should be entered for Hourly Traffic, Vehicle Demand, Vehicles That Travel Work Zone, and Vehicles That Travel Queue. The affected traffic has now been determined and the analyst should now identify the road user cost components to be computed.

3.2 Queue Delay

The queue delay per vehicle is only computed during forced flow conditions. Before computing the actual road user cost, the delay time through the queue (if applicable) must be known. Although the number of vehicles that travel the queue has been determined, the amount of delay can only be computed after knowing the queue length and queue speed. It is therefore necessary to determine the queue length and queue speed for each time period where a queue exists.

The delay time through the queue is determined by subtracting the time it takes to travel the queue length when it is present, from the time it takes to travel the same distance when it is not present. Worksheet 3.2 has been developed to aid the analyst in computing the overall queue delay per vehicle and is discussed below.

Queue Period - *Column 3.2 (A)*

A queue period is generally the hours a physical queue exists. It is not uncommon to have several queue periods within a 24-hour period. A physical queue develops when vehicle demand exceeds the roadway capacity and continues until all queued vehicles have been dissipated. The actual queue period(s) can be determined from the results of Worksheet 3.1.

Queue Volume - *Column 3.2 (B)*

The only way for traffic to exit the queue is through the work zone and therefore the volume through the queue section is limited to the capacity of the work zone.

Normal Capacity - *Column 3.2 (C)*

The normal capacity of the facility is the capacity of the roadway section operating in an unrestricted flow condition.

V/C Ratio - *Column 3.2 (D)*

The volume to capacity (V/C) ratio is calculated by dividing Column 3.2 (B) by Column 3.2 (C) for each queue period.

Worksheet 3.2

Queue Delay

	3.2(A)	3.2(B)	3.2(C)	3.2(D)	3.2(E)	3.2(F)	3.2(G)	3.2(H)
	Queue Period (hour)	Queue Volume (veh/hr)	Normal Capacity (veh/hr)	V/C Ratio	Average Queue Speed (mph)	Normal Speed (mph)	Maximum Queued Vehicles per Queue Period (#)	Queue Lanes (#)
1								
2								
3								
4								
5								

	3.2(I)	3.2(J)	3.2(K)	3.2(L)	3.2(M)	3.2(N)	3.2(O)
	Average Vehicle Length (ft/veh)	Average Queue Length (mile)	Queue Travel Time at Normal Speed (hr/veh)	Queue Travel Time at Queue Speed (hr/veh)	Added Time to Travel Queue (hr/veh)	Vehicles That Travel Queue per Queue Period (#)	Added Time per Queue Period (hour)
1							
2							
3							
4							
5							
				Totals			
				Added Time Weighted Average			hr/veh

Average Queue Speed - *Column 3.2 (E)*

The average queue speed for each queue period is determined by using the V/C Ratio and the graph in Figure 3.1 shown below. The graph in Figure 3.1 can be reduced to the following equation:

Queue Speed = $3.587 * [V/C]^3 + 7.681 * [V/C]^2 + 14.407 * [V/C]$

Figure 3.1

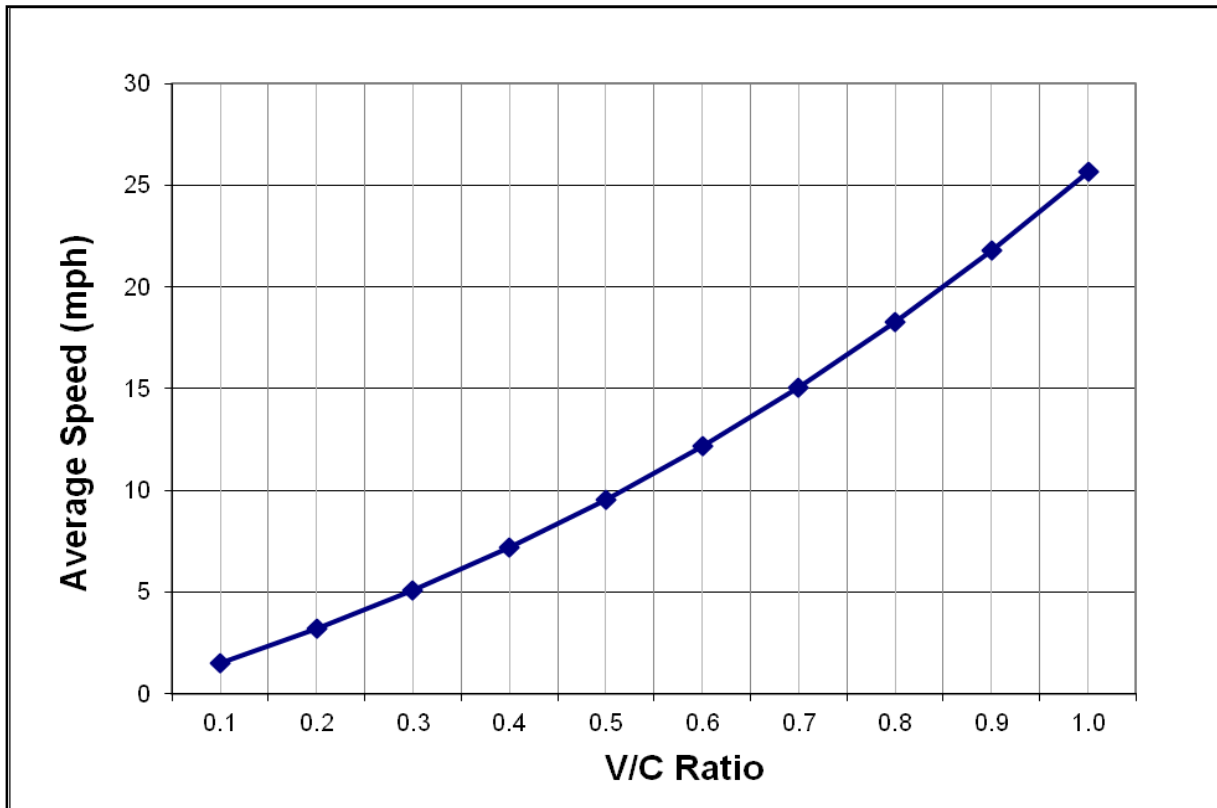**Average Queue Speed Versus V/C Ratio**

(Source: NCHRP 133)

Normal Speed - *Column 3.2 (F)*

The unrestricted speed of the facility is generally the posted speed limit of the section operating in an unrestricted flow condition.

Maximum Queued Vehicles Per Queue Period - *Column 3.2 (G)*

The maximum number of queued vehicles for each queue period is obtained from column 3.1 (G) of Worksheet 3.1.

Queue Lanes - *Column 3.2 (H)*

The number of queue lanes for each queue period is the available lanes upstream of the work zone that are occupied by vehicles when a physical queue develops.

Average Vehicle Length - *Column 3.2 (I)*

The average vehicle length for each queue period includes an assumed vehicle length (VL) and the space between vehicles. The VL is based on the percent of cars and trucks in the traffic stream and the average vehicle classification length. Figure 3.2 shows an average vehicle length by vehicle class based on FHWA research. NJDOT has developed an average vehicle length for the "Car" and "Truck" designations in this manual by utilizing the FHWA research and the percent of vehicle class from its own traffic counting stations. The resulting average vehicle lengths are 16 feet and 48 feet respectively. The space between vehicles is computed as one VL for every 10 mph of queue speed. Therefore, a traffic stream of 20% trucks and 80% cars travelling at 10 mph during queuing conditions would result in a 44.8 foot average vehicle length.
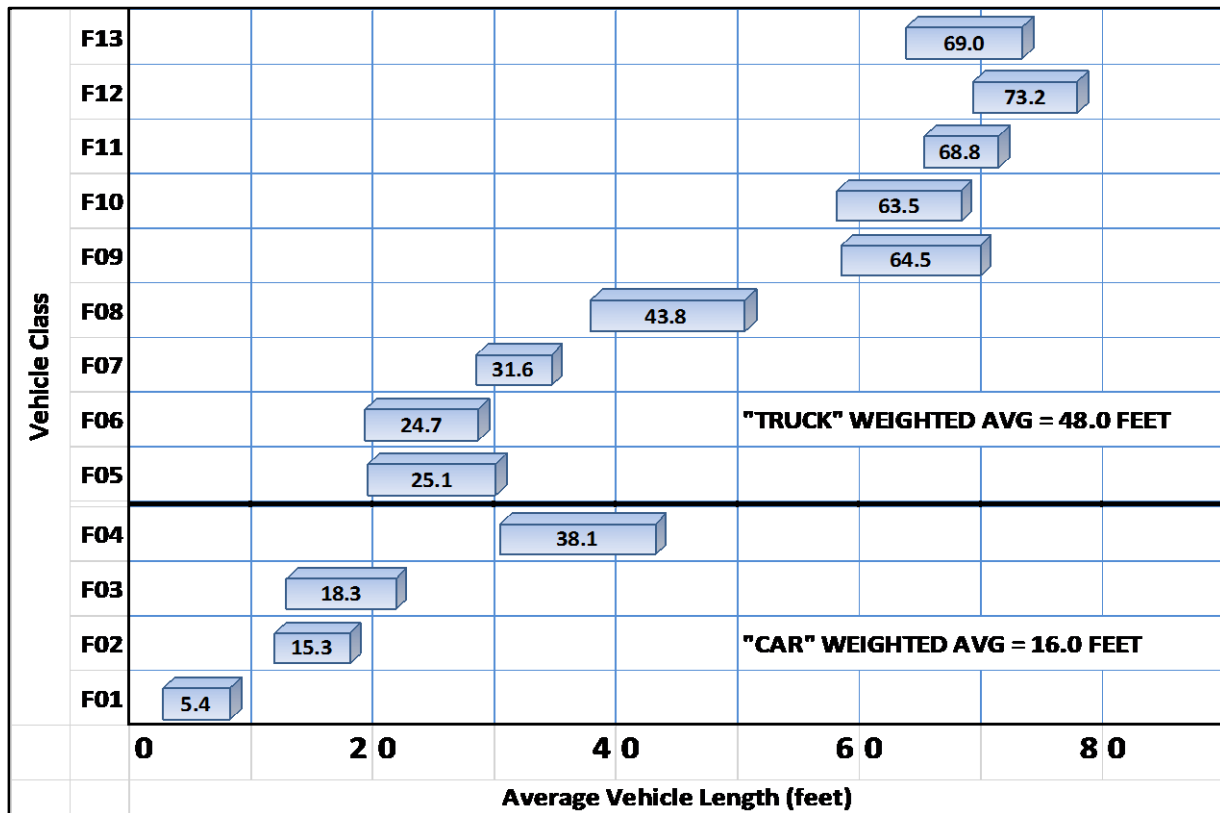

Figure 3.2

Axle Classification Versus Length Classification

(Source: FHWA)

Average Queue Length - *Column 3.2 (J)*

The average queue length for each queue period is computed by multiplying Column 3.2 (G) with Column 3.2 (I) and then dividing by Column 3.2 (H) and 5280 feet/mile.

Queue Travel Time At Normal Speed - *Column 3.2 (K)*

This is the time necessary to travel the average queue length at the normal speed and is computed by dividing Column 3.2 (J) by Column 3.2 (F).

Queue Travel Time At Queue Speed - *Column 3.2(L)*

This is the time necessary to travel the average queue length at the average queue speed and is computed by dividing Column 3.2 (J) by Column 3.2 (E).

Added Time To Travel Queue - *Column 3.2 (M)*

The added time to travel the queue for each queue period is computed by subtracting Column 3.2 (K) from Column 3.2 (L).

Vehicles That Travel Queue Per Queue Period- *Column 3.2 (N)*

The affected vehicles per queue period is the number of vehicles that travel the queue during that period and is only required if there is more than one queue period in 24 hours.

Added Time Per Queue Period - *Column 3.2 (O)*

The added time per queue period is computed by multiplying Column 3.2 (M) and Column 3.2 (N) and is only required if there is more than one queue period in 24 hours.

Added Time Weighted Average

The added time weighted average is computed by dividing the total of Column 3.2 (O) by the total of Column 3.2 (N).

3.3 Queue Idling VOC

The queue idling VOC is only computed during forced flow conditions. At this point, an overall queue delay per vehicle has been determined. The queue idling VOC is computed by multiplying the number of vehicles that travel the queue, the overall queue delay per vehicle, and the current idling cost rate associated with "stop and go" driving in the queue. The current idling cost rate is computed in Section 3.7.

3.4 Work Zone, Flagging And Circuity Delays

Before computing the actual road user cost, the delay time through the work zone, flagging zone and/or detour (circuity) must be known. Although the number of vehicles delayed has been determined, the amount of delay can only be computed after knowing the work/flagging zone and/or detour lengths and the times through them. The delay time through the work zone, flagging zone and detour are computed in the same manner. In each case, the delay is determined by subtracting the time it takes to travel the work zone, flagging zone and/or detour when they are present, from the time it takes to travel the same distance when they are not present. Worksheet 3.3 has been developed to aid the analyst in computing the Work Zone, Flagging and Circuity Delays and is discussed below.

Work Zone Length - *Column 3.3 (A)*

The work zone length is generally the length of lane restrictions including transitions.

Work Zone Speed - *Column 3.3 (B)*

The work zone speed is generally a 10 mph to15 mph reduction in the normal speed.

Normal Speed - *Column 3.3 (C)*

The normal speed of the facility is generally the posted speed limit of the section operating in an unrestricted flow condition.

Work Zone Travel Time At Normal Speed - *Column 3.3 (D)*

This is the time necessary to travel the work zone length at the normal speed and is computed by dividing Column 3.3 (A) by Column 3.3 (C).

Work Zone Travel Time At Work Zone Speed - *Column 3.3 (E)*

This is the time necessary to travel the work zone length at the work zone speed and is computed by dividing Column 3.3 (A) by Column 3.3 (B).

Added Time To Travel Work Zone - *Column 3.3 (F)*

The added time to travel the work zone is computed by subtracting Column 3.3 (D) from Column 3.3 (E).

Travel Length Without Detour - *Column 3.3 (G)*

This is the existing travel length prior to any lane restrictions or road closures.

Travel Length With Detour - *Column 3.3 (H)*

This is the length of the proposed detour or alternate route.

Added Travel Length - *Column 3.3 (I)*

The added travel length is computed by subtracting Column 3.3 (G) from Column 3.3 (H).

Worksheet 3.3

Work Zone, Flagging and Circuity Delays

Work Zone Delay

3.3(A)	3.3(B)	3.3(C)	3.3(D)	3.3(E)	3.3(F)
Work Zone Length (mile)	Work Zone Speed (mph)	Normal Speed (mph)	Work Zone Travel Time at Normal Speed (hr/veh)	Work Zone Travel Time at Work Zone Speed (hr/veh)	Added Time to Travel Work Zone (hr/veh)

Circuity (Detour) Delay

3.3(G)	3.3(H)	3.3(I)	3.3(J)	3.3(K)	3.3(L)
Travel Length without Detour (mile)	Travel Length with Detour (mile)	Added Travel Length (mile)	Travel Time without Detour (hr/veh)	Travel Time with Detour (hr/veh)	Added Time to Travel Detour (hr/veh)

Alternating Traffic (Flagging) Delay

3.3(M)	3.3(N)	3.3(O)	3.3(P)	3.3(Q)	3.3(R)	3.3(S)
Flagging Zone Length (mile)	Flagging Zone Speed (mph)	Normal Speed (mph)	Flagging Zone Cycle Time (minute)	Flagging Zone Wait Time (hr/veh)	Flagging Zone Travel Time (hr/veh)	Added Time to Travel Flagging Zone (hr/veh)

Travel Time Without Detour - *Column 3.3 (J)*

This is the time necessary to travel the existing facility prior to the proposed detour.

Travel Time With Detour - *Column 3.3 (K)*

This is the time necessary to travel the detour route.

Added Time To Travel Detour - *Column 3.3 (L)*

The added time to travel the detour is computed by subtracting Column 3.3 (J) from Column 3.3 (K).

Flagging Zone Length - *Column 3.3 (M)*

The flagging zone length is generally limited to a maximum length of ½ mile.

Flagging Zone Speed - *Column 3.3 (N)*

The flagging zone speed is generally limited to a travel speed of 25 mph.

Normal Speed - *Column 3.3 (O)*

The normal speed of the facility is generally the posted speed limit of the section operating in an unrestricted flow condition.

Flagging Zone Cycle Time - *Column 3.3 (P)*

The flagging zone cycle time is the time necessary to complete a flagging zone pass for each direction of travel.

Flagging Zone Wait Time - *Column 3.3 (Q)*

For computation purposes, the flagging zone wait time is considered to be 50% of the flagging zone cycle time.

Flagging Zone Travel Time - *Column 3.3 (R)*

The flagging zone travel time is the time necessary to travel the flagging zone length at the flagging zone speed subtracted by the time necessary to travel the flagging zone length at the normal speed.

Added Time To Travel Flagging Zone - *Column 3.3 (S)*

The added time to travel the flagging zone is computed by adding Column 3.3 (Q) and Column 3.3 (R).

3.5 Circuity (Detour) VOC

The circuity VOC is only computed when a formal detour route has been established. At this point, an overall added travel length per vehicle has been determined. The circuity VOC is computed by multiplying the number of vehicles that travel the detour, the overall added travel length per vehicle, and the current VOC cost rate associated with driving the added distance. The current VOC cost rate is computed in Section 3.7.

3.6 Escalation Factors & Cost Rates

The National Cooperative Highway Research Program (NCHRP) Report 133, *Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects*, provides 1970 travel time values of $3.00/hour for cars and $5.00/hour for trucks. The 1970 Idling Costs are provided in Table 5 of the same report and the average 1970 VOC values are derived from Figures A-13, A-14, and A-15 of the same report. The 1970 values are generally accepted to provide reliable costs although changes may have occurred regarding trip purpose and driving habits.

To escalate the values shown in NCHRP Report 133 to reflect current year dollars, the NJDOT uses the unadjusted Consumer Price Index for All Urban Consumers (CPI-U). The CPI-U is an accepted escalation tool and the values are available in Almanacs or at the Bureau of Labor Statistics website. Also, in the event that research studies update or supercede the NCHRP Report 133 values, the use of the CPI-U for escalation purposes remains applicable. Worksheet 3.4 has been developed to aid the analyst in computing the appropriate escalation factors and current cost rates and is discussed below. NJDOT updates the escalation factors and cost rates annually.

Cost Factors - *Column 3.4 (A)*

The Idling and VOC cost factors are based on the "Transportation Component" of the CPI-U. The Time Value cost factor is based on the "All Items Component" of the CPI-U.

1970 (CPI–U) - *Column 3.4 (B)*

The "Transportation Component" of the CPI-U was 37.5 in 1970. The "All Items Component" of the CPI-U was 38.8 in 1970.

Current (CPI-U) - *Column 3.4 (C)*

The current "Transportation Component" is obtained from the Bureau of Labor Statistics website Table 3 (http://www.bls.gov/news.release/cpi.t03.htm) and the current "All Items Component" is obtained from the Bureau of Labor Statistics website Table 1 (http://stats.bls.gov/news.release/cpi.t01.htm).

Escalation Factor - *Column 3.4 (D)*

The escalation factor for each cost factor is computed by dividing the Current CPI-U in Column 3.4 (C) by the 1970 CPI-U in Column 3.4 (B).

Vehicle Class - *Column 3.4 (E)*

Section 1.7 of this manual stated that 13 different vehicle classifications exist. "Car" and "Truck" classifications are only considered in the road user cost computations.

1970 Time Value Cost Rate - *Column 3.4 (F)*

NCHRP Report 133 reflects 1970 travel time value cost rates as $3.00/hour for cars and $5.00/hour for all trucks.

Worksheet 3.4

Escalation Factors and Cost Rates

Escalation Factors

3.4(A)	3.4(B)	3.4(C)	3.4(D)
Cost Factors	1970 (CPI-U)	Current (CPI-U)*	Escalation Factor
IDLING and VOC (transportation component)	37.5		
TIME VALUE (all components)	38.8		

* CPI-U = Unadjusted Consumer Price Index for all Urban Consumers, US City Average, _____

Cost Rates

3.4(E)	3.4(F)	3.4(G)	3.4(H)	3.4(I)	3.4(J)	3.4(K)
Vehicle Class	1970 Time Value Cost Rate ($/veh-hr)	1970 Idling Cost Rate ($/veh-hr)	1970 VOC Cost Rate ($/mile)	Current Time Value Cost Rate ($/veh-hr)	Current Idling Cost Rate ($/veh-hr)	Current VOC Cost Rate ($/mile)
CAR	3.00	0.1819	0.06			
TRUCK	5.00	0.2092	0.12			

1970 Idling Cost Rate - *Column 3.4 (G)*

NCHRP Report 133 reflects 1970 Idling cost rates as $0.1819/veh-hr for cars, $0.2017/veh-hr for single unit trucks, and $0.2166/veh-hr for combination trucks. The cost rate for single unit trucks and combination trucks has been averaged to reflect $0.2092/veh-hr for all trucks.

1970 VOC Cost Rate - *Column 3.4 (H)*

NCHRP Report 133 reflects average 1970 VOC cost rates as $0.06/mile for cars, $0.09/mile for single unit trucks, and $0.14/mile for combination trucks. The cost rate for single unit trucks and combination trucks has been averaged to reflect $0.12/mile for all trucks.

Current Time Value Cost Rate - *Column 3.4 (I)*

The current time value cost rate for each vehicle class is computed by multiplying the 1970 time value cost rate in Column 3.4 (F) by the Time Value escalation factor in Column 3.4 (D).

Current Idling Cost Rate - *Column 3.4 (J)*

The current idling cost rate for each vehicle class is computed by multiplying the 1970 idling cost rate in Column 3.4 (G) by the Idling escalation factor in Column 3.4 (D).

Current VOC Cost Rate - *Column 3.4 (K)*

The current VOC cost rate for each vehicle class is computed by multiplying the 1970 VOC cost rate in Column 3.4 (H) by the VOC escalation factor in Column 3.4 (D).

3.7 Road User Costs

At this point, all the necessary data to compute road user costs has been compiled. It is now necessary to distribute the traffic impacted by the various road user cost components to the appropriate vehicle classes. Worksheet 3.5 has been developed to aid the analyst in computing the road user costs and is discussed below.

Road User Cost Component - *Column 3.5 (A)*

There are ten potential work zone related road user cost components that can occur. The five components shown are generally computed fairly accurately and account for the majority of the road user costs.

Vehicle Class - *Column 3.5 (B)*

"Car" and "Truck" vehicle classifications are only considered for each road user cost component.

Percent Class - *Column 3.5 (C)*

The percent of each vehicle class in the traffic stream should be part of the data obtained from the traffic monitoring section. The percent class will for each appropriate road user cost component will automatically populate once entered into Worksheet 3.1.

Worksheet 3.5

Road User Costs

3.5(A)	3.5(B)	3.5(C)	3.5(D)	3.5(E)	3.5(F)	3.5(G)	3.5(H)
Road User Cost Component	Vehicle Class	Percent Class (%)	Total Vehicles (#)	Added Travel Length (mile/veh)	Added Time (hr/veh)	Cost Rate ($/veh-hr, $/mile)	Road User Cost ($)
Queue/Flagging Delay (Added Time)	CAR			■			
	TRUCK			■			
Queue/Flagging Idling VOC (Added Cost)	CAR			■			
	TRUCK			■			
Work/Flagging Zone Delay (Added Time)	CAR			■			
	TRUCK			■			
Circuity Delay (Added Time)	CAR			■			
	TRUCK			■			
Circuity VOC (Added Cost)	CAR				■		
	TRUCK				■		

Total Vehicles that Travel Queue:	_____	Daily / Hourly Road User Cost	
Total Vehicles that Travel Work Zone:	_____	Calculated Road User Cost (CRUC)	
Total Vehicles that Travel Detour:	_____	Daily RUC (1) or Hourly RUC (0)	
Percent Passenger Cars:	_____	Total Road User Cost (per Day)	
Percent Trucks:	_____	Total Road User Cost (per minute)	

Total Vehicles - *Column 3.5 (D)*

The number of total vehicles that travel the queue, work zone or detour over a desired period are obtained from Worksheet 3.1. The total vehicles are entered at the bottom left of the worksheet and will automatically populate for each appropriate road user cost component.

Added Travel Length - *Column 3.5 (E)*

The appropriate value for added travel length is obtained from Worksheet 3.3.

Added Time - *Column 3.5 (F)*

The appropriate values for added time are obtained from Worksheets 3.2 & 3.3.

Cost Rate - *Column 3.5 (G)*

The appropriate cost rates for time, idling, and VOC will automatically populate and are obtained from Worksheet 3.4.

Road User Cost - Column 3.5 *(H)*

The road user cost associated with each component is obtained by multiplying the values across each row for each vehicle class and rounding to the nearest dollar.

Daily / Hourly Road User Cost

The daily / hourly road user cost is computed by totaling the road user costs for each component.

Calculated Road User Cost (CRUC)

The calculated road user cost is computed by multiplying the daily road user cost by a 75% reduction factor. The reduction factor is used to accommodate for variations in traffic data, roadway capacities, and cost rates.

Daily RUC or Hourly RUC

The calculated road user cost can be computed as an hourly or daily cost.

Total Road User Cost

The total road user cost (per day) is generally based on a 24-hour analysis period. The total road user cost (per minute) is generally based on a 1-hour analysis period.

Section 4   Applications

The calculation of road user costs provides information enabling the designer to make better informed decisions in regards to staging, allowable work hours, project delivery method, and the actual design itself. Therefore, before a scheme is finalized, traffic volumes should be evaluated on a 7 day 24 hour basis. Staging should be evaluated for potential queues. Often, queues can be avoided by simply allowing lane closures only during non-peak hours. If the proposed design reveals substantial road user costs, an alternative scheme that reduces these costs may be a better choice. At other times, the queues are not avoidable, and thus an alternative project delivery method (i.e., A+B Bidding, Incentive/Disincentive) should be considered. In all cases, the significant risks and costs associated with night operations including safety, quality, and productivity should be considered. The many applications of road user costs in projects will be discussed in the following sections.

4.1 Liquidated Damages

A failure to complete a project or portion of a project on time results in damages in terms of delay on the use of the Project and delay to the traveling public using the facility. A failure to complete on time also results in additional costs to the Department for engineering, inspection, and administration of the Contract.

A "liquidated damage" is a liquidated sum or specified amount of damages in the event of a noncompliance with the specifications where it is difficult or impossible to accurately estimate the damages incurred. The liquidated damages a contractor may pay include the Construction Engineering Charge, the Road User Charge, and the Lane Occupancy Charge. The purpose of these charges is intended to constitute a reasonable liquidated sum designed to compensate for the damages incurred by the traveling public and the Department. The charges are not imposed for the purpose of ensuring timely compliance with the lane closure time limits or project completion requirements in the contract documents. The charges collected are in turn intended to be used in conjunction with future capital transportation projects so as to help relieve traffic congestion and to improve travel time and convenience for the traveling public. Each component of the liquidated damages is discussed in the following sections.

4.2 Construction Engineering Charge

Construction Engineering (CE) costs are the costs incurred by the Department for engineering, inspection, and administration of a project. As per Section 108 of the Standard Specifications, for each day of overrun in the Substantial Completion Date the contractor will pay 100% of the Construction Engineering Charge and for each day of overrun in the Completion Date the contractor will pay 50% of the Construction Engineering Charge.

4.3 Road User Charge

Road User Costs (RUC) are added vehicle operating costs (VOC) and delay costs to the traveling public resulting from the establishment of construction, maintenance, or rehabilitation work zones. The procedures in this manual provide a reasonable estimate of the added VOC and delay in terms of dollars per day. If the highway facility is exceeding capacity prior to construction, only the road user costs associated with the proposed construction activity are considered. As per Section 108 of the Standard Specifications, for each day of overrun in the Substantial Completion Date the contractor will pay 100% of the Road User Charge. The Road User Charge is in addition to the Construction Engineering Charge. There is no Road User Charge associated with overrun of the Completion Date.

The road user costs incurred by the traveling public during a Project can be extremely high. If this risk were to be transferred wholly to the contractor, it would lead to higher bid prices. The Department has determined that the maximum Road User Charge to be collected from the contractor for any one day will be $10,000. However, the maximum amount can be exceeded when using an A+B Bidding or Incentive/Disincentive project delivery method, which are discussed later in this section.

4.4 Lane Occupancy charge

The contract documents provide Allowable Lane Closure time limits for the contractor's use and occupancy of a lane or lanes to perform work. In the event that the contractor fails to reopen a lane or lanes of traffic on time, the contractor will pay a Lane Occupancy Charge (LOC) for the period of time a lane is unavailable to the traveling public beyond the allowable lane closure time limits. A Lane Occupancy Charge will not be collected when a lane or lanes are closed by extraordinary circumstances as defined in Section 108 of the Standard Specifications.

If the Allowable Lane Closure time limits permit the contractor to close lanes more than once a day, several occupancy charges are possible. For example, if a contractor can close a lane from 9 AM to 4 PM and again from 8 PM to 6 AM, an occupancy charge may be collected for the overrun of time beyond 6 AM and the overrun of time beyond 4 PM.

Each occupancy charge is calculated by multiplying the overrun of time, in minutes, by the chargeable rate per minute. The chargeable rate per minute is based on using the procedures in this manual to calculate the road user costs incurred by the traveling public during the next hour of each period the contractor fails to open a lane or lanes. For the Allowable Lane Closures shown above, the road user costs would be calculated for 6 AM to 7 AM and 4 PM to 5 PM and then divided by 60 to obtain the chargeable rate per minute (rounded up to the nearest ten dollars).

If the chargeable rate is $20/minute for 6 AM to 7 AM and $50/minute for 4 PM to 5 PM, a 30 minute overrun in each period would result in a $600 and $1,500 Lane

Occupancy Charge respectively. The Department has determined that the maximum Lane Occupancy Charge to be collected from the contractor for any one day will be $10,000.

4.5 Interim Completion Charge

Contract documents may require a portion of work, stage of construction, or critical path item to be completed by a specified interim date or within a specified number of days. In these cases, the associated charge is generally based on the road user cost or other supporting justification. As per Section 108 of the Standard Specifications, for each day of overrun in the Interim Completion, the contractor will pay 100% of the Interim Completion Charge. This charge can be different than those calculated for the entire project completion, depending on the type and location of work being specified for the interim date or time frame.

For example, the Department has determined a project has a road user charge of $4,000/day and a construction engineering charge of $7,000/day. The associated liquidated damage amounts for Interim Completion, Substantial Completion and Completion would be $4,000/day, $11,000/day and $3,500/day respectively.

4.6 Project Delivery Methods

A contract that establishes proper completion dates for a construction project is more important today than ever before. Most construction projects now involve the reconstruction of existing highways, which means that traffic is often maintained with lane and shoulder restrictions while the reconstruction takes place. A standard contract delivery method should include a completion date based on the shortest practical duration of construction to minimize road user impacts while allowing the contractor a reasonable amount of time to complete the work.

An agency may desire to accelerate construction of a project in order to reduce high road user costs, improve safety, or to avoid a winter/summer season. The Designer shall consider the Calculated Road User Cost (CRUC) as a useful tool to determine the most appropriate project delivery method to accelerate construction. Several project delivery enhancement methods are discussed in the sections that follow.

4.7 Increased Production Rate

Increased Production Rate project delivery method is the simplest method to speed up the construction. This method utilizes multiple crews, longer workdays, night work, and/or an around-the-clock work schedule to establish the contract completion date. Production rates can generally increase by 20% or more based on the type of work, the necessary equipment, and the available working space.

4.8 A+B Bidding

An A+B Bidding project delivery method is a cost plus time bidding procedure that selects the low bidder based on a monetary combination of the contract bid items (A) and the time (B) needed to complete the project or a critical portion of the project. The award is based on the lowest combined bid using the following formula.

Bid Amount for Evaluation = A + (B x RUV). Where:

(A) = Bidder's Estimate of Contract Bid Items ($)

(B) = Bidder's Estimate of Construction Time (Days)

(RUV) = Road User Value ($/Day). This value is determined by the Department and is often based on a percentage of the Calculated Road User Cost (CRUC).

For example, a project's CRUC is $22,000/day and RUV is $5,000/day. The bids are received as follows:

Bidder	Tortoise Company	Fox Company	Hare Company
(A) Value	$2,500,000	$2,600,000	$2,700,000
RUV	$5,000/day	$5,000/day	$5,000/day
(B) Value	140 Days	110 Days	95 Days
Time Value (B x RUV)	$700,000	$550,000	$475,000
(A) + (B) Combined Bid	**$3,200,000**	**$3,150,000**	**$3,175,000**

The Fox Company would be awarded the contract based on the lowest combined bid. The contract amount for payment purpose is the (A) value of $2,600,000. The project completion date and liquidated damages will be based on the (B) value of 110 days and (RUV) value of $5,000/day respectively.

4.9 Incentive and Disincentive

An Incentive/Disincentive (I/D) project delivery method is intended to motivate the contractor to complete the project, or a particular construction stage, on or ahead of an accelerated schedule. I/D projects compensate the contractor a daily amount for completing the work ahead of the I/D completion date or assess a daily amount for finishing later than the I/D completion date. The I/D value selected is based on a starting percentage (25%) of the CRUC and can be increased or decreased based on available monies and the scheduled duration of the accelerated work. The I/D value should be sufficient enough to cover the

contractor's additional costs to accelerate the work. The total accumulated I/D payment is limited to 5% of the estimated construction cost based on FHWA Technical Advisory T5080.10, dated February 8, 1989.

For example, a $20 million project's CRUC is $50,000/day. Based on 25% of the CRUC, the I/D Value would be $12,500/day. Therefore, the contractor would receive a $12,500/day incentive bonus for each day he finishes prior to the specified completion date up to a maximum incentive portion of $1,000,000 (5% of the project construction cost). Conversely, the contractor would be assessed a liquidated damage of $12,500/day for each day of overrun in the contract completion date up to a maximum disincentive portion of $1,000,000.

4.10 Lane Rental

Lane Rental is an innovative project delivery method which charges a contractor daily or hourly fees for occupying lanes and/or shoulders to perform work during hours other than the allowable times. The rental fee rate is based on the road user costs incurred by the traveling public and/or costs incurred by the Department. The Department will deduct these costs from the monies due the Contractor. A sample Lane Rental table is shown below.

Lane Rental Availability & Charges					
Roadway Direction	**Closure Description**	**Closure Time**			**Rental Rate**
		Day	**Start Time**	**End Time**	
Route 123 NB	Single Lane Closure Stages 1 and 3 only	Mon. - Fri.	4:00 PM	7:00 PM	$4,000 per hour
Route 123 SB	Single Lane Closure Stages 2 and 5 only	Mon. – Fri.	6:00 AM	9:00 AM	$2,000 per hour

4.11 Alternative Selection

Each project, and sometimes each stage of a project, may have unique road user costs and require potential mitigation strategies. Travel delays may become less acceptable as traffic volumes increase. As road user costs increase, effective traffic mitigation strategies may include reducing the construction duration or the travel delays during construction. The example below illustrates a useful method for comparing staging alternatives.

Alt.	Staging Description	# of Stages	Duration (days)	Project Cost in Millions			
				Construction	CE	RUC (25% Value)	Total
A	1 Lane WB & EB	3	500	2.6	1.5	0.1	**4.2**
B	1 Lane WB, EB detoured	2	360	2.1	1.1	0.4	**3.6**
C	WB & EB detoured	1	180	1.8	0.5	0.5	**2.8**

Based on the comparison, Alternative C is the preferred option.

4.12 Benefit / Cost Ratio

The Benefit/Cost Ratio (B/C) is a useful tool for the designer to measure the benefits of transportation improvements and increase the value of a project. It is also useful in comparing the value of two or more alternative projects. The B/C Ratios of approved, dormant, and rejected projects should be documented and maintained to aid the Department in prioritizing project needs. The user benefits are defined as the savings in vehicle operating costs and travel time that the facility users will experience.

For example, an intersection improvement project is being designed. Exclusive right turn lanes (RTL) are being considered for the northbound and westbound approaches. The calculated B/C ratio without exclusive right turn lanes is 2.5:1 and the overall intersection LOS is 'C'. The specific improvement information is shown below.

Northbound RTL	Exclusive Right Turn Lane	Westbound RTL
300	Projected Peak Hour Volume	150
E	Projected Peak Hour LOS (No Build)	C
C	Projected Peak Hour LOS (Build)	A
$3 Million	User Benefits (25% x CRUC)	$1 Million
$1 Million	ROW and Construction Costs	$0.2 Million
3:1	**Benefit/Cost Ratio**	**5:1**

The results show that the B/C for each improvement exceeds the 2.5:1 ratio established from the original design. Therefore, adding either of these elements to the project would increase the B/C ratio for the project.

4.13 Life Cycle Cost

Life Cycle Cost Analysis (LCCA) is an analysis technique that supports more informed and better investment decisions. It builds on some well-founded principles of economic analysis that have been used in evaluating highway and transit programs with a slightly stronger focus on the long term. It incorporates discounted long term agency, user, and other relevant costs over the life of a highway or bridge to identify the best value for investment expenditures (i.e. the lowest long term cost). It can be applied to a wide variety of investment related decision levels to evaluate the economic worth of various designs, projects, and alternatives to get the best return on the dollar.

Road user cost may be considered in the LCCA. For example, a State Highway Agency is conducting a Life Cycle Cost Analysis for a proposed six lane facility. The 30 year analysis period is utilizing the initial and future costs to the agency and the road users to help determine a preferred alternative. Compute the total Net Present Worth (NPW) for each alternative based on the future rehabilitation occurring at Year 20 with a discount rate of 4%. The present worth factor at Year 20 is 0.4564.

Project Data	Alternative A		Alternative B	
	Initial Construction	Future Rehab.	Initial Construction	Future Rehab.
Agency Cost ($ million)	15	10	20	15
Road User Cost ($ million)	15	10	5	5

Alternative A	Project Data	Alternative B
$15 Million	Agency Cost (Initial)	$20 Million
$15 Million	Road User Cost (Initial)	$5 Million
$4.56 Million	Agency Cost (Future)	$6.85 Million
$4.56 Million	Road User Cost (Future)	$2.28 Million
$39.12 Million	**Total Net Present Worth (NPW)**	**$34.13 Million**

The results show that Alternative A has the lowest initial agency cost. However, Alternative B is the preferred option (lowest NPW) when future and road user costs are considered. Therefore, Alternative B would be the preferred alternative.

Section 5   Work Zone Examples

The example problems presented are intended to aid the analyst in understanding and computing road user cost impacts from various work zone scenarios. These examples represent the most common types of work zones a highway user may encounter. The NJDOT developed workbook/template is an easy-to-follow analytic tool that allows for a quick and flexible estimation of work zone road user costs.

5.1 Example #1 - Full-Time (24 Hour) Lane Reduction - Freeway

One eastbound lane of a six-lane freeway is undergoing rehabilitation. The eastbound lanes carry 50,000 vehicles per day of which 90% are passenger cars and 10% are trucks. A 3.0 mile work zone will be in place 24 hours a day until construction is complete. The normal posted speed of the facility is 55 mph and the speed through the work zone is posted at 45 mph. The normal capacity of the roadway is estimated at 6,300 vehicles per hour while the work zone capacity is estimated at 3,000 vehicles per hour. Compute the daily road user cost.

Answer   The Daily Road User Cost is $45, 749 per day (2015 Dollars).

Worksheet 3.1: Analysis of the Work Zone

Work Zone:	24 Hour Lane Reduction					Normal Capacity:			6,300
Normal Speed (mph):	55		Percent Cars:	90		Work Zone Capacity:			3,000
Directional ADT:	50,000		Percent Truck:	10		Lanes Under Normal Operation:			3

3.1(A)	3.1(B)	3.1(C)	3.1(D)	3.1(E)	3.1(F)	3.1(G)	3.1(H)	3.1(I)	3.1(J)
Time Period (hour)	Hourly Traffic (%)	Vehicle Demand (vph)	Lanes Open (#)	Roadway Capacity (vph)	Queue Rate (vph)	Queued Vehicles (vph)	Work Zone Present? (Y or N)	Vehicles that Travel Work Zone (vph)	Vehicles that Travel Queue (vph)
12-1 AM	0.7	350	2	3,000	-2,650	0	Y	350	0
1-2	0.5	250	2	3,000	-2,750	0	Y	250	0
2-3	0.4	200	2	3,000	-2,800	0	Y	200	0
3-4	0.6	300	2	3,000	-2,700	0	Y	300	0
4-5	1.8	900	2	3,000	-2,100	0	Y	900	0
5-6	4.4	2,200	2	3,000	-800	0	Y	2,200	0
6-7	6.2	3,100	2	3,000	100	100	Y	3,000	3,000
7-8	7.2	3,600	2	3,000	600	700	Y	3,000	3,000
8-9	5.6	2,800	2	3,000	-200	500	Y	3,000	3,000
9-10	5.0	2,500	2	3,000	-500	0	Y	3,000	3,000
10-11	4.8	2,400	2	3,000	-600	0	Y	2,400	0
11-12 PM	5.1	2,550	2	3,000	-450	0	Y	2,550	0
12-1	5.3	2,650	2	3,000	-350	0	Y	2,650	0
1-2	5.5	2,750	2	3,000	-250	0	Y	2,750	0
2-3	5.6	2,800	2	3,000	-200	0	Y	2,800	0
3-4	6.5	3,250	2	3,000	250	250	Y	3,000	3,000
4-5	6.9	3,450	2	3,000	450	700	Y	3,000	3,000
5-6	6.4	3,200	2	3,000	200	900	Y	3,000	3,000
6-7	5.9	2,950	2	3,000	-50	850	Y	3,000	3,000
7-8	4.9	2,450	2	3,000	-550	300	Y	3,000	3,000
8-9	4.0	2,000	2	3,000	-1,000	0	Y	2,300	900
9-10	3.0	1,500	2	3,000	-1,500	0	Y	1,500	0
10-11	2.1	1,050	2	3,000	-1,950	0	Y	1,050	0
11-12	1.6	800	2	3,000	-2,200	0	Y	800	0
TOTALS	100.0	50,000						50,000	27,900

Project:	EXAMPLE #1	Date:	01/01/15
Description:	24 Hour Lane Reduction		

Worksheet 3.2: Queue Delay

	3.2(A)	3.2(B)	3.2(C)	3.2(D)	3.2(E)	3.2(F)	3.2(G)	3.2(H)
	Queue Period (hour)	Queue Volume (veh/hr)	Normal Capacity (veh/hr)	V/C Ratio	Average Queue Speed (mph)	Normal Speed (mph)	Maximum Queued Vehicles per Queue Period (#)	Queue Lanes (#)
1	6A-10A	3,000	6,300	0.48	9	55	700	3
2	3P-9P	3,000	6,300	0.48	9	55	900	3
3		3,000	6,300	0.48	9	55		3
4		3,000	6,300	0.48	9	55		3
5		3,000	6,300	0.48	9	55		3

	3.2(I)	3.2(J)	3.2(K)	3.2(L)	3.2(M)	3.2(N)	3.2(O)
	Average Vehicle Length (ft/veh)	Average Queue Length (mile)	Queue Travel Time at Normal Speed (hr/veh)	Queue Travel Time at Queue Speed (hr/veh)	Added Time to Travel Queue (hr/veh)	Vehicles That Travel Queue per Queue Period (#)	Added Time per Queue Period (hour)
1	36.5	0.81	0.015	0.090	0.075	12,000	900.000
2	36.5	1.04	0.019	0.115	0.096	15,900	1526.400
3	36.5						
4	36.5						
5	36.5						
					Totals	27,900	2426.400
					Added Time Weighted Average	0.087	hr/veh

Project: **EXAMPLE #1**   Date: **01/01/15**

Description: **24 Hour Lane Reduction**

Worksheet 3.3: Work Zone, Flagging and Circuity Delays

Work Zone Delay

3.3(A)	3.3(B)	3.3(C)	3.3(D)	3.3(E)	3.3(F)
Work Zone Length (mile)	Work Zone Speed (mph)	Normal Speed (mph)	Work Zone Travel Time at Normal Speed (hr/veh)	Work Zone Travel Time at Work Zone Speed (hr/veh)	Added Time to Travel Work Zone (hr/veh)
3.0	45	55	0.055	0.067	0.012

Circuity (Detour) Delay

3.3(G)	3.3(H)	3.3(I)	3.3(J)	3.3(K)	3.3(L)
Travel Length without Detour (mile)	Travel Length with Detour (mile)	Added Travel Length (mile)	Travel Time without Detour (hr/veh)	Travel Time with Detour (hr/veh)	Added Time to Travel Detour (hr/veh)
0.0	0.0	0.0	0.000	0.000	0.000

Alternating Traffic (Flagging) Delay

3.3(M)	3.3(N)	3.3(O)	3.3(P)	3.3(Q)	3.3(R)	3.3(S)
Flagging Zone Length (mile)	Flagging Zone Speed (mph)	Normal Speed (mph)	Flagging Zone Cycle Time (minute)	Flagging Zone Wait Time (hr/veh)	Flagging Zone Travel Time (hr/veh)	Added Time to Travel Flagging Zone (hr/veh)
0.0	0	55	0.0	0.000	0.000	0.000

Project: **EXAMPLE #1** **Date:** **01/01/15**

Description: **24 Hour Lane Reduction**

Worksheet 3.4: Escalation Factors and Cost Rates

Escalation Factors

3.4(A)	3.4(B)	3.4(C)	3.4(D)
Cost Factors	1970 (CPI-U)	Current (CPI-U)*	Escalation Factor
IDLING and VOC (transportation component)	37.5	**199.8**	5.33
TIME VALUE (all components)	38.8	**234.8**	6.05

* CPI-U = Unadjusted Consumer Price Index for all Urban Consumers, US City Average,   January 2015

Cost Rates

3.4(E)	3.4(F)	3.4(G)	3.4(H)	3.4(I)	3.4(J)	3.4(K)
Vehicle Class	1970 Time Value Cost Rate ($/veh-hr)	1970 Idling Cost Rate ($/veh-hr)	1970 VOC Cost Rate ($/mile)	Current Time Value Cost Rate ($/veh-hr)	Current Idling Cost Rate ($/veh-hr)	Current VOC Cost Rate ($/mile)
CAR	3.00	0.1819	0.06	18.15	0.9695	0.320
TRUCK	5.00	0.2092	0.12	30.25	1.1150	0.640

Project:	**EXAMPLE #1**	**Date:** **01/01/15**
Description:	**24 Hour Lane Reduction**	

Worksheet 3.5: Road User Costs

3.5(A)	3.5(B)	3.5(C)	3.5(D)	3.5(E)	3.5(F)	3.5(G)	3.5(H)
Road User Cost Component	Vehicle Class	Percent Class (%)	Total Vehicles (#)	Added Travel Length (mile/veh)	Added Time (hr/veh)	Cost Rate ($/veh-hr, $/mile)	Road User Cost ($)
Queue/Flagging Delay (Added Time)	CAR	90	27,900		0.087	18.15	39,650
	TRUCK	10	27,900		0.087	30.25	7,343
Queue/Flagging Idling VOC (Added Cost)	CAR	90	27,900		0.087	0.9695	2,118
	TRUCK	10	27,900		0.087	1.1150	271
Work/Flagging Zone Delay (Added Time)	CAR	90	50,000		0.012	18.15	9,801
	TRUCK	10	50,000		0.012	30.25	1,815
Circuity Delay (Added Time)	CAR	90	0		0.000	18.15	0
	TRUCK	10	0		0.000	30.25	0
Circuity VOC (Added Cost)	CAR	90	0	0.0		0.320	0
	TRUCK	10	0	0.0		0.640	0

Total Vehicles that Travel Queue:	27,900		Daily / Hourly Road User Cost	60,998
Total Vehicles that Travel Work Zone:	50,000		Calculated Road User Cost (CRUC)	45,749
Total Vehicles that Travel Detour:	0		Daily RUC (1) or Hourly RUC (0)	1
Percent Passenger Cars:	90%		Total Road User Cost (per Day)	45,749
Percent Trucks:	10%		Total Road User Cost (per minute)	

Project: **EXAMPLE #1** Date: **01/01/15**

Description: **24 Hour Lane Reduction**

5.2 Example #2 - Off-Peak Hour Lane Reduction - Freeway

Using the information from Example 1, Compute the following:

A)   The daily road user cost when work zone is only permitted during the allowable off-peak lane closure hours of 9 AM to 3 PM and 8 PM to 6 AM.

B)   The Lane Occupancy Charge (LOC) associated with a 1-hour overrun in the allowable hours in part A.

Answer Part A   The Daily Road User Cost is $4,391 per day (2015 Dollars). Note the large reduction in Road User Costs when the work zone is not permitted during the peak   hours.

Answer Part B   The Hourly Road User Cost for 6 AM to 7 AM is $1,027 (2015 Dollars).

The rate per minute is $17.11 (Round up to next $10)

The Lane Occupancy Charge rate is $20/minute

The Hourly Road User Cost for 3 PM to 4 PM is $1,759   (2015 Dollars).

The rate per minute is $29.31 (Round up to next $10)

The Lane Occupancy Charge rate is $30/minute

Worksheet 3.1: Analysis of the Work Zone

Work Zone:	Off-Peak Hour Lane Reduction							Normal Capacity:	6,300
Normal Speed (mph):	55			Percent Cars:	90		Work Zone Capacity:		3,000
Directional ADT:	50,000			Percent Truck:	10		Lanes Under Normal Operation:		3

3.1(A)	3.1(B)	3.1(C)	3.1(D)	3.1(E)	3.1(F)	3.1(G)	3.1(H)	3.1(I)	3.1(J)
Time Period (hour)	Hourly Traffic (%)	Vehicle Demand (vph)	Lanes Open (#)	Roadway Capacity (vph)	Queue Rate (vph)	Queued Vehicles (vph)	Work Zone Present? (Y or N)	Vehicles that Travel Work Zone (vph)	Vehicles that Travel Queue (vph)
12-1 AM	0.7	350	2	3,000	-2,650	0	Y	350	0
1-2	0.5	250	2	3,000	-2,750	0	Y	250	0
2-3	0.4	200	2	3,000	-2,800	0	Y	200	0
3-4	0.6	300	2	3,000	-2,700	0	Y	300	0
4-5	1.8	900	2	3,000	-2,100	0	Y	900	0
5-6	4.4	2,200	2	3,000	-800	0	Y	2,200	0
6-7	6.2	3,100	3	6,300	-3,200	0	N	0	0
7-8	7.2	3,600	3	6,300	-2,700	0	N	0	0
8-9	5.6	2,800	3	6,300	-3,500	0	N	0	0
9-10	5.0	2,500	2	3,000	-500	0	Y	2,500	0
10-11	4.8	2,400	2	3,000	-600	0	Y	2,400	0
11-12 PM	5.1	2,550	2	3,000	-450	0	Y	2,550	0
12-1	5.3	2,650	2	3,000	-350	0	Y	2,650	0
1-2	5.5	2,750	2	3,000	-250	0	Y	2,750	0
2-3	5.6	2,800	2	3,000	-200	0	Y	2,800	0
3-4	6.5	3,250	3	6,300	-3,050	0	N	0	0
4-5	6.9	3,450	3	6,300	-2,850	0	N	0	0
5-6	6.4	3,200	3	6,300	-3,100	0	N	0	0
6-7	5.9	2,950	3	6,300	-3,350	0	N	0	0
7-8	4.9	2,450	3	6,300	-3,850	0	N	0	0
8-9	4.0	2,000	2	3,000	-1,000	0	Y	2,000	0
9-10	3.0	1,500	2	3,000	-1,500	0	Y	1,500	0
10-11	2.1	1,050	2	3,000	-1,950	0	Y	1,050	0
11-12	1.6	800	2	3,000	-2,200	0	Y	800	0
TOTALS	100.0	50,000						25,200	0

| Project: | EXAMPLE #2 | Date: | 01/01/15 |
| Description: | Off-Peak Hour Lane Reduction, Part A | | |

Worksheet 3.1: Analysis of the Work Zone

Work Zone:	Off-Peak Hour Lane Reduction					Normal Capacity:			6,300
Normal Speed (mph):	55		Percent Cars:	90		Work Zone Capacity:			3,000
Directional ADT:	50,000		Percent Truck:	10		Lanes Under Normal Operation:			3

3.1(A)	3.1(B)	3.1(C)	3.1(D)	3.1(E)	3.1(F)	3.1(G)	3.1(H)	3.1(I)	3.1(J)
Time Period (hour)	Hourly Traffic (%)	Vehicle Demand (vph)	Lanes Open (#)	Roadway Capacity (vph)	Queue Rate (vph)	Queued Vehicles (vph)	Work Zone Present? (Y or N)	Vehicles that Travel Work Zone (vph)	Vehicles that Travel Queue (vph)
12-1 AM	0.7	350	2	3,000	-2,650	0	Y	350	0
1-2	0.5	250	2	3,000	-2,750	0	Y	250	0
2-3	0.4	200	2	3,000	-2,800	0	Y	200	0
3-4	0.6	300	2	3,000	-2,700	0	Y	300	0
4-5	1.8	900	2	3,000	-2,100	0	Y	900	0
5-6	4.4	2,200	2	3,000	-800	0	Y	2,200	0
6-7	6.2	3,100	2	3,000	100	100	Y	3,000	3,000
7-8	7.2	3,600	3	6,300	-2,700	0	N	0	0
8-9	5.6	2,800	3	6,300	-3,500	0	N	0	0
9-10	5.0	2,500	2	3,000	-500	0	Y	2,500	0
10-11	4.8	2,400	2	3,000	-600	0	Y	2,400	0
11-12 PM	5.1	2,550	2	3,000	-450	0	Y	2,550	0
12-1	5.3	2,650	2	3,000	-350	0	Y	2,650	0
1-2	5.5	2,750	2	3,000	-250	0	Y	2,750	0
2-3	5.6	2,800	2	3,000	-200	0	Y	2,800	0
3-4	6.5	3,250	3	6,300	-3,050	0	N	0	0
4-5	6.9	3,450	3	6,300	-2,850	0	N	0	0
5-6	6.4	3,200	3	6,300	-3,100	0	N	0	0
6-7	5.9	2,950	3	6,300	-3,350	0	N	0	0
7-8	4.9	2,450	3	6,300	-3,850	0	N	0	0
8-9	4.0	2,000	2	3,000	-1,000	0	Y	2,000	0
9-10	3.0	1,500	2	3,000	-1,500	0	Y	1,500	0
10-11	2.1	1,050	2	3,000	-1,950	0	Y	1,050	0
11-12	1.6	800	2	3,000	-2,200	0	Y	800	0
TOTALS	100.0	50,000						28,200	3,000

Project:	EXAMPLE #2	Date:	01/01/15
Description:	Off-Peak Hour Lane Reduction, Part B (AM LOC)		

Worksheet 3.1: Analysis of the Work Zone

Work Zone:	Off-Peak Hour Lane Reduction					Normal Capacity:			6,300
Normal Speed (mph):	55		Percent Cars:		90	Work Zone Capacity:			3,000
Directional ADT:	50,000		Percent Truck:		10	Lanes Under Normal Operation:			3

3.1(A)	3.1(B)	3.1(C)	3.1(D)	3.1(E)	3.1(F)	3.1(G)	3.1(H)	3.1(I)	3.1(J)
Time Period (hour)	Hourly Traffic (%)	Vehicle Demand (vph)	Lanes Open (#)	Roadway Capacity (vph)	Queue Rate (vph)	Queued Vehicles (vph)	Work Zone Present? (Y or N)	Vehicles that Travel Work Zone (vph)	Vehicles that Travel Queue (vph)
12-1 AM	0.7	350	2	3,000	-2,650	0	Y	350	0
1-2	0.5	250	2	3,000	-2,750	0	Y	250	0
2-3	0.4	200	2	3,000	-2,800	0	Y	200	0
3-4	0.6	300	2	3,000	-2,700	0	Y	300	0
4-5	1.8	900	2	3,000	-2,100	0	Y	900	0
5-6	4.4	2,200	2	3,000	-800	0	Y	2,200	0
6-7	6.2	3,100	3	6,300	-3,200	0	N	0	0
7-8	7.2	3,600	3	6,300	-2,700	0	N	0	0
8-9	5.6	2,800	3	6,300	-3,500	0	N	0	0
9-10	5.0	2,500	2	3,000	-500	0	Y	2,500	0
10-11	4.8	2,400	2	3,000	-600	0	Y	2,400	0
11-12 PM	5.1	2,550	2	3,000	-450	0	Y	2,550	0
12-1	5.3	2,650	2	3,000	-350	0	Y	2,650	0
1-2	5.5	2,750	2	3,000	-250	0	Y	2,750	0
2-3	5.6	2,800	2	3,000	-200	0	Y	2,800	0
3-4	6.5	3,250	2	3,000	250	250	Y	3,000	3,000
4-5	6.9	3,450	3	6,300	-2,850	0	N	0	0
5-6	6.4	3,200	3	6,300	-3,100	0	N	0	0
6-7	5.9	2,950	3	6,300	-3,350	0	N	0	0
7-8	4.9	2,450	3	6,300	-3,850	0	N	0	0
8-9	4.0	2,000	2	3,000	-1,000	0	Y	2,000	0
9-10	3.0	1,500	2	3,000	-1,500	0	Y	1,500	0
10-11	2.1	1,050	2	3,000	-1,950	0	Y	1,050	0
11-12	1.6	800	2	3,000	-2,200	0	Y	800	0
TOTALS	100.0	50,000						28,200	3,000

Project:	EXAMPLE #2	Date:	01/01/15
Description:	Off-Peak Hour Lane Reduction, Part B (PM LOC)		

Worksheet 3.2: Queue Delay

	3.2(A)	3.2(B)	3.2(C)	3.2(D)	3.2(E)	3.2(F)	3.2(G)	3.2(H)
	Queue Period (hour)	Queue Volume (veh/hr)	Normal Capacity (veh/hr)	V/C Ratio	Average Queue Speed (mph)	Normal Speed (mph)	Maximum Queued Vehicles per Queue Period (#)	Queue Lanes (#)
1		3,000	6,300	0.48	9	55		3
2		3,000	6,300	0.48	9	55		3
3		3,000	6,300	0.48	9	55		3
4		3,000	6,300	0.48	9	55		3
5		3,000	6,300	0.48	9	55		3

	3.2(I)	3.2(J)	3.2(K)	3.2(L)	3.2(M)	3.2(N)	3.2(O)
	Average Vehicle Length (ft/veh)	Average Queue Length (mile)	Queue Travel Time at Normal Speed (hr/veh)	Queue Travel Time at Queue Speed (hr/veh)	Added Time to Travel Queue (hr/veh)	Vehicles That Travel Queue per Queue Period (#)	Added Time per Queue Period (hour)
1	36.5						
2	36.5						
3	36.5						
4	36.5						
5	36.5						
				Totals			
				Added Time Weighted Average			hr/veh

Project: **EXAMPLE #2**   Date: **01/01/15**

Description: **Off-Peak Hour Lane Reduction, Part A**

Worksheet 3.2: Queue Delay

	3.2(A)	3.2(B)	3.2(C)	3.2(D)	3.2(E)	3.2(F)	3.2(G)	3.2(H)
	Queue Period (hour)	Queue Volume (veh/hr)	Normal Capacity (veh/hr)	V/C Ratio	Average Queue Speed (mph)	Normal Speed (mph)	Maximum Queued Vehicles per Queue Period (#)	Queue Lanes (#)
1	6A-7A	3,000	6,300	0.48	9	55	100	3
2		3,000	6,300	0.48	9	55		3
3		3,000	6,300	0.48	9	55		3
4		3,000	6,300	0.48	9	55		3
5		3,000	6,300	0.48	9	55		3

	3.2(I)	3.2(J)	3.2(K)	3.2(L)	3.2(M)	3.2(N)	3.2(O)
	Average Vehicle Length (ft/veh)	Average Queue Length (mile)	Queue Travel Time at Normal Speed (hr/veh)	Queue Travel Time at Queue Speed (hr/veh)	Added Time to Travel Queue (hr/veh)	Vehicles That Travel Queue per Queue Period (#)	Added Time per Queue Period (hour)
1	36.5	0.12	0.002	0.013	0.011	3,000	33.000
2	36.5						
3	36.5						
4	36.5						
5	36.5						
				Totals		3,000	33.000
			Added Time Weighted Average			0.011	hr/veh

Project: **EXAMPLE #2**   Date: **01/01/15**

Description: **Off-Peak Hour Lane Reduction, Part B (AM LOC)**

Worksheet 3.2: Queue Delay

	3.2(A)	3.2(B)	3.2(C)	3.2(D)	3.2(E)	3.2(F)	3.2(G)	3.2(H)
	Queue Period (hour)	Queue Volume (veh/hr)	Normal Capacity (veh/hr)	V/C Ratio	Average Queue Speed (mph)	Normal Speed (mph)	Maximum Queued Vehicles per Queue Period (#)	Queue Lanes (#)
1	3P-4P	3,000	6,300	0.48	9	55	250	3
2		3,000	6,300	0.48	9	55		3
3		3,000	6,300	0.48	9	55		3
4		3,000	6,300	0.48	9	55		3
5		3,000	6,300	0.48	9	55		3

	3.2(I)	3.2(J)	3.2(K)	3.2(L)	3.2(M)	3.2(N)	3.2(O)
	Average Vehicle Length (ft/veh)	Average Queue Length (mile)	Queue Travel Time at Normal Speed (hr/veh)	Queue Travel Time at Queue Speed (hr/veh)	Added Time to Travel Queue (hr/veh)	Vehicles That Travel Queue per Queue Period (#)	Added Time per Queue Period (hour)
1	36.5	0.29	0.005	0.032	0.027	3,000	81.000
2	36.5						
3	36.5						
4	36.5						
5	36.5						
				Totals		3,000	81.000
				Added Time Weighted Average		0.027	hr/veh

Project: **EXAMPLE #2**   Date: **01/01/15**

Description: **Off-Peak Hour Lane Reduction, Part B (PM LOC)**

Worksheet 3.3: Work Zone, Flagging and Circuity Delays

Work Zone Delay

3.3(A)	3.3(B)	3.3(C)	3.3(D)	3.3(E)	3.3(F)
Work Zone Length (mile)	Work Zone Speed (mph)	Normal Speed (mph)	Work Zone Travel Time at Normal Speed (hr/veh)	Work Zone Travel Time at Work Zone Speed (hr/veh)	Added Time to Travel Work Zone (hr/veh)
3.0	45	55	0.055	0.067	0.012

Circuity (Detour) Delay

3.3(G)	3.3(H)	3.3(I)	3.3(J)	3.3(K)	3.3(L)
Travel Length without Detour (mile)	Travel Length with Detour (mile)	Added Travel Length (mile)	Travel Time without Detour (hr/veh)	Travel Time with Detour (hr/veh)	Added Time to Travel Detour (hr/veh)
0.0	0.0	0.0	0.000	0.000	0.000

Alternating Traffic (Flagging) Delay

3.3(M)	3.3(N)	3.3(O)	3.3(P)	3.3(Q)	3.3(R)	3.3(S)
Flagging Zone Length (mile)	Flagging Zone Speed (mph)	Normal Speed (mph)	Flagging Zone Cycle Time (minute)	Flagging Zone Wait Time (hr/veh)	Flagging Zone Travel Time (hr/veh)	Added Time to Travel Flagging Zone (hr/veh)
0.0	0	55	0.0	0.000	0.000	0.000

Project: **EXAMPLE #2**   Date: **01/01/15**

Description: **Off-Peak Hour Lane Reduction, Part A**

Worksheet 3.4: Escalation Factors and Cost Rates

Escalation Factors

3.4(A)	3.4(B)	3.4(C)	3.4(D)
Cost Factors	1970 (CPI-U)	Current (CPI-U)*	Escalation Factor
IDLING and VOC (transportation component)	37.5	199.8	5.33
TIME VALUE (all components)	38.8	234.8	6.05

* CPI-U = Unadjusted Consumer Price Index for all Urban Consumers, US City Average,   **January 2015**

Cost Rates

3.4(E)	3.4(F)	3.4(G)	3.4(H)	3.4(I)	3.4(J)	3.4(K)
Vehicle Class	1970 Time Value Cost Rate ($/veh-hr)	1970 Idling Cost Rate ($/veh-hr)	1970 VOC Cost Rate ($/mile)	Current Time Value Cost Rate ($/veh-hr)	Current Idling Cost Rate ($/veh-hr)	Current VOC Cost Rate ($/mile)
CAR	3.00	0.1819	0.06	18.15	0.9695	0.320
TRUCK	5.00	0.2092	0.12	30.25	1.1150	0.640

Project:	**EXAMPLE #2**	**Date:** 01/01/15
Description:	**Off-Peak Hour Lane Reduction, Part A & Part B**	

Worksheet 3.5: Road User Costs

3.5(A)	3.5(B)	3.5(C)	3.5(D)	3.5(E)	3.5(F)	3.5(G)	3.5(H)
Road User Cost Component	Vehicle Class	Percent Class (%)	Total Vehicles (#)	Added Travel Length (mile/veh)	Added Time (hr/veh)	Cost Rate ($/veh-hr, $/mile)	Road User Cost ($)
Queue/Flagging Delay (Added Time)	CAR	90	0		0.000	18.15	0
	TRUCK	10	0		0.000	30.25	0
Queue/Flagging Idling VOC (Added Cost)	CAR	90	0		0.000	0.9695	0
	TRUCK	10	0		0.000	1.1150	0
Work /Flagging Zone Delay (Added Time)	CAR	90	25,200		0.012	18.15	4,940
	TRUCK	10	25,200		0.012	30.25	915
Circuity Delay (Added Time)	CAR	90	0		0.000	18.15	0
	TRUCK	10	0		0.000	30.25	0
Circuity VOC (Added Cost)	CAR	90	0	0.0		0.320	0
	TRUCK	10	0	0.0		0.640	0

Total Vehicles that Travel Queue:	0		Daily / Hourly Road User Cost	5,855
Total Vehicles that Travel Work Zone:	25,200		Calculated Road User Cost (CRUC)	4,391
Total Vehicles that Travel Detour:	0		Daily RUC (1) or Hourly RUC (0)	1
Percent Passenger Cars:	90%		Total Road User Cost (per Day)	4,391
Percent Trucks:	10%		Total Road User Cost (per minute)	

Project: **EXAMPLE #2**   Date: **01/01/15**

Description: **Off-Peak Hour Lane Reduction, Part A**

Worksheet 3.5: Road User Costs

3.5(A)	3.5(B)	3.5(C)	3.5(D)	3.5(E)	3.5(F)	3.5(G)	3.5(H)
Road User Cost Component	Vehicle Class	Percent Class (%)	Total Vehicles (#)	Added Travel Length (mile/veh)	Added Time (hr/veh)	Cost Rate ($/veh-hr, $/mile)	Road User Cost ($)
Queue/Flagging Delay (Added Time)	CAR	90	3,000		0.011	18.15	539
	TRUCK	10	3,000		0.011	30.25	100
Queue/Flagging Idling VOC (Added Cost)	CAR	90	3,000		0.011	0.9695	29
	TRUCK	10	3,000		0.011	1.1150	4
Work /Flagging Zone Delay (Added Time)	CAR	90	3,000		0.012	18.15	588
	TRUCK	10	3,000		0.012	30.25	109
Circuity Delay (Added Time)	CAR	90	0		0.000	18.15	0
	TRUCK	10	0		0.000	30.25	0
Circuity VOC (Added Cost)	CAR	90	0	0.0		0.320	0
	TRUCK	10	0	0.0		0.640	0

Total Vehicles that Travel Queue:	3,000		Daily / Hourly Road User Cost	1,369
Total Vehicles that Travel Work Zone:	3,000		Calculated Road User Cost (CRUC)	1,027
Total Vehicles that Travel Detour:	0		Daily RUC (1) or Hourly RUC (0)	0
Percent Passenger Cars:	90%		Total Road User Cost (per Day)	
Percent Trucks:	10%		Total Road User Cost (per minute)	17.11

Project: **EXAMPLE #2**   Date: **01/01/15**

Description: **Off-Peak Hour Lane Reduction, Part B (AM LOC)**

Worksheet 3.5: Road User Costs

3.5(A)	3.5(B)	3.5(C)	3.5(D)	3.5(E)	3.5(F)	3.5(G)	3.5(H)
Road User Cost Component	Vehicle Class	Percent Class (%)	Total Vehicles (#)	Added Travel Length (mile/veh)	Added Time (hr/veh)	Cost Rate ($/veh-hr, $/mile)	Road User Cost ($)
Queue/Flagging Delay (Added Time)	CAR	90	3,000		0.027	18.15	1,323
	TRUCK	10	3,000		0.027	30.25	245
Queue/Flagging Idling VOC (Added Cost)	CAR	90	3,000		0.027	0.9695	71
	TRUCK	10	3,000		0.027	1.1150	9
Work/Flagging Zone Delay (Added Time)	CAR	90	3,000		0.012	18.15	588
	TRUCK	10	3,000		0.012	30.25	109
Circuity Delay (Added Time)	CAR	90	0		0.000	18.15	0
	TRUCK	10	0		0.000	30.25	0
Circuity VOC (Added Cost)	CAR	90	0	0.0		0.320	0
	TRUCK	10	0	0.0		0.640	0

Total Vehicles that Travel Queue:	3,000	
Total Vehicles that Travel Work Zone:	3,000	
Total Vehicles that Travel Detour:	0	
Percent Passenger Cars:	90%	
Percent Trucks:	10%	

Daily / Hourly Road User Cost	2,345
Calculated Road User Cost (CRUC)	1,759
Daily RUC (1) or Hourly RUC (0)	0
Total Road User Cost (per Day)	
Total Road User Cost (per minute)	29.31

Project: **EXAMPLE #2**   Date: **01/01/15**

Description: **Off-Peak Hour Lane Reduction, Part B (PM LOC)**

5.3 Example Problem #3 - Road Closure - Detour in Effect

A one-mile section of a two-lane coastal facility will be closed during a $15 million bridge replacement project. The facility carries 25,000 vehicles per day of which 80% are passenger cars and 20% are trucks. A 9.0 mile detour will be in effect until construction is completed. The existing facility is posted at 55 mph and the average speed through the detour route is 35 mph. The normal capacity of the existing facility is 2,400 vehicles per hour and the detour route capacity is estimated at 1,900 vehicles per hour. Compute the daily road user cost incurred by the traffic traveling the detour

Answer   The Daily Road User Cost $149,780 per day (2015 Dollars). Note the large road user cost impact associated with long detours.

Worksheet 3.1: Analysis of the Work Zone

Work Zone:	9 Mile Detour					Normal Capacity:			2,400
Normal Speed (mph):	45		Percent Cars:	80		Work Zone Capacity:			1,900
Directional ADT:	25,000		Percent Truck:	20		Lanes Under Normal Operation:			2

3.1(A)	3.1(B)	3.1(C)	3.1(D)	3.1(E)	3.1(F)	3.1(G)	3.1(H)	3.1(I)	3.1(J)
Time Period (hour)	Hourly Traffic (%)	Vehicle Demand (vph)	Lanes Open (#)	Roadway Capacity (vph)	Queue Rate (vph)	Queued Vehicles (vph)	Work Zone Present? (Y or N)	Vehicles that Travel Work Zone (vph)	Vehicles that Travel Queue (vph)
12-1 AM	0.7	175	0	1,900	-1,725	0	Y	175	0
1-2	0.6	150	0	1,900	-1,750	0	Y	150	0
2-3	0.4	100	0	1,900	-1,800	0	Y	100	0
3-4	0.4	100	0	1,900	-1,800	0	Y	100	0
4-5	0.6	150	0	1,900	-1,750	0	Y	150	0
5-6	1.6	400	0	1,900	-1,500	0	Y	400	0
6-7	4.4	1,100	0	1,900	-800	0	Y	1,100	0
7-8	6.0	1,500	0	1,900	-400	0	Y	1,500	0
8-9	5.3	1,325	0	1,900	-575	0	Y	1,325	0
9-10	5.1	1,275	0	1,900	-625	0	Y	1,275	0
10-11	5.2	1,300	0	1,900	-600	0	Y	1,300	0
11-12 PM	5.7	1,425	0	1,900	-475	0	Y	1,425	0
12-1	6.3	1,575	0	1,900	-325	0	Y	1,575	0
1-2	6.5	1,625	0	1,900	-275	0	Y	1,625	0
2-3	6.4	1,600	0	1,900	-300	0	Y	1,600	0
3-4	6.2	1,550	0	1,900	-350	0	Y	1,550	0
4-5	6.2	1,550	0	1,900	-350	0	Y	1,550	0
5-6	6.3	1,575	0	1,900	-325	0	Y	1,575	0
6-7	6.5	1,625	0	1,900	-275	0	Y	1,625	0
7-8	6.0	1,500	0	1,900	-400	0	Y	1,500	0
8-9	4.6	1,150	0	1,900	-750	0	Y	1,150	0
9-10	3.8	950	0	1,900	-950	0	Y	950	0
10-11	2.9	725	0	1,900	-1,175	0	Y	725	0
11-12	2.3	575	0	1,900	-1,325	0	Y	575	0
TOTALS	100.0	25,000						25,000	0

Project:	EXAMPLE #3	Date:	01/01/15
Description:	9 Mile Detour		

Worksheet 3.2: Queue Delay

	3.2(A)	3.2(B)	3.2(C)	3.2(D)	3.2(E)	3.2(F)	3.2(G)	3.2(H)
	Queue Period (hour)	Queue Volume (veh/hr)	Normal Capacity (veh/hr)	V/C Ratio	Average Queue Speed (mph)	Normal Speed (mph)	Maximum Queued Vehicles per Queue Period (#)	Queue Lanes (#)
1		1,900	2,400	0.79	18	45		2
2		1,900	2,400	0.79	18	45		2
3		1,900	2,400	0.79	18	45		2
4		1,900	2,400	0.79	18	45		2
5		1,900	2,400	0.79	18	45		2

	3.2(I)	3.2(J)	3.2(K)	3.2(L)	3.2(M)	3.2(N)	3.2(O)
	Average Vehicle Length (ft/veh)	Average Queue Length (mile)	Queue Travel Time at Normal Speed (hr/veh)	Queue Travel Time at Queue Speed (hr/veh)	Added Time to Travel Queue (hr/veh)	Vehicles That Travel Queue per Queue Period (#)	Added Time per Queue Period (hour)
1	62.7						
2	62.7						
3	62.7						
4	62.7						
5	62.7						
				Totals			
				Added Time Weighted Average			hr/veh

Project: **EXAMPLE #3**   Date: **01/01/15**

Description: **9 Mile Detour**

Worksheet 3.3: Work Zone, Flagging and Circuity Delays

Work Zone Delay

3.3(A)	3.3(B)	3.3(C)	3.3(D)	3.3(E)	3.3(F)
Work Zone Length (mile)	Work Zone Speed (mph)	Normal Speed (mph)	Work Zone Travel Time at Normal Speed (hr/veh)	Work Zone Travel Time at Work Zone Speed (hr/veh)	Added Time to Travel Work Zone (hr/veh)
0.0	0	45	0.000	0.000	0.000

Circuity (Detour) Delay

3.3(G)	3.3(H)	3.3(I)	3.3(J)	3.3(K)	3.3(L)
Travel Length without Detour (mile)	Travel Length with Detour (mile)	Added Travel Length (mile)	Travel Time without Detour (hr/veh)	Travel Time with Detour (hr/veh)	Added Time to Travel Detour (hr/veh)
1.0	9.0	8.0	0.018	0.257	0.239

Alternating Traffic (Flagging) Delay

3.3(M)	3.3(N)	3.3(O)	3.3(P)	3.3(Q)	3.3(R)	3.3(S)
Flagging Zone Length (mile)	Flagging Zone Speed (mph)	Normal Speed (mph)	Flagging Zone Cycle Time (minute)	Flagging Zone Wait Time (hr/veh)	Flagging Zone Travel Time (hr/veh)	Added Time to Travel Flagging Zone (hr/veh)
0.0	0	45	0.0	0.000	0.000	0.000

Project: **EXAMPLE #3**   Date: **01/01/15**

Description: **9 Mile Detour**

Worksheet 3.4: Escalation Factors and Cost Rates

Escalation Factors

3.4(A)	3.4(B)	3.4(C)	3.4(D)
Cost Factors	1970 (CPI-U)	Current (CPI-U)*	Escalation Factor
IDLING and VOC (transportation component)	37.5	**199.8**	5.33
TIME VALUE (all components)	38.8	**234.8**	6.05

* **CPI-U = Unadjusted Consumer Price Index for all Urban Consumers, US City Average, January 2015**

Cost Rates

3.4(E)	3.4(F)	3.4(G)	3.4(H)	3.4(I)	3.4(J)	3.4(K)
Vehicle Class	1970 Time Value Cost Rate ($/veh-hr)	1970 Idling Cost Rate ($/veh-hr)	1970 VOC Cost Rate ($/mile)	Current Time Value Cost Rate ($/veh-hr)	Current Idling Cost Rate ($/veh-hr)	Current VOC Cost Rate ($/mile)
CAR	3.00	0.1819	0.06	18.15	0.9695	0.320
TRUCK	5.00	0.2092	0.12	30.25	1.1150	0.640

Project:	**EXAMPLE #3**	**Date:**	**01/01/15**
Description:	**9 Mile Detour**		

Worksheet 3.5: Road User Costs

3.5(A)	3.5(B)	3.5(C)	3.5(D)	3.5(E)	3.5(F)	3.5(G)	3.5(H)
Road User Cost Component	Vehicle Class	Percent Class (%)	Total Vehicles (#)	Added Travel Length (mile/veh)	Added Time (hr/veh)	Cost Rate ($/veh-hr, $/mile)	Road User Cost ($)
Queue/Flagging Delay (Added Time)	CAR	80	0		0.000	18.15	0
	TRUCK	20	0		0.000	30.25	0
Queue/Flagging Idling VOC (Added Cost)	CAR	80	0		0.000	0.9695	0
	TRUCK	20	0		0.000	1.1150	0
Work/Flagging Zone Delay (Added Time)	CAR	80	0		0.000	18.15	0
	TRUCK	20	0		0.000	30.25	0
Circuity Delay (Added Time)	CAR	80	25,000		0.239	18.15	86,757
	TRUCK	20	25,000		0.239	30.25	36,149
Circuity VOC (Added Cost)	CAR	80	25,000	8.0		0.320	51,200
	TRUCK	20	25,000	8.0		0.640	25,600

Total Vehicles that Travel Queue:	0	
Total Vehicles that Travel Work Zone:	0	
Total Vehicles that Travel Detour:	25,000	
Percent Passenger Cars:	80%	
Percent Trucks:	20%	

Daily / Hourly Road User Cost	199,706
Calculated Road User Cost (CRUC)	149,780
Daily RUC (1) or Hourly RUC (0)	1
Total Road User Cost (per Day)	149,780
Total Road User Cost (per minute)	

Project: **EXAMPLE #3** Date: **01/01/15**

Description: **9 Mile Detour**

5.4 Example Problem #4 - Alternating Traffic Pattern - Two-Lane Highway

A two-lane facility in a central business district is undergoing resurfacing. The facility carries 10,000 vehicles per day of which 90% are passenger cars and 10% are trucks. A 0.5 mile alternating traffic work zone with flagmen will be in place around the clock until the resurfacing is completed. The facility is posted at 45 mph and the speed through the flagging zone is limited to 25 mph. Traffic Engineering estimates the flagging operation cycle time to be 6 minutes. The normal capacity of the two-lane facility is estimated at 2,400 vehicles per hour while the flagging work zone capacity is estimated at 750 vehicles per hour. Compute the daily road user cost.

Answer   The Daily Road User Cost is $10,139 per day (2015 Dollars).

Worksheet 3.1: Analysis of the Work Zone

Work Zone:	Alternating Traffic Pattern					Normal Capacity:			2,400
Normal Speed (mph):	45		Percent Cars:	90		Work Zone Capacity:			750
Directional ADT:	10,000		Percent Truck:	10		Lanes Under Normal Operation:			2

3.1(A)	3.1(B)	3.1(C)	3.1(D)	3.1(E)	3.1(F)	3.1(G)	3.1(H)	3.1(I)	3.1(J)
Time Period (hour)	Hourly Traffic (%)	Vehicle Demand (vph)	Lanes Open (#)	Roadway Capacity (vph)	Queue Rate (vph)	Queued Vehicles (vph)	Work Zone Present? (Y or N)	Vehicles that Travel Work Zone (vph)	Vehicles that Travel Queue (vph)
12-1 AM	0.8	80	1	750	-670	0	Y	80	0
1-2	0.4	40	1	750	-710	0	Y	40	0
2-3	0.3	30	1	750	-720	0	Y	30	0
3-4	0.3	30	1	750	-720	0	Y	30	0
4-5	0.4	40	1	750	-710	0	Y	40	0
5-6	1.3	130	1	750	-620	0	Y	130	0
6-7	4.0	400	1	750	-350	0	Y	400	0
7-8	6.4	640	1	750	-110	0	Y	640	0
8-9	5.7	570	1	750	-180	0	Y	570	0
9-10	4.8	480	1	750	-270	0	Y	480	0
10-11	4.9	490	1	750	-260	0	Y	490	0
11-12 PM	5.6	560	1	750	-190	0	Y	560	0
12-1	6.0	600	1	750	-150	0	Y	600	0
1-2	5.9	590	1	750	-160	0	Y	590	0
2-3	6.3	630	1	750	-120	0	Y	630	0
3-4	7.6	760	1	750	10	10	Y	750	750
4-5	8.3	830	1	750	80	90	Y	750	750
5-6	8.0	800	1	750	50	140	Y	750	750
6-7	6.2	620	1	750	-130	10	Y	750	750
7-8	5.1	510	1	750	-240	0	Y	520	31
8-9	4.3	430	1	750	-320	0	Y	430	0
9-10	3.4	340	1	750	-410	0	Y	340	0
10-11	2.4	240	1	750	-510	0	Y	240	0
11-12	1.6	160	1	750	-590	0	Y	160	0
TOTALS	100.0	10,000						10,000	3,031

Project:	EXAMPLE #4	Date:	01/01/15
Description:	Alternating Traffic Pattern		

Worksheet 3.2: Queue Delay

	3.2(A)	3.2(B)	3.2(C)	3.2(D)	3.2(E)	3.2(F)	3.2(G)	3.2(H)
	Queue Period (hour)	Queue Volume (veh/hr)	Normal Capacity (veh/hr)	V/C Ratio	Average Queue Speed (mph)	Normal Speed (mph)	Maximum Queued Vehicles per Queue Period (#)	Queue Lanes (#)
1	3P-8P	750	2,400	0.31	5	45	140	2
2		750	2,400	0.31	5	45		2
3		750	2,400	0.31	5	45		2
4		750	2,400	0.31	5	45		2
5		750	2,400	0.31	5	45		2

	3.2(I)	3.2(J)	3.2(K)	3.2(L)	3.2(M)	3.2(N)	3.2(O)
	Average Vehicle Length (ft/veh)	Average Queue Length (mile)	Queue Travel Time at Normal Speed (hr/veh)	Queue Travel Time at Queue Speed (hr/veh)	Added Time to Travel Queue (hr/veh)	Vehicles That Travel Queue per Queue Period (#)	Added Time per Queue Period (hour)
1	28.8	0.19	0.004	0.038	0.034	3,031	103.054
2	28.8						
3	28.8						
4	28.8						
5	28.8						
					Totals	3,031	103.054
					Added Time Weighted Average	0.034	hr/veh

Project: **EXAMPLE #4**   Date: **01/01/15**

Description: **Alternating Traffic Pattern**

Worksheet 3.3: Work Zone, Flagging and Circuity Delays

Work Zone Delay

3.3(A)	3.3(B)	3.3(C)	3.3(D)	3.3(E)	3.3(F)
Work Zone Length (mile)	Work Zone Speed (mph)	Normal Speed (mph)	Work Zone Travel Time at Normal Speed (hr/veh)	Work Zone Travel Time at Work Zone Speed (hr/veh)	Added Time to Travel Work Zone (hr/veh)
0.0	**0**	45	0.000	0.000	0.000

Circuity (Detour) Delay

3.3(G)	3.3(H)	3.3(I)	3.3(J)	3.3(K)	3.3(L)
Travel Length without Detour (mile)	Travel Length with Detour (mile)	Added Travel Length (mile)	Travel Time without Detour (hr/veh)	Travel Time with Detour (hr/veh)	Added Time to Travel Detour (hr/veh)
0.0	**0.0**	0.0	**0.000**	**0.000**	0.000

Alternating Traffic (Flagging) Delay

3.3(M)	3.3(N)	3.3(O)	3.3(P)	3.3(Q)	3.3(R)	3.3(S)
Flagging Zone Length (mile)	Flagging Zone Speed (mph)	Normal Speed (mph)	Flagging Zone Cycle Time (minute)	Flagging Zone Wait Time (hr/veh)	Flagging Zone Travel Time (hr/veh)	Added Time to Travel Flagging Zone (hr/veh)
0.5	**25**	45	**6.0**	0.050	0.009	0.059

Project: **EXAMPLE #4**   Date: **01/01/15**

Description: **Alternating Traffic Pattern**

Worksheet 3.4: Escalation Factors and Cost Rates

Escalation Factors

3.4(A)	3.4(B)	3.4(C)	3.4(D)
Cost Factors	1970 (CPI-U)	Current (CPI-U)*	Escalation Factor
IDLING and VOC (transportation component)	37.5	199.8	5.33
TIME VALUE (all components)	38.8	234.8	6.05

* CPI-U = Unadjusted Consumer Price Index for all Urban Consumers, US City Average, January 2015

Cost Rates

3.4(E)	3.4(F)	3.4(G)	3.4(H)	3.4(I)	3.4(J)	3.4(K)
Vehicle Class	1970 Time Value Cost Rate ($/veh-hr)	1970 Idling Cost Rate ($/veh-hr)	1970 VOC Cost Rate ($/mile)	Current Time Value Cost Rate ($/veh-hr)	Current Idling Cost Rate ($/veh-hr)	Current VOC Cost Rate ($/mile)
CAR	3.00	0.1819	0.06	18.15	0.9695	0.320
TRUCK	5.00	0.2092	0.12	30.25	1.1150	0.640

Project:	**EXAMPLE #4**	**Date:**	**01/01/15**
Description:	**Alternating Traffic Pattern**		

Worksheet 3.5: Road User Costs

3.5(A)	3.5(B)	3.5(C)	3.5(D)	3.5(E)	3.5(F)	3.5(G)	3.5(H)
Road User Cost Component	Vehicle Class	Percent Class (%)	Total Vehicles (#)	Added Travel Length (mile/veh)	Added Time (hr/veh)	Cost Rate ($/veh-hr, $/mile)	Road User Cost ($)
Queue/Flagging Delay (Added Time)	CAR	90	3,031		0.034	18.15	1,683
	TRUCK	10	3,031		0.034	30.25	312
Queue/Flagging Idling VOC (Added Cost)	CAR	90	3,031		0.034	0.9695	90
	TRUCK	10	3,031		0.034	1.1150	11
Work/Flagging Zone Delay (Added Time)	CAR	90	10,000		0.059	18.15	9,638
	TRUCK	10	10,000		0.059	30.25	1,785
Circuity Delay (Added Time)	CAR	90	0		0.000	18.15	0
	TRUCK	10	0		0.000	30.25	0
Circuity VOC (Added Cost)	CAR	90	0	0.0		0.320	0
	TRUCK	10	0	0.0		0.640	0

Total Vehicles that Travel Queue:	3,031	Daily / Hourly Road User Cost	13,519
Total Vehicles that Travel Work Zone:	10,000	Calculated Road User Cost (CRUC)	10,139
Total Vehicles that Travel Detour:	0	Daily RUC (1) or Hourly RUC (0)	1
Percent Passenger Cars:	90%	Total Road User Cost (per Day)	10,139
Percent Trucks:	10%	Total Road User Cost (per minute)	

Project: **EXAMPLE #4**

Date: **01/01/15**

Description: **Alternating Traffic Pattern**

Section 6 Resource Documents

National Cooperative Highway Research Program (NCHRP) Report 133:

Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects (1972)

American Association of State Highway and Transportation Officials (AASHTO):

A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements (1977)

Transportation Research Board (TRB) & National Research Council (NRC) Special Report 209:

Highway Capacity Manual, Third Edition (1994)

Federal Highway Administration (FHWA), Pavement Divisions Interim Technical Bulletin:

Life Cycle Cost Analysis in Pavement Design (1998)

Federal Highway Administration (FHWA):

Work Zone Road User Costs – Concepts and Applications (2011)

Federal Highway Administration (FHWA), Highway Information Seminar:

Axle and Length Classification (2011)

U.S. Department of Labor, Bureau of Labor Statistics:

Consumer Price Index Table 1 & Table 3

New Jersey Department of Transportation:

Standard Specifications for Road and Bridge Construction (1996 & 2007)