Work Zone Road User Costs

Concepts and Applications

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Final Report

WORK ZONE ROAD USER COSTS

CONCEPTS AND APPLICATIONS

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16. Abstract
On-site construction activities can result in significant mobility and safety impacts to road users. The presence of work zone can also result in inconvenience to local business and community, noise and environmental impacts. Minimizing the adverse impacts of work zones has become a higher priority especially since the inception of the FHWA Rule on Work Zone Safety and Mobility (23 CFR 630 Subpart J). Work zone road user costs (WZ RUC) provide the economic basis for quantifying these adverse impacts which can then be used for effective decision-making to improve work zone mobility and safety. This report provides practitioners with information on WZ RUC analysis concepts and their applications using case studies drawn from real world projects.

WZ RUC primarily refers to monetized components of mobility and safety impacts; increasingly, non-monetary and qualitative components, such as environmental, business, and societal impacts, are being utilized. In this report, each of the monetary components is explored and the computations of these components are illustrated using examples. It presents step-by-step procedures to derive unit costs for monetary components. It lists the cost sources for each cost component as well as the ways to update those using economic indices. It also explores input requirements and various tools available for use in WZ RUC analysis.

This report presents the application of both monetary and qualitative components of WZ RUC in MOT alternative analysis using a decision analysis framework. Another key application of WZ RUC is in selecting appropriate project delivery/contracting strategies to minimize WZ RUCs and related impacts through early project completion. Approaches for determining an appropriate level of incentives and disincentives are also discussed. Three "real-world" case studies from the *Highways for LIFE* program are presented to demonstrate the applications of WZ RUCs in selecting the preferred Maintenance of Traffic (MOT) alternatives and project delivery/contracting strategies.

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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Vehicle miles traveled (VMT) on U.S. highways doubled in the last three decades, while the highway lane miles of all functional classes increased by only 5 percent during the same period.[1] The cost of congestion, incurred by the road users for travel delay and extra vehicle fuel, has risen from $24 billion in 1982 to $115 billion in 2009, while the yearly peak delay has risen from 14 hours to 34 hours during the same period. To keep up with the pace of growing congestion, the investment in our highways through Federal, State, or local funding has tripled over the same period.

As a result, the number of significant construction activities has been increasing over the years, and the majority of active work zones are located on existing roads already carrying traffic.[2] These activities typically are undertaken in heavily urbanized areas and can cause traffic disruptions, safety implications to motorists and construction workers, and negative impacts on local businesses and the community. These problems are aggravated by delays in project delivery, a common problem with highway construction.

To address these issues effectively, the Federal Highway Administration (FHWA) has established several programs and measures to enhance work zone mobility and safety and to shorten project construction time, such as:

- Work Zone Mobility and Safety Rule — Effective since October 2007, this rule requires all State and local highway agencies to develop and implement policies and procedures for assessing and managing work zone impacts on individual projects. The goal of the rule is to provide a decision making framework for considering the broader work zone safety and mobility impacts across project development stages, and to facilitate the implementation of additional strategies that help manage these impacts during project delivery. The provisions of the rule apply to all highway construction projects financed in whole or in part with Federal-aid highway funds.[3]
- Special Experimental Program (SEP) No. 14 — Established in 1988, the SEP-14 program serves as a functional platform to evaluate "project-specific" innovative contracting practices on Federal-aid projects that focus on shortening project delivery time and minimizing work zone road user impacts without affecting product quality. This program provides some administrative flexibility to State highway agencies from specific Federal legislative requirements typically required in Federal-aid projects. After a period of evaluation under this program, alternative contracting practices such

[1] FHWA, Our Nation's Highways 2010, Publication No. FHWA-PL-10-023, Office of Highway Policy Information, Federal Highway Administration Washington D.C., 2010. http://www.fhwa.dot.gov/policyinformation/pubs/hf/pl10023/onh2010.pdf

[2] Federal Highway Administration, Facts and Statistics, Work Zone Mobility and Safety Program, Office of Operations, Federal Highway Administration Washington D.C., 2008. http://www.ops.fhwa.dot.gov/wz/resources/facts_stats.htm

[3] Frequently Asked Questions for the Work Zone Safety and Mobility Rule. http://www.ops.fhwa.dot.gov/wz/resources/final_rule/rule_faqs.htm

as cost plus time bidding, lane rental, and design-build contracting were declared suitable for operational use.[4]

- Highways for LIFE (HfL) — Under FHWA HfL pilot program established by the U.S. Congress established in 2005, the FHWA offers technical assistance and incentives to highway agencies to use readily available but rarely used innovations in standard practice that focus on shortening project delivery, improving mobility and safety through work zones, and enhancing quality and user satisfaction.
- Every Day Counts (EDC) — The EDC Innovation Initiative was introduced in 2010 to identify and deploy innovation aimed at shortening project delivery, enhancing roadway safety, and protecting the environment. The core elements of this initiative include:

    - Accelerating Technology and Innovation Deployment — This toolkit includes effective, field-proven, market ready technologies such as Prefabricated Bridge, Safety Edge, Adaptive Signal Control for widespread deployment to improve highway mobility and safety.
    - Shortening Project Delivery — This toolkit presents various approaches for improving project delivery times by providing solutions to a number of frequently cited problem areas that impede on-time project delivery. The toolbox includes strategies for accelerating project delivery and eliminating time-consuming duplication of effort, and by encouraging the use of existing regulatory flexibilities.

In all these contexts, the goal of minimizing the negative work zone impacts gains prominence through effective transportation management plans (TMP), alternative program delivery and contracting strategies, and accelerated construction techniques focusing on quicker project delivery. It is equally imperative to quantify these negative impacts to help devise policy and mitigation measures, implement them, and further evaluate and monitor their performance. The concept of "work zone road user costs" (WZ RUC) provides the economic basis for quantifying the work zone impacts for use in work zone management.

The use of WZ RUC in transportation decision making is not a new phenomenon. Though WZ RUC is not a part of an agency's budgeted cost, it serves as one of the surrogate economic measures representing the public's interests in the agency's decision making process. The WZ RUC is applied in various stages a transportation facility's life cycle including planning, design, construction, operations and preservation. The WZ RUC often is applied in an agency's life cycle cost analysis (LCCA) and benefit-cost decisions relating to capital investment, system preservation and improvements, strategy selection, and contract administration. The WZ RUC has been traditionally applied in the LCCA of highway structures such as pavements and bridges, and the process is well established. However, the application of WZ RUC in other areas is still nascent.

Several surveys cited in the literature have reported that, despite the importance of WZ RUC in an agency's decision making, not all States compute WZ RUC.[5,6] Furthermore, among those

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[4] FWHA, Special Experimental Projects No. 14 - Alternative Contracting, Office of Program Administration, Federal Highway Administration, Washington, DC. http://www.fhwa.dot.gov/programadmin/contracts/sep_a.cfm

[5] Saito, M., M. R. Adams, T. G. Jin, *Development of a User Cost Estimation Procedure for Work Zones*, Report No. UT-05.11, Utah Department of Transportation, Salt Lake City, UT, 2005.

States computing WZ RUC, there is no apparent uniformity in their practices with regard to defining the cost components, deriving unit costs for travel delay and vehicle operating cost computations, estimating lane capacity values, and travel delay/queuing algorithms. For example, some agencies may consider the average vehicle occupancy in deriving the unit cost for travel delay, while others may not take vehicle occupancy into account. Owing to the differences in regional characteristics and agency needs, these differences are justifiable; however, the basis for inconsistency in their approaches remains largely unknown. These differences in approach speak to the need for an updated guidance on user cost estimation.

1.2 Objectives and Scope

The primary objective of this report is to present the concepts that transportation practitioners can use to:

- Perform work zone road user cost analysis.
- Apply WZ RUC analysis methods/tools in maintenance of traffic (MOT) alternative selection.
- Apply WZ RUC analysis methods/tools in contract administration to expedite project completion and minimize adverse work zone effects.

This document presents a detailed discussion of the key components of WZ RUC, input needs, and available tools. Step-by-step procedures to derive unit costs for monetary RUC components based on available cost sources and models are also provided. Finally, this document presents a process for applying RUC concepts in selecting an appropriate MOT and contracting strategy for managing work zone impacts and shortening project completion time. Because of the differences in agency decision making processes, it is expected that each agency will modify the recommended procedures to meet its specific needs.

1.3 Report Organization and Use

This report is organized into six chapters.

Chapter 1 of this report presents the introductory material. It provides a discussion on the importance of WZ RUC in enhancing work zone mobility and safety and shortening project construction time.

Chapter 2 presents procedures for computing various quantifiable components and their unit costs. It also presents a discussion of the input requirements for WZ RUC analysis and various tools available for use.

Chapter 3 presents the application of WZ RUC in identifying and evaluating potential traffic control strategies for MOT alternative analysis.

Chapter 4 presents a discussion of various alternative contracting strategies that focus on reducing WZ RUC and minimizing work zone impacts. It also presents an approach for selecting an appropriate schedule-focused contracting strategy based on project needs. It

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[6] Salem, O. and A. Genaidy, *Improved Models for User Costs Analysis*, Report No. FHWA/OH-2008/3, Ohio Department of Transportation, Columbus, OH, 2008.

also discusses incentive/disincentive amounts and identifying a balance between construction costs and the level of schedule acceleration required to minimize WZ RUC.

Chapter 5 presents three case studies illustrating the application of WZ RUC analysis and concepts in each application area: MOT alternative analysis, alternative contracting strategy selection, and benefit-cost analysis of conventional and accelerated construction techniques.

Chapter 6 presents the key components of a typical WZ RUC analysis report covering background information of the project, data collection, existing conditions, impact assessment, alternative analysis, and recommendations.

CHAPTER 2. WORK ZONE ROAD USER COSTS

2.1 DEFINITION OF WORK ZONE ROAD USER COST

A **work zone** is defined in the Highway Capacity Manual (HCM) as a segment of highway in which maintenance and construction operations impinge on the number of lanes available to traffic or affect the operational characteristics of traffic flowing through the segment.[7]

A **work zone** is defined in the Manual on Uniform Traffic Control Devices (MUTCD) as an area of a highway with construction, maintenance, or utility work activities. A work zone typically is marked by signs, channelizing devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign or high-intensity rotating, flashing, oscillating, or strobe lights on a vehicle to the END ROAD WORK sign or the last temporary traffic control device.[8]

Work zone road user cost is defined as the additional costs borne by motorists and the community at-large as a result of work zone activity.

Within the context of this document, WZ RUC primarily refers to the monetized components of work zone impacts, such as the user delay costs, vehicle operating costs (VOC), crash costs and emission costs. Increasingly, other off-site components such as noise, business and local community impacts are being utilized in WZ RUC applications. These off-site impacts are hard to monetize since the factors that influence their computation are often site-specific and no generalized method or tool is yet available to determine them. In this document, these off-site impacts are either considered as quantitative /non-monetary (e.g. noise) or qualitative (e.g. inconvenience to local community) factors. The components of WZ RUC are illustrated in Figure 1 and discussed in greater detail in the sections that follow. The practitioners can use their discretion in selecting appropriate work zone impacts to be used in WZ RUC analysis.

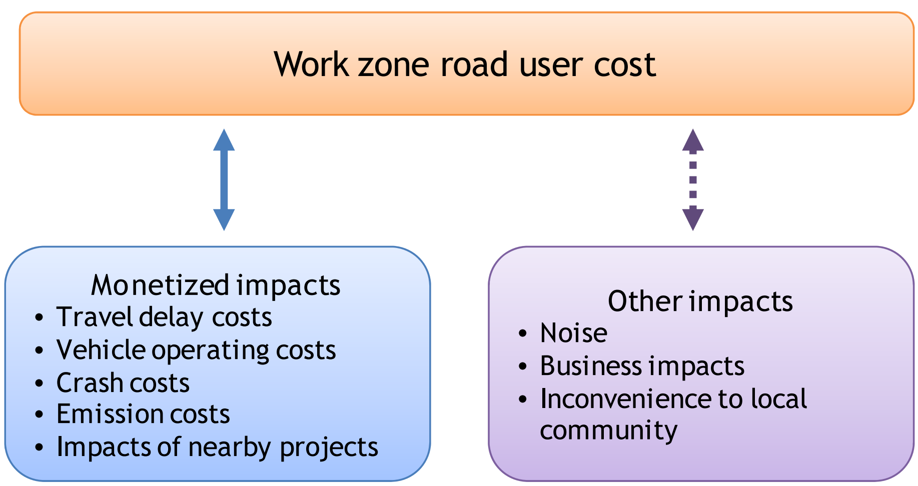


Figure 1. Road user cost components.

[7] Highway Capacity Manual 2000, Transportation Research Board, Washington, DC, 2000. http://www.trb.org/Main/Blurbs/Highway_Capacity_Manual_2000_152169.aspx
[8] Manual on Uniform Traffic Control Devices for Streets and Highways, 2009 Edition, Federal Highway Administration, Washington, DC, 2009. http://mutcd.fhwa.dot.gov/pdfs/2009/mutcd2009edition.pdf

The WZ RUC computation process is based on the assessment of mobility, safety, environmental, business, and local community impacts resulting from the work zone activities of a roadway project. The WZ RUC computation along with the work zone impacts assessment evolves through various stages of the project development process from planning through construction. The precision of WZ RUC estimate and, the type and level of detail of impacts assessment vary depending upon the project development stage.[9] For example, in the project scoping stage, a conceptual estimation or qualitative information of WZ RUC may be used in identifying the significance of potential impacts; and during preliminary engineering a rough estimation of WZ RUC will be determined for use in MOT strategy selection; whereas, in the 90 percent design stage, a precise estimate will be determined for use in setting the contract provisions such as lane rental fee and incentives/disincentives.

The WZ RUC computation process involves the following key steps:

1. Data gathering for work zone impact assessment.
2. Estimation of work zone impacts.
3. Computation of unit costs for each impact type.
4. Estimation of WZ RUC components.

This chapter presents a detailed discussion of the key concepts of quantifiable monetary impacts. The process involved in deriving the monetary components and their unit costs is illustrated using step-by-step procedures. A less-rigorous discussion of non-monetary and qualitative factors is also presented. Later sections of this chapter focus on data requirements for mobility analysis and computation tools available for WZ RUC estimation.

2.2 TRAVEL DELAY COSTS

Travel delay costs are calculated by multiplying the estimated delays to personal travel, truck travel, and freight inventory caused by the work zone by the unit cost ($/hr) of travel time. Figure 2 presents the computation of travel delay costs schematically.

2.2.1 Delay Time

Delay time is the additional travel time necessary to traverse the work zone or to detour around it. Delay time is an aggregation of the following components:

- Speed change delay is the additional time necessary to decelerate from the upstream approach speed to the work zone speed and then to accelerate back to the initial approach speed after traversing the work zone under unrestricted (free) traffic flow.
- Reduced speed delay is the additional time necessary to traverse the work zone at the lower posted speed; it depends on the upstream and work zone speed differential and length of the work zone under both unrestricted and restricted (forced) traffic flow.
- Detour delay is the additional time necessary to travel the excess distance by selecting a detour route.

[9] Sankar, P., K. Jeannotte, J. P. Arch, M. Romero, and J. E. Bryden, *Work Zone Impacts Assessment – An Approach to Assess and Manage Work Zone Safety and Mobility Impacts of Road Projects*, Report No. FHWA-HOP-05-068, Office of Operations, Federal Highway Administration, Washington, DC, 2006.

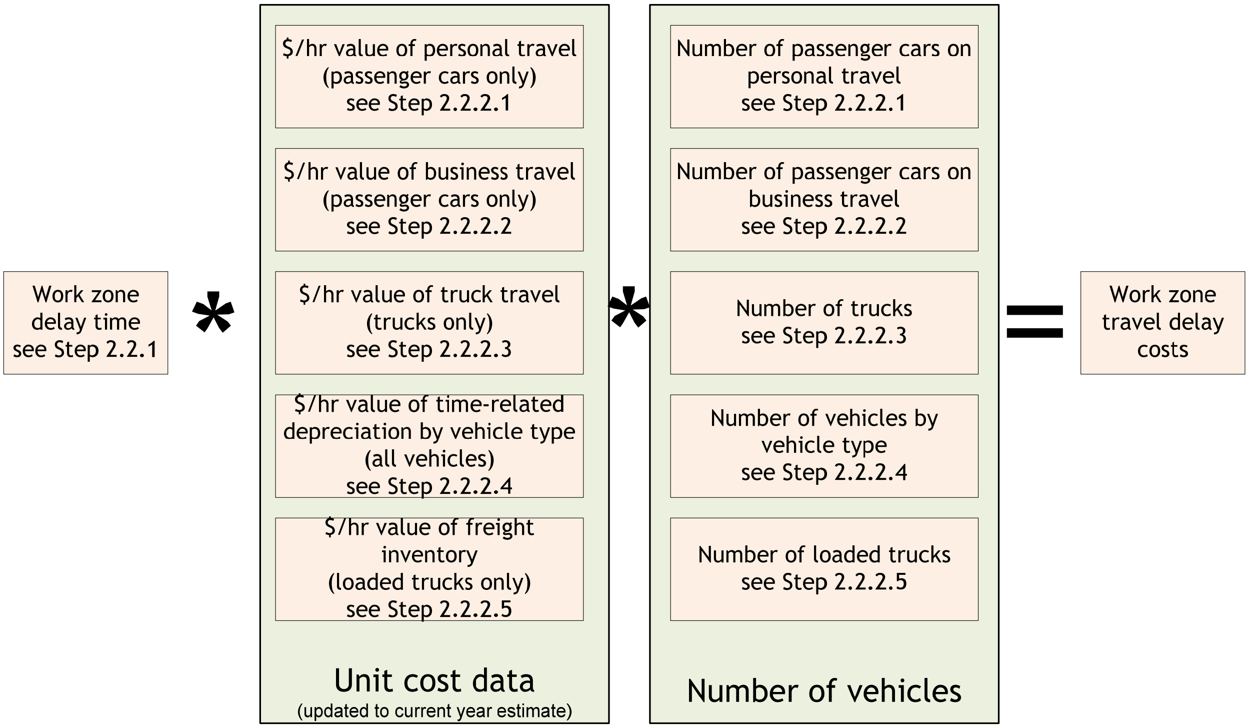


Figure 2. Schematic illustrating the components of travel delay costs.

- Stopping delay is the additional time necessary to come to a complete stop from the upstream approach speed (instead of just slowing to the work zone speed) and the additional time to accelerate back to the approach speed after traversing the work zone under restricted traffic flow.
- Queue delay is the additional time necessary to creep through the queue under restricted traffic flow.

NOTE

Some highway agencies do not consider speed change delay and stopping delay in delay time computations, as these components may not contribute significantly to the overall delay time. To those interested in including these components, the FHWA RealCost[10] software provides a methodology for computing them.

Work zone traffic delay time estimates can be obtained using mobility impact analysis methods such as demand-capacity analysis and simulation methods. The inputs required for mobility analysis are discussed in section 2.8. A discussion of various tools readily available for delay time estimation and WZ RUC computation is presented in section 2.9. Note that the estimated mobility parameters may change based on the selected tool, as the methodologies utilized in these tools may be different. Delay time during construction also can be estimated using the floating-car technique, where a test car is driven by an observer along the work zone section a number of times to measure the travel time.

[10] RealCost, *Life-Cycle Cost Analysis Software*, Version 2.5, Office of Asset Management, Federal Highway Administration, Washington, DC, 2009. http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.cfm

NOTE

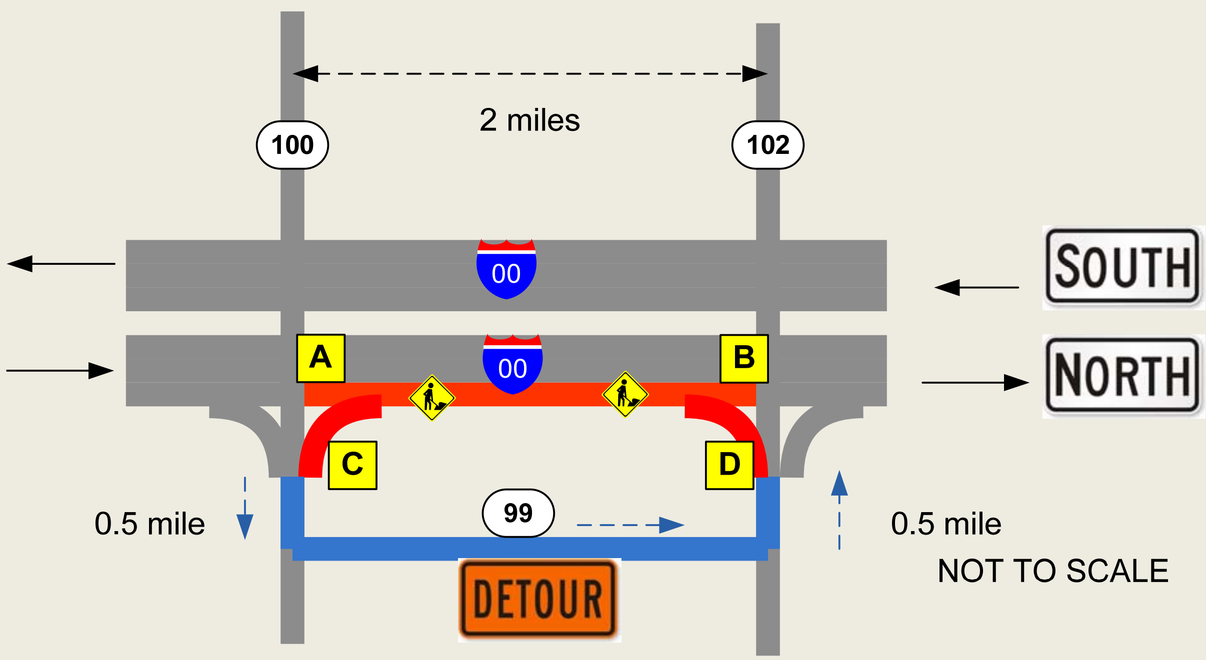
The precision of mobility related performance measures, such as the travel delay time and queue length, may vary with the type of traffic analysis tool selected for the work zone impact analysis. Microscopic simulation tools generally provide more precise estimates than spreadsheet-based tools.

Example 2.0: Description of a hypothetical work zone used in illustrative examples

A hypothetical example is presented herein to illustrate the computation of travel delay and vehicle operating costs. The information presented in this example is intended for illustrative purposes only.

One northbound lane of a six-lane, urban facility, Interstate 00, is undergoing bituminous pavement rehabilitation. The northbound lanes carry an average daily traffic of 33,000 vehicles of which 8 percent are single-unit trucks and 4 percent are combination trucks. A 2.0-mile work zone (marked in red) with a 24-hour/day, single lane closure will be in effect between point A and point B until the construction is complete. The unrestricted upstream approach speed is posted at 55 mph, and the work zone speed is posted at 45 mph. The estimated duration to complete pavement rehabilitation is 20 days.

The entry ramp connecting Hwy 100 and I-00 northbound lanes is closed; a 3-mile detour on Route 99 through Hwy 102 is in effect for the ramp traffic. Similarly, the exit ramp connecting I-00 northbound lanes and Hwy 102 is closed. The ramp traffic is expected to take a detour through Hwy 100 exit ramp and Route 99. The blue arrow in the figure below indicates the travel direction for the designated detour. The traffic volume on both exit and entry ramps is 1,000 vehicles a day, of which 3 percent are single-unit trucks and 2 percent are combination trucks. The average speed through the detour is 40 mph.



Example 2.1: Understanding the components of work zone travel delay time

For the hypothetical work zone scenario presented in Example 2.0, the computation of travel delay time involves the following computation:

- Speed change delay - the expected time the vehicles take to decelerate from the upstream speed of 55 mph to the work zone speed of 45 mph when approaching point A and the time to accelerate from 45 mph to 55 mph after crossing point B.
- Stopping delay - the expected time the vehicles take to decelerate from the upstream speed of 55 mph to a complete stop (0 mph) under restricted flow or queuing conditions, and the time to accelerate to 55 mph.
- Reduced speed delay - the expected additional time the vehicles take to cross the 2-mile segment at 45 mph compared to the time to cross the segment at 55 mph.
- Queue delay - the expected time the vehicles take to cross the 2-mile work zone under restricted flow or queuing conditions.
- Detour delay - the expected additional time the vehicles take from a northbound lane to reach Hwy 102 by traveling through the I-00to Hwy 100 exit ramp and Route 99. It also applies to the vehicles taking Route 99 and Hwy 102 to I-00 entry ramp to merge into I-00 through traffic.

Example 2.2: Computation of work zone travel delay time

A work zone travel delay analysis was performed for the mainline I-00 traffic. The various components of travel delays computed using the FHWA's RealCost program are summarized in the following table:

Time*	Volume	WZ Capacity	Queued Vehicles	Speed Change Delay**	Reduced Speed Delay**	Stopping Delay**	Queuing Delay**	Flow Condition
00-01	304	2554	0	0.07	0.24	0	0	No queue (unrestricted flow)
01-02	304	2554	0	0.07	0.24	0	0	
02-03	304	2554	0	0.07	0.24	0	0	
03-04	456	2554	0	0.07	0.24	0	0	
04-05	646	2554	0	0.07	0.24	0	0	
05-06	988	2554	0	0.07	0.24	0	0	
06-07	1558	2554	0	0.07	0.24	0	0	
07-08	2964	2554	410	0.40	0.24	0.40	23.81	Queue (restricted flow)
08-09	3610	2554	1466	0.40	0.24	0.40	23.81	
09-10	2470	2554	1382	0.40	0.24	0.40	23.81	
10-11	1786	2554	614	0.40	0.24	0.40	23.81	
11-12	1710	2554	0	0.47	0.24	0.40	23.81	
12-13	1634	2554	0	0.07	0.24	0	0	No queue
13-14	1710	2554	0	0.07	0.24	0	0	
14-15	1862	2554	0	0.07	0.24	0	0	
15-16	2470	2554	0	0.07	0.24	0	0	
16-17	3002	2554	448	0.40	0.24	0.40	23.81	Queue
17-18	3534	2554	1428	0.40	0.24	0.40	23.81	
18-19	2432	2554	1306	0.40	0.24	0.40	23.81	
19-20	1482	2554	234	0.40	0.24	0.40	23.81	
20-21	1254	2554	0	0.47	0.24	0.40	23.81	
21-22	684	2554	0	0.07	0.24	0	0	No queue
22-23	456	2554	0	0.07	0.24	0	0	
23-24	380	2554	0	0.07	0.24	0	0	

Note: (*) RealCost does not report the output results as presented in this table. The results obtained from the RealCost worksheets were modified for illustration purposes.
(**) Delay times were reported as average delay time per vehicle in minutes.

This table presents the work zone lane capacity and 24-hour cycle of hourly traffic demand on the northbound lanes. Two of the three available lanes are open in the northbound direction. When the hourly volume is less than the capacity, unrestricted flow exists, and as expected, no queue is formed. Only the delay time components due to speed change and reduced speed are calculated. However, when the hourly volume exceeds the capacity, the traffic flow is restricted, and a queue is formed. The restricted flow condition remains until the queue is cleared fully.

Detour delay time = (detour length/detour speed)- (normal travel length/upstream speed)
= (3.0 mile/40 mph) – (2.0 mile/55 mph) = 2.32 min/vehicle

The various components of work zone travel delay are combined to compute the total delay time, as illustrated in the following table:

Time	Mainline Traffic Volume	Total Delay Time (minutes/vehicle)					Delay Time for all Vehicles (veh-hours /day)
		Speed Change	Reduced Speed	Stopping	Queuing	Total	
00-01	304	0.07	0.24	0	0	0.32	1.60
01-02	304	0.07	0.24	0	0	0.32	1.60
02-03	304	0.07	0.24	0	0	0.32	1.60
03-04	456	0.07	0.24	0	0	0.32	2.41
04-05	646	0.07	0.24	0	0	0.32	3.41
05-06	988	0.07	0.24	0	0	0.32	5.22
06-07	1558	0.07	0.24	0	0	0.32	8.22
07-08	2964	0.40	0.24	0.40	23.81	24.85	1227.34
08-09	3610	0.40	0.24	0.40	23.81	24.85	1494.84
09-10	2470	0.40	0.24	0.40	23.81	24.85	1022.79
10-11	1786	0.40	0.24	0.40	23.81	24.85	739.55
11-12	1710	0.47	0.24	0.40	23.81	24.92	710.20
12-13	1634	0.07	0.24	0	0	0.32	8.62
13-14	1710	0.07	0.24	0	0	0.32	9.03
14-15	1862	0.07	0.24	0	0	0.32	9.83
15-16	2470	0.07	0.24	0	0	0.32	13.04
16-17	3002	0.40	0.24	0.40	23.81	24.85	1243.08
17-18	3534	0.40	0.24	0.40	23.81	24.85	1463.37
18-19	2432	0.40	0.24	0.40	23.81	24.85	1007.05
19-20	1482	0.40	0.24	0.40	23.81	24.85	613.67
20-21	1254	0.47	0.24	0.40	23.81	24.92	520.81
21-22	684	0.07	0.24	0	0	0.32	3.61
22-23	456	0.07	0.24	0	0	0.32	2.41
23-24	380	0.07	0.24	0	0	0.32	2.01
Total delay time of mainline through traffic							=10,115.32
Detour delay time = 2.32 min/vehicle * 2000 vehicles= 4636 min							= 77.28
Total estimated delay time per day							10,192.6

The delay time for all vehicles traveling through the I-00 work zone = 10,192.6 vehicle-hours per day.

The average delay time for a vehicle traveling through the I-00 work zone = 10,192.6/33,000
= 0.309 hr/veh/day.

> Traditionally the work zone mobility impacts are evaluated in terms of simple averages of travel time delays. As the travel times of road users vary greatly from day to day, the use of average delay time values does not reflect the "real world" experience of road users.
>
> Increasingly, the concept of "travel time reliability" is rapidly gaining importance in travel congestion studies. This measure takes the difference between the actual and the expected travel time into account. The commonly used travel time reliability metrics include the Buffer Time Index, 95th percentile of travel times, Travel Time Index percent "on-time performance", and travel time window.

2.2.2 Monetary Value of Travel Time

Like goods and services, time spent traveling in a vehicle is a resource with economic value. The monetary value of travel time is based on the concept that time spent traveling otherwise would have been spent productively, whether for remunerative work or recreation. The United States Department of Transportation (USDOT) Office of the Secretary of Transportation (OST) provides guidelines and procedures for calculating the value of travel time saved or lost by road users.[11,12]

Monetary value of travel time is a sum of:

- Dollar value of personal travel time (only passenger cars).
- Dollar value of business travel time (only passenger cars).
- Value of truck travel time (only trucks).
- Cost of freight inventory delay (only trucks).
- Cost of vehicle depreciation (all vehicles).

Note that the available unit cost data used in the computation of these monetary components may not reflect current or most recent year statistics. Practitioners are advised to adjust the existing year data to current year data using appropriate adjustment factors mentioned herein. In addition, the highway agencies can use their discretion in combining or eliminating smaller cost components as deemed appropriate.

2.2.2.1 Monetary Value of Personal Travel Time

The hourly dollar value of road users' personal travel time is estimated based on some percentage of their wages. The steps involved in monetizing the personal travel delay time are enumerated as follows.

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[11] USDOT, *Valuation of Travel Time in Economic Analysis-Revised Departmental Guidance*, Memorandum, Office of the Secretary of Transportation, U.S. Department of Transportation, Washington, DC. 2003.

[12] The value of travel time can be established using the wage rate method or road users' stated/revealed preference. The OST guidance is based on the wage rate method. Under the stated/revealed preference method, the information on road users' alternative choice of route or travel mode is gathered through surveys or polling. Based on the collected information, the associated travel time and cost differentials between the baseline and the preferred alternative choices are used in establishing the value of travel time through statistical modeling.

Step 1. **Determine the proportion of passenger cars on personal travel**. This proportion may vary with the type of travel: *local* or *intercity*. The number of person miles reported in the National Household Transportation Survey (NHTS) is used in determining the proportion of passenger cars on personal travel. Travel patterns reported in the NHTS and the Nationwide Personal Transportation Survey (NPTS) over the past 20 years are summarized in Table 1.

Table 1. Ratio of personal and business travel.

Study	Travel Type	Personal	Business
1990 NPTS [13]	Local[a]	95.8%	4.2%
	Intercity[b]	95.0%	5.0%
1995 NPTS [14]	Not Specified	94.2%	5.8%
2001 NHTS [15]	Not Specified	91.9%	8.1%
2009 NHTS[16]	Not Specified	93.7%	6.3%

Note:
([a]) Reported in 1990 NPTS Databook, Vol. I, Table 4.41, page 4-72.
([b]) Reported in 1990 NPTS Databook, Vol. II, Table 8.13, page 8-22.

NOTE

This report uses the national travel behavior statistics obtained from the NHTS sampling data. To reflect local trends, agencies are encouraged to use location-specific or region-specific statistics obtained from their travel behavior survey programs using the same methodology described herein.

Step 2. **Establish the average vehicle occupancy (AVO) of passenger cars**. The AVO is the ratio of person-miles of travel and vehicle-miles of travel by trip type.[16] Refer to Table 2 for the recent NHTS estimates of AVO values. The average AVO for personal travel was 1.67 in 2009. The AVO of intercity personal travel is higher than that of local personal travel. Estimates of 1990 NPTS (Vol. 2, Table 8.15, of the NPTS report) indicate that the AVO factor for intercity travel was 2.30, whereas the AVO for local travel was 1.66. By selecting an appropriate AVO, the delay time can be converted from person-hours to vehicle-hours or vice-versa.

[13] Hu, P. S. and J. Young, *1990 Nationwide Personal Transportation Survey (NPTS) Databook*, Report No. FHWA-PL-94-010A, Prepared by Oak Ridge National Laboratory, Submitted to the Office of Highway Information Management, Federal Highway Administration, Washington, DC, November 1993. http://nhts.ornl.gov/1990/doc/databook.pdf

[14] Oak Ridge National Laboratory, 1995 Nationwide Personal Transportation Survey (NPTS) Databook, Report No. ORNL/TM-2001/248, Prepared for FHWA Office of Highway Information Management, Oak Ridge National Laboratory, Oak Ridge, TN, October, 2001. http://nhts.ornl.gov/1995/Doc/ORNL_TM_2001_248.pdf

[15] Hu, P. S. and T. R. Reuscher, Summary of Travel Trends, 2001 National Household Travel Survey, Prepared by Oak Ridge National Laboratory, Submitted to the Federal Highway Administration, Washington, DC, November 2004. http://nhts.ornl.gov/2001/pub/STT.pdf

[16] Obtained from NHTS Online Analysis Tools -Table Designer using the variables: 1990 Trip Purpose and the annual person miles of travel (for Step 4)/ average vehicle occupancy (for Step 5). http://nhts.ornl.gov/tools.shtml

Table 2. NHTS estimates of average vehicle occupancy factors of personal and business travel.

Purpose of Trip (1990 definition)		1995	2001	2009
Work-related business		1.20	1.22	1.24
Personal	To or from work	1.14	1.14	1.13
	Shopping	1.74	1.77	1.78
	Other family /personal business	1.78	1.85	1.84
	School/church	1.68	1.76	1.77
	Doctor/dentist	1.51	1.64	1.59
	Vacation	2.33	2.42	2.7
	Visit friends or relatives	1.83	1.88	2.08
	Other social or recreational	2.18	2.09	2.2
	Other	1.82	1.89	1.96
	Not ascertained	2.39	1.65	1.93
	Overall personal	1.67	1.75	1.67
All travel		1.59	1.63	1.67

Source: NHTS Online Analysis Tools

Step 3. **Estimate per hour monetary value of travel time for a person on personal travel**. The dollar value of personal travel time (per person–hr) is estimated using the median annual income for all U.S. households reported by the U.S. Census Bureau, in accordance with the OST guidelines (see Table 3).[17]

Table 3. OST guidelines for calculating value of personal travel time.

Travel Type	Per Person-Hour as a percent of Wage Rate	Data Source
Local	50% (35-60%)	Median annual income for all U.S. households divided by 2080 hours. Reported in U.S. Census Bureau. State or local income data can be substituted in lieu of national statistics.
Intercity	70% (60-90%)	

Hourly value of personal travel time per person is calculated as:

For local personal travel,

Hourly value of personal travel time per person = 50% of median annual household income ÷ 2080 hours.

Median annual income for all U.S. households = $49,445 (for 2010).[18]

Hourly value of personal travel time = 0.5 $49,445/2080 = $11.89/person -hr*

For intercity personal travel,

Hourly value of personal travel time per person = 70% of median annual household income ÷ 2080 hours.

[17] Median Household Income reported by US Census Bureau. http://www.census.gov/hhes/www/income/income.html

[18]DeNavas-Walt, C., B. D. Proctor, J. C. Smith, *Income, Poverty, and Health Insurance Coverage in the United States: 2010*, Report No. P60-239, US Census Bureau, September 2011. http://www.census.gov/prod/2011pubs/p60-239.pdf

Median annual income for all U.S. households = $49,445 (for 2010)

Hourly value of personal travel time = 0.7 $49,445 /2080 = $16.64/person –hr*

Step 4. **Compute per hour monetary value of travel time for a vehicle on personal travel.** The dollar value of personal travel time for all occupants in a vehicle, in terms of dollar/vehicle-hr, is computed by multiplying the dollar value of hourly travel time per person with an appropriate AVO factor. In other words, the hourly travel time per person is converted to hourly travel time per vehicle to estimate delay time costs based on the number of vehicles (instead of the number of persons) traveling on the roadway.

For local personal travel,

Hourly value of a person's travel time in a vehicle= $11.89/person -hr

Average vehicle occupancy = 1.67 persons per vehicle

*Hourly travel time value of all occupants in a vehicle or the hourly value of a vehicle on personal travel = $11.89 * 1.67 = $19.85/vehicle-hr*

The hourly travel time value of a vehicle on personal travel is same as the vehicle's delay time costs.

For intercity personal travel,

Hourly value of travel time = $16.75/person -hr

Average vehicle occupancy = 2.30 persons per vehicle

*Hourly value of vehicle delay time = $16.64 * 2.30 = $38.27/vehicle-hr*

Step 5. **Compute travel delay costs for passenger cars on personal travel**. Multiply the hourly dollar value of vehicle delay time with the delay time of passenger cars on personal travel. For local or personal travel,

Total delay time for passenger cars on personal travel = Average delay time Number of passenger car vehicles on personal travel (and)*

*Travel delay costs for passenger cars on personal travel = Total delay time for passenger cars on personal travel * hourly $ value of vehicle delay time*

NOTE

Travel delay time for buses are computed by multiplying the average number of passengers in a bus with the unit cost ($/hr) of personal travel time of a passenger.

2.2.2.2 Monetary Value of Business Travel Time

The hourly dollar value of road users' business travel time is estimated based on the employer's costs of employees that include both wages and benefits. The steps involved in calculating the cost component of the business travel time are enumerated as follows:

Step 1. **Determine the proportion of passenger cars on business travel.** The number of person miles reported in the NHTS is used in determining the proportion of passenger cars on business travel (see Table 1).

Step 2. **Establish the AVO of passenger cars**. As shown in Table 2, the average AVO for business travel was 1.24 in 2009. Alternatively, agency-specific travel behavior statistics can be used to reflect local trends.

Step 3. **Estimate per hour monetary value of travel time for a person on business travel**. Hourly dollar value of a person's time on business travel is estimated using the OST guidelines presented in Table 4. Total hourly wages and benefits of all civilian workers reported in the Bureau of Labor Statistics (BLS) Employer Costs for Employee Compensation (ECEC) are used.[19] For current year estimates, the ECEC data released every quarter can be used for computations, or adjustments can be made using the BLS Employment Cost Index (ECI) data.[19]

For both local and intercity business travel,

Hourly value of a person's time on business travel = 100% of median hourly wages plus benefits.

Hourly employment cost = $29.75 (December, 2010)

Hourly value of a person's time on business travel = $29.75/person –hr.

Table 4. OST guidelines for calculating value of business travel time.

Travel Type	Per Person-Hour as a percent of Wage Rate	Data Source
Local	100% (80-120%)	Total compensation (wages and benefits) cost per hour. Reported in Bureau of Labor Statistics, Employer Costs for Employee Compensation
Intercity	100% (80-120%)	

Step 4. **Compute per hour monetary value of travel time for a vehicle on business travel.** Multiply the hourly value of a person's time on business travel with the AVO factor. Note that the AVO is assumed to be the same for passenger cars on business travel for both local and intercity travel.

Hourly value of a person's time on business travel = $29.75/person -hr

Average vehicle occupancy = 1.24 persons per vehicle

*Hourly time value of a vehicle on business travel = $29.75 * 1.24 = $36.89/veh-hr*

Step 5. **Compute travel delay costs for passenger cars on business travel**. Multiply the hourly dollar value of vehicle delay time with the delay time of passenger cars on business travel.

For business travel,

Total delay time for passenger cars on business travel = Average delay time Number of passenger car vehicles on business travel (and)*

*Travel delay costs for passenger cars on business travel = Total delay time for passenger cars on business travel * hourly $ value of vehicle delay time*

[19] http://stats.bls.gov/ncs/ect/

Example 2.3: Computing travel delay costs for passenger cars

The computation of travel delay costs for passenger cars for the I-00 work zone scenario involves computing the hourly dollar value of travel delay time for passenger cars on both personal and business travel, then multiplying their weighted average with the estimated delay time of all passenger cars. Assume that the median annual household income for the area, where the I-00 work zone is located, is $52,000.

Step 1. Estimate the unit value of personal travel time for passenger cars

Median annual household income of the area = $52,000

Hourly time value of a person on personal travel = 50% of $52,000÷2080 hrs

Hourly time value of a person on personal travel = $12.5/person-hr

Average vehicle occupancy for personal travel = 1.67 persons per vehicle

Hourly time value of a vehicle on personal travel = 1.67 * 12.5 = $20.88/vehicle-hr

Step 2. Estimate the unit value of business travel time

Estimate the sum of hourly wages and benefits from the ECEC statistics available on the BLS website.

Hourly employment cost for the quarter December 2010= $29.75

Hourly time value of a person on business travel = $29.75/person-hr

Average vehicle occupancy = 1.24 persons per vehicle

Hourly time value of vehicle on business travel = $29.75 * 1.24 = $36.89/vehicle-hr

Step 3. Compute the weighted average of travel time values for passenger cars considering both personal and business travel

Per 2009 NHTS statistics, 93.7% and 6.3% of passenger cars are expected on personal and business travel, respectively. Therefore,

Hourly time value of a vehicle on personal travel = $20.88/vehicle-hr

Hourly time value of vehicle on business travel = $36.89/vehicle-hr

Weighted average of hourly time value of passenger cars= 93.7% of $20.88 + 6.3% of $36.89 = $21.89/hr

Hourly time value of passenger cars = $21.89/hr

Step 4. Estimate the delay costs for passenger cars on the northbound lanes

Percent of passenger cars = 88% (from Example 2.0)

Estimated delay time for all vehicles = 10,192.6 vehicle-hours/day (from Example 2.2)

Estimated delay time for passenger cars = 0.88* 10,192.6 = 8969.49 vehicle-hours/day

Estimated delay costs for passenger cars = 8969.49 * $21.89 /hr = $196,342.10 /day

2.2.2.3 Monetary Value of Truck Travel Time

Hourly dollar value of truck travel time is estimated based on the compensation costs of truck drivers that include both wages and benefits. The steps involved in calculating the cost component of the truck travel time are enumerated as follows:

Step 1. **Determine the average vehicle occupancy of trucks**. NHTS data provide AVO values only for cars and light-duty trucks. There are no national averages or sources for AVO values of trucks. Agencies can use region-specific data, if available. In the absence of national or region-specific values, the truck AVOs recommended in the Highway

Economic Requirement System (HERS)-ST Technical Report can be utilized.[20] HERS-ST recommends an AVO of 1.025 for a single-unit truck (i.e., 1.05 for single-unit, six-tire trucks and 1.0 for heavier single-unit trucks) and 1.12 for combination trucks. The weighted average of AVOs of different truck types can be used.

Step 2. **Determine the average wages and benefits for truck drivers**. Per the BLS National Occupational Employment and Wage Estimates published in May 2009, the median hourly wages for truck drivers are presented as follows:[21]

Truck Drivers, Heavy and Tractor-Trailer = $18.87/hr (May 2009)

Truck Drivers, Light or Delivery Services (capacity of under 26,000 lb gross vehicle weight [GVW])

= $14.90/hr (May 2009)

Truck Drivers (both light and heavy) = $16.89/hr (May 2009)

Per the BLS ECEC data, the average benefit for employees in transportation and material moving jobs is $7.60/hr (for June 2009). Note that the wage rates and benefits can be adjusted to the current year using the current release of the BLS ECI or the Occupational Employment Statistics. State or local estimates of wages and benefits can be substituted for national estimates.

The following computation shows how to adjust the existing hourly compensation data to the current year data:

Wages & benefits of truck drives (both light and heavy) = $16.89/hr (May 2009)
Employment Cost Index (June 2009)[22] = 110.3
Employment Cost Index (Dec 2010) = 113.3
*Wages & benefits adjusted for Dec 2010 = $16.89 * 113.3/110.3 =* $ 17.35 /hr

Step 3. **Estimate per hour monetary value of truck travel time**. Determine the hourly dollar value of truck travel time by multiplying the hourly compensation (sum of wages and benefits) of truck drivers with the AVO factor.

*Single-unit trucks = 1.025 * ($14.90 + $7.60) = $23.06/hr (May 2009)*
*Combination-unit trucks = 1.12 * ($18.87 + $7.60) = $29.65/hr (May 2009)*

Step 4. **Compute delay costs for truck travel.** To determine the delay cost component of truck travel, multiply the hourly dollar value with travel delay time of trucks, either by truck type (single-unit or combination trucks) or the total number of trucks.

[20] FHWA, Highway Economic Requirements System-State Version, Technical Report, Federal Highway Administration, Washington, DC, 2005.
[21] Occupational Employment Statistics, Published by Bureau of Labor Statistics, US Department of Labor. http://www.bls.gov/news.release/ocwage.toc.htm
[22] Historical ECI data can be obtained from ECT databases on the BLS website. Total compensation, all civilian, index numbers and all workers were used in determining the ECI value.

Example 2.4: Computing travel delay costs for trucks

For the I-00 work zone scenario, the travel delay costs for trucks are computed by multiplying the estimated delay time for trucks by the hourly compensation (including wages and benefits) of truck drivers. If the hourly compensation rates are calculated separately for single-unit and combination trucks, the delay costs can be computed separately using appropriate hourly compensation values and summed later.

Step 1. Estimate the unit value of truck travel time

Average compensation of drivers of single-unit trucks = $22.50/person-hr

Average vehicle occupancy of single-unit trucks = 1.025

Hourly time value of single-unit trucks = 1.025 * $22.50 = $23.06/hr

Average compensation of drivers of combination trucks = $26.47/person-hr

Average vehicle occupancy of combination trucks = 1.12

Hourly time value of combination trucks = 1.12 * $26.47 = $29.65/hr

Step 2. Estimate the delay costs for both single-unit and combination trucks on the northbound lanes

Percent of single-unit trucks = 8% (from Example 2.0)

Estimated delay time for all vehicles = 10,192.6 vehicle-hours/day (from Example 2.2)

Estimated delay time for single-unit trucks = 0.08* 10,192.6 = 815.41 vehicle-hours/day

Estimated delay costs for single-unit trucks = 815.41 * $23.06/hr = $18,803.31/day

Percent of combination trucks = 4% (from Example 2.0)

Estimated delay time for combination trucks = 0.04* 10,192.6 = 407.7 vehicle-hours/day

Estimated delay costs for combination trucks = 407.7 * $29.65/hr = $12,088.42/day

Estimated delay costs for all trucks = $18,803.31+ 12,088.42 = $30,891.73

2.2.2.4 Cost of Time-Related Vehicle Depreciation

Vehicles depreciate as a function of aging and usage over time. Total vehicle depreciation costs are estimated from the average annual ownership costs of vehicles, while mileage-related vehicle depreciation costs are estimated using the VOC procedure discussed in section 2.3. Time-related vehicle depreciation costs typically are estimated by subtracting mileage-related depreciation from total depreciation. Time-related vehicle depreciation costs incurred by vehicle owners due to work zone delay are estimated herein using the methodology outlined in the HERS-ST Technical Report. The steps involved in computing the time-related vehicle depreciation costs are as follows:

Step 1. **Determine the HERS-ST estimates of hourly cost of time-related vehicle depreciation for each vehicle type in 1995 dollars**. Table 5 presents the HERS-ST estimates of hourly cost of total, mileage-related, and time-related vehicle depreciation (in 1995 dollars) for various vehicle types.

Step 2. **Adjust the depreciation costs from 1995 dollars to current year dollars.** To adjust 1995 dollars to current year dollars, the use of the Producer Price Index (PPI)—Commodity data for transportation equipment (Item 14) is recommended.[23]

[23] Producer Price Indexes, Published by Bureau of Labor Statistics, US Department of Labor. http://bls.gov/ppi (the use of multi-screen search tool is suggested).

As the time-related depreciation largely depends on the initial price of the vehicles, the use of the PPI for cost adjustment is deemed appropriate. However, this adjustment may not consider the change in vehicle registration, licensing and permit taxes, insurance premiums, and financing costs over time. Table 6 presents the hourly costs of time-related vehicle depreciation adjusted to 2010 values.

Table 5. Hourly costs of time-related vehicle depreciation in 1995 dollars.

Vehicle Type	**Total Depreciation ($/hr)**	**Mileage-Related Depreciation**		**Time-Related Depreciation ($/hr)**
		$/mile	**$/hr**	
Small autos	1.72	0.109	0.63	1.09
Medium-sized to large autos	2.02	0.098	0.57	1.45
Four-tire single-unit trucks	2.18	0.045	0.28	1.90
Six-tire trucks	3.08	0.079	0.43	2.65
3+ axles combination trucks	8.80	0.175	1.64	7.16
3 or 4 axles	7.42	0.057	1.01	6.41
5+ axles	7.98	0.060	1.82	6.16

Source: HERS-ST Technical Manual (2005)[20]

In addition to the depreciation values provided by the HERS-ST, practitioners also can use the following resources:

- American Automobile Association (AAA) [24]
- American Transportation Research Institute (ATRI)[25]

Table 6. Hourly costs of time-related vehicle depreciation in 2010 dollars.

Vehicle Type	**Time-Related Depreciation ($/hr) in 1995 $**	**PPI**		**Adjustment Factor= PPI_{2010}/PPI_{1995}**	**Time-Related Depreciation ($/hr) in 2010 $**
		1995	**2010**		
Small autos	1.09	134.1	129.0[a]	0.962	1.05
Medium-sized to large autos	1.45	159.0	153.3[b]	0.964	1.40
Four-tire single-unit trucks	1.9	144.1	195.7[c]	1.358	2.58
Six-tire trucks	2.65	144.1	195.7[c]	1.358	3.60
3+ axles combination trucks	7.16	124.5	175.9[d]	1.413	10.12
3 or 4 axles	6.41	124.5	175.9[d]	1.413	9.06
5+ axles	6.16	124.5	175.9[d]	1.413	8.70

Notes:
[a] PPI for passenger cars (Item # 141101).
[b] PPI for trucks with GVW less than 14,000 lb (Item # 141105).
[c] PPI for trucks with GVW over 14,000 lb (Item # 141106).
[d] PPI for truck trailers (Item # 141406).

[24] American Automobile Association, *Your Driving Costs*. http://www.aaaexchange.com/Assets/Files/201145734460.DrivingCosts2011.pdf

[25] Trego, T., and D. Murray (2010), http://trid.trb.org/view.aspx?id=910437

NOTE

The relationship between the vehicle types provided in Tables 5 and 6 and the FHWA Traffic Monitoring Guide (TMG) vehicle classification scheme is presented in section 2.8.2. Depending on the vehicle classification data available, the average depreciation costs of various vehicle types can be computed as appropriate.

Step 3. **Compute the hourly costs of time-related vehicle depreciation.** Total depreciation cost is computed for each vehicle type by multiplying the hourly depreciation costs with the vehicle delay time.

Example 2.5: Computing time-related vehicle depreciation costs

For the I-00 work zone scenario, the time-related vehicle classification costs are calculated by multiplying the total delay time with the hourly time-related depreciation costs presented in Table 6.

Step 1. Estimate the hourly time-related depreciation costs for vehicle types

Since there are no vehicle class data (categorized using the FHWA TMG classification scheme), it is assumed that simple averages of hourly cost data (presented in Table 6) would represent the traffic composition on the I-00 project.

Hourly depreciation cost for passenger cars = simple average of hourly costs of small, medium sized, and large autos = (1.05 + 1.40)/2 = $1.225/hr

Hourly depreciation cost for single-unit trucks = simple average of hourly costs of four-tire and six-tire single-unit trucks = (2.58 + 3.60)/2 = $3.09/hr

Hourly depreciation cost for combination trucks = simple average of hourly costs of 3 or 4 axles, 3+ axle and 5+ axles combination trucks = (10.12 + 9.06 + 8.70)/3 = $9.29/hr

Step 2. Estimate the time-related depreciation cost for passenger cars, single-unit trucks, and combination trucks on the northbound lanes

Estimated delay time for all vehicles = 10,192.6 vehicle-hours/day (from Example 2.2)

Percent of passenger cars = 88% (from Example 2.0)

Estimated delay time for passenger cars = 0.88* 10,192.6 = 8969.49 vehicle-hours/day

Estimated time-related depreciation costs for passenger cars = 8969.49 * $1.225/hr
= $10,987.62/day

Percent of single-unit trucks = 8% (from Example 2.0)

Estimated delay time for single-unit trucks = = 0.08* 10,192.6 = 815.4 vehicle-hours/day

Estimated time-related depreciation costs for single-unit trucks = 815.4 * $3.09/hr
= $2,519.59/day

Percent of combination trucks = 4% (from Example 2.0)

Estimated delay time for combination trucks = 0.04* 10,192.6 = 407.7 vehicle-hours/day

Estimated time-related depreciation costs for combination trucks = 407.7 * $9.29/hr
= $3,787.53/day

Estimated time-related depreciation costs for all vehicles = $10,987.62 + 2,519.59 + 3,787.53 = $17,294.74/day

2.2.2.5 Cost of Freight Inventory Delay

Hourly dollar value of freight inventory delay is estimated using the procedure described in the HERS-ST Technical Report. The inventory cost is computed by multiplying the average payload of the truck with the average value of commodities shipped by truck. HERS-ST recommends the calculation of inventory delay costs only for combination trucks; however, this report provides the calculation steps for both single-unit and combination trucks:

Step 1. **Determine the number of loaded (partially or fully) freight trucks by FHWA vehicle class or vehicle type and their average pay loads**. This information can be obtained from weigh-in-motion (WIM) data representative of the project. In the absence of such data, follow the discussion presented in Steps 2 and 3. Otherwise, skip to Step 4.

Step 2. **Estimate the number of empty and loaded trucks**. The number of loaded freight trucks can be obtained from subtracting the empty trucks from the total trucks. Note that the truck composition may also consist of empty trucks (otherwise called backhaul trucks) returning from the original destination point to the point of origin. The number of loaded trucks can be estimated from the national averages of percent empty trucks presented in Table 7.

Table 7. Percent of empty trucks.

Truck Type	Percent of Empty Trucks
Single-unit truck	29
Combination truck with semitrailer	27
Combination truck with trailer	24
Combination truck with double trailer	24
Combination truck with triple trailer	19

Source: FHWA Office of Freight Management and Operations, 2007.[26]

Step 3. **Estimate the average payload of trucks.** Use the national averages presented in Table 8 to estimate average truck payload. These averages were obtained from an FAF[2] study that utilized the U.S. Census Bureau's Vehicle Inventory and Use Survey (VIUS) database in the freight analysis. Practitioners may also use the State-specific payload data presented in Table 9 or local data.

Step 4. **Determine the hourly discount rate**. Hourly discount rate is the annual discount rate divided by the number of hours in a year (8,760 hours). The annual discount rate is the average prime bank lending rate plus 1 percent. The average prime bank lending rate for 2010 is 3.25 percent.[27]

Hourly discount rate for 2010 = (3.25% +1%)/8760 = 0.000485%

[26] Alam, M., E. Fekpe, and M. Majed, FAF2 Freight Traffic Analysis, Submitted to FHWA Office of Freight Management and Operations, 2007. (Refer to Table 4) http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports7/index.htm

[27] Prime bank lending rates for current can be obtained from the Statistics & Historical Data releases of the Federal Reserve. http://www.federalreserve.gov/releases/h15/data/Annual/H15_PRIME_NA.txt

Table 8. Average payload (lb) by distance traveled and truck type – national statistics.

Distance Traveled	Single-Unit			Truck/Tractor Trailers			Combination Trucks		
	2-axle	3-axle	4-axle or more	4-axle or less	5-axle	6-axle or more	5-axle or less	6-axle	7-axle or more
Off-the-road	9,235	24,210	37,058	22,034	46,144	39,989	N.A.	N.A.	68,099
Less than 50 miles	7,223	25,293	35,198	13,392	42,135	44,964	37,611	47,330	77,886
51 to 100 miles	6,851	23,736	36,198	18,590	43,911	48,072	48,328	46,877	73,810
101 to 200 miles	7,509	23,463	35,732	21,207	42,061	53,637	40,054	43,074	71,319
201 to 500 miles	7,085	21,407	32,938	18,909	41,588	35,180	33,250	35,455	61,586
501 miles or more	6,231	21,334	39,368	21,271	40,184	47,807	38,505	39,928	67,979

Source: FHWA Office of Freight Management and Operations, 2007[28]

Table 9. Average payload (lb) by distance traveled and truck type by State.

State	Single-Unit			Truck/Tractor Trailers			Combination Trucks		
	2-axle	3-axle	4-axle or more	4-axle or less	5-axle	6-axle or more	5-axle or less	6-axle	7-axle or more
Alabama	6,534	26,277	47,116	16,272	43,141	42,072	28,000	27,000	-
Alaska	5,859	22,573	31,430	15,695	39,528	51,935	-	31,800	70,325
Arizona	6,281	22,278	38,708	13,974	39,146	17,793	44,300	43,225	-
Arkansas	7,184	22,697	32,204	15,025	44,629	32,551	-	33,960	54,500
California	5,639	20,023	33,732	16,746	40,403	42,462	49,511	47,073	41,530
Colorado	7,594	25,252	37,090	14,105	42,974	46,373	51,000	-	-
Connecticut	7,265	25,769	37,803	13,729	40,415	46,281	37,000	59,000	-
Delaware	7,250	30,254	41,258	17,303	42,457	28,605	-	-	-
District of Columbia	5,346	20,388	11,978	3,500	-	-	-	-	-
Florida	6,637	30,529	38,986	14,857	42,885	34,338	30,667	23,000	-
Georgia	6,801	24,925	31,954	12,172	37,304	42,892	-	-	-
Hawaii	5,651	21,442	35,388	15,699	36,369	41,519	-	-	-
Idaho	9,127	26,349	34,967	15,157	44,307	52,455	59,900	-	67,000
Illinois	7,444	23,364	27,380	21,667	44,606	41,816	38,993	39,675	53,983
Indiana	8,700	30,144	32,671	14,165	41,512	44,022	35,000	60,218	58,000
Iowa	8,680	23,560	30,398	16,602	44,449	42,275	-	-	37,500
Kansas	10,101	24,547	30,116	20,853	45,064	38,650	44,737	42,500	36,170
Kentucky	8,889	25,942	38,711	15,125	40,730	42,766	-	-	37,280
Louisiana	7,144	25,256	34,072	14,327	47,028	47,319	-	-	59,224
Maine	9,127	27,086	36,926	17,650	40,267	55,838	-	-	-
Maryland	6,205	29,582	38,000	11,114	32,038	38,109	-	-	-
Massachusetts	5,247	26,974	38,085	11,834	45,852	39,958	-	-	-
Michigan	6,771	20,065	30,697	15,412	37,088	61,272	38,000	40,000	100,145
Minnesota	7,581	23,509	31,129	14,178	41,868	39,443	36,000	31,500	-
Mississippi	6,223	28,608	29,248	15,779	44,716	44,753	-	-	-
Missouri	9,105	26,110	31,533	13,636	42,471	39,272	-	-	-
Montana	10,912	25,410	29,729	17,813	43,243	49,817	-	-	70,824
Nebraska	11,054	24,528	32,747	15,087	41,550	50,195	-	36,500	53,013

[28] Alam, M., and G. Rajamanickam, Development of Truck Payload Equivalent Factor, Submitted to FHWA Office of Freight Management and Operations, 2007. (Refer to Table 3) http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports9/index.htm

Table 9. Average payload (lb) by distance traveled and truck type by State.

State	Single-Unit			Truck/Tractor Trailers			Combination Trucks		
	2-axle	3-axle	4-axle or more	4-axle or less	5-axle	6-axle or more	5-axle or less	6-axle	7-axle or more
Nevada	7,550	22,711	40,499	17,123	42,319	51,454	48,553	45,265	68,513
New Hampshire	7,313	25,825	34,054	13,667	40,755	53,346	-	-	-
New Jersey	7,154	29,850	44,487	15,388	41,927	30,040	38,190	-	-
New Mexico	6,655	23,854	33,538	16,277	42,173	32,867	51,000	53,525	87,000
New York	6,883	25,703	38,705	9,568	42,558	54,837	51,000	-	90,755
North Carolina	7,522	24,688	32,827	19,043	41,852	35,086	31,529	34,000	34,000
North Dakota	13,344	25,525	29,259	17,158	46,730	50,459	-	-	69,500
Ohio	7,021	22,493	33,568	12,799	41,318	41,881	-	45,000	30,000
Oklahoma	8,030	23,057	33,847	18,560	40,674	42,141	24,817	30,333	-
Oregon	5,244	22,832	27,449	16,998	44,978	47,662	48,166	40,492	62,234
Pennsylvania	6,540	25,872	39,530	8,976	40,187	32,124	-	-	26,000
Rhode Island	5,576	31,550	42,570	11,907	44,264	52,904	-	-	-
South Carolina	7,280	24,417	35,520	14,789	42,222	43,311	-	-	-
South Dakota	11,210	24,178	29,315	17,687	45,679	46,840	-	-	77,997
Tennessee	6,561	26,774	41,064	14,827	41,013	36,271	45,000	-	32,000
Texas	7,275	26,224	36,280	17,665	42,948	42,209	23,514	21,583	110,000
Utah	5,917	16,510	32,118	15,307	41,196	53,222	27,606	32,503	77,802
Vermont	8,439	27,309	34,971	12,803	45,788	45,911	-	61,400	-
Virginia	7,352	27,859	34,654	16,424	42,527	47,412	37,159	40,282	45,500
Washington	6,638	22,209	35,971	14,366	39,919	56,690	37,728	51,149	64,585
West Virginia	7,120	27,446	36,591	13,947	41,495	49,097	-	-	-
Wisconsin	6,865	22,474	37,909	16,624	42,399	44,392	13,000	-	-
Wyoming	8,067	24,995	34,214	14,983	43,061	54,541	51,000	-	70,772

Source: FHWA Office of Freight Management and Operations, 2007.[28]

> NOTE
>
> For less rigorous analysis, practitioners may use the average payload thee-axle truck (FHWA vehicle class 5) for single-unit trucks and five-axle truck/tractor trailers (FHWA vehicle class 9) for combination trucks. The average payloads of these two truck groups are reasonable for most traffic streams (except on major bus routes). It is reasonable to assume 25,000 lb and 42,000 lb as average payload values for single-unit and combination trucks, respectively.

Step 5. **Determine the average value of commodities shipped by truck**. The HERS-ST Technical Report cites that the average value of commodities shipped by truck (on a ton-mile weighted basis) was $1.35 per pound in 1993.[29] Adjust this value to the current year using the Implicit Price Deflators for Gross Domestic Product-Goods.[30]

Average value of commodities shipped by truck = $1.35/lb (in year 1993)
Implicit Price Deflator for GDP-Goods = 93.786 (for year 1993)
Implicit Price Deflator for GDP-Goods = 105.405 (for year 2010)
*Adjusted value of commodities shipped by truck in 2010 = $1.35 * (105.405/93.786) = $1.52/lb*

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[29] The practitioners are recommended to periodically check with the FHWA Office of Freight Management and Operations for updated dollar value of commodities shipped by trucks.
[30] Implicit Price Deflators for GDP can be obtained from Table 1.1.9 of the National Income and Product Account (NIPA) published by the Bureau of Economic Analysis. http://www.bea.gov/national/nipaweb/SelectTable.asp

Step 6. **Determine the hourly value of freight shipped by truck**. Multiply the current year value of commodities by the hourly discount rate.

*Hourly value of freight inventory for 2010 = $1.52/lb * 0.000485%*
= $7.37E-06/lb/hr

Step 7. **Determine the hourly inventory cost for each truck**. Multiply the hourly value of commodities ($/lb/hr) by the average payload of each truck type. The hourly inventory costs for the suggested payload values of single-unit trucks (25,000 lb) and combination trucks (42,000 lb) are $0.18 and $0.31 in 2010 dollars, respectively. Table 10 presents the hourly inventory costs for the average payload values presented in Table 8.

Table 10. Hourly cost ($/hr) of freight inventory by distance traveled and truck type – national averages in 2010 dollars.

Distance Traveled	Single Unit			Truck/Tractor Trailers			Combination Trucks		
	2-axle	3-axle	4-axle or more	4-axle or less	5-axle	6-axle or more	5-axle or less	6-axle	7-axle or more
Off-the-road	0.07	0.18	0.27	0.16	0.34	0.29	N.A.	N.A.	0.50
< 50 miles	0.05	0.19	0.26	0.10	0.31	0.33	0.28	0.35	0.57
51- 100 miles	0.05	0.17	0.27	0.14	0.32	0.35	0.36	0.35	0.54
101 - 200 miles	0.06	0.17	0.26	0.16	0.31	0.40	0.30	0.32	0.53
201 - 500 miles	0.05	0.16	0.24	0.14	0.31	0.26	0.25	0.26	0.45
> 500 miles	0.05	0.16	0.29	0.16	0.30	0.35	0.28	0.29	0.50

Step 8. **Compute freight inventory delay costs**. Multiply the number of loaded freight trucks (by truck type) by their hourly cost of freight inventory values.

Example 2.6: Computing the cost of freight inventory delay

For the I-00 work zone scenario, the cost of freight inventory delay is computed by multiplying the number of single-unit and combination trucks carrying freight by the hourly cost of freight inventory values.

Step 1. Estimate the hourly cost of freight inventory values

The hourly freight inventory costs suggested in Step 7 of section 2.2.2.5 are found reasonable for the I-00 Pavement Rehabilitation project.

Hourly freight inventory costs for single-unit trucks = $0.18/hr

Hourly freight inventory costs for combination trucks = $0.31/hr

Step 2. Estimate the number of loaded freight trucks

Estimated percent of empty single-unit trucks (from Table 7) = 29%

Estimated percent of empty combination trucks (from Table 7) = 27%

Annual average daily traffic = 33,000 (from Example 2.0)

Percent of single-unit trucks = 8% (from Example 2.0)

Total number of single-unit trucks = 0.08 * 33,000 = 2,640

Estimated number of empty single-unit trucks = 0.29*2,640 = 766

Estimated number of loaded single-unit trucks =2640 - 766 = 1,874

Percent of combination trucks = 4% (from Example 2.0)

Total number of combination trucks = 0.04 * 33,000 = 1,320

Estimated number of empty combination trucks =0.27*1320 = 356

Estimated number of loaded combination trucks =1,320 - 356 = 964

Step 3. Estimate the cost of freight inventory delay

Average delay time for a vehicle = 10,192.6/33,000 = 0.309 hr/veh/day (from Example 2.2)

Cost of freight inventory delay for single-unit trucks = hourly cost for average payload * number of single-unit trucks * average delay time = 0.18 * 1,874 * 0.309 = $104.23/day

Cost of freight inventory delay for combination trucks = hourly cost for average payload * number of combination trucks * average delay time = 0.31 * 964 * 0.309 = $92.34/day

Cost of freight inventory delay = $104.23 + 92.34 = $196.57/day

Example 2.7: Computing the total travel delay costs

For the I-00 work zone scenario, the total travel delay costs are computed by summing the component costs as shown below:

1. Travel delay costs for passenger cars = $196,342.10 /day (from Example 2.3)
2. Travel delay costs for trucks = $30,891.73 (from Example 2.4)
3. Time-related depreciation costs for all vehicles = $17,294.74/day (from Example 2.5)
4. Cost of freight inventory delay = $196.57/day (from Example 2.6)

Total delay costs = $196,342.10 + 30,891.73 + 17,294.74 + 196.57 = $244,725.14/day

2.3 Vehicle Operating Costs

VOC are the expenses incurred by road users as a result of vehicle use. VOC are the running costs that vary with the degree of vehicle use, and are thus mileage dependent, and do not include fixed costs such as insurance, time-dependent depreciation, financing, and storage.

In WZ RUC analysis, VOC is an aggregation of the following components:

- Speed change VOC is the additional cost under unrestricted conditions associated with decelerating from the upstream approach speed to the work zone speed and then accelerating back to the approach speed after leaving the work zone.
- Stopping VOC is the additional cost under restricted conditions associated with stopping from the upstream approach speed and accelerating back up to the approach speed after traversing the work zone.
- Queue idling VOC is the additional cost associated with stop-and-go driving in the queue. The idling cost rate multiplied by the additional time spent in the queue is an approximation of actual VOC associated with stop-and-go conditions. When a queue exists, stopping delay and VOC replace the free-flow speed change delay and VOC.
- Detour VOC is the additional cost associated with the excess distance to be traveled by selecting a detour route under unrestricted or restricted conditions.

Example 2.8: Understanding the components of VOC

For the work zone scenario presented in Example 2.0, the computation of vehicle operating costs for the I-00 work zone scenario involves the following:

- Speed change VOC - the additional costs incurred for the vehicles to decelerate from the upstream speed of 55 mph to the work zone speed of 45 mph when approaching point A and the time to accelerate from 45 mph to 55 mph after crossing point B.
- Stopping VOC - the additional costs incurred for the vehicles to decelerate from the upstream speed of 55 mph to a complete stop (0 mph) under restricted flow or queuing conditions, and the time to accelerate to 55 mph.
- Queue idling VOC - the additional costs incurred for the vehicles idling in the queue under restricted flow conditions.
- Detour VOC - the additional costs incurred for the extra distance the vehicles have to travel through the I-00→Hwy 100 exit ramp and Route 99 to reach Hwy 102 as opposed to taking I-00→Hwy 100 exit ramp. It also applies to the vehicles taking Route 99 and Hwy 102→I-00 entry ramp to merge into I-00 through traffic.

2.3.1 Estimating VOC

VOC includes the consumption costs of the following resources:

- Fuel consumption.
- Engine oil consumption.
- Tire-wear.
- Repair and maintenance.
- Mileage-related depreciation.

VOC is measured by quantifying the consumption of these resources while driving a vehicle between two points and multiplying those quantities with the corresponding unit cost of resources. Figure 3 presents the computation of VOC schematically.

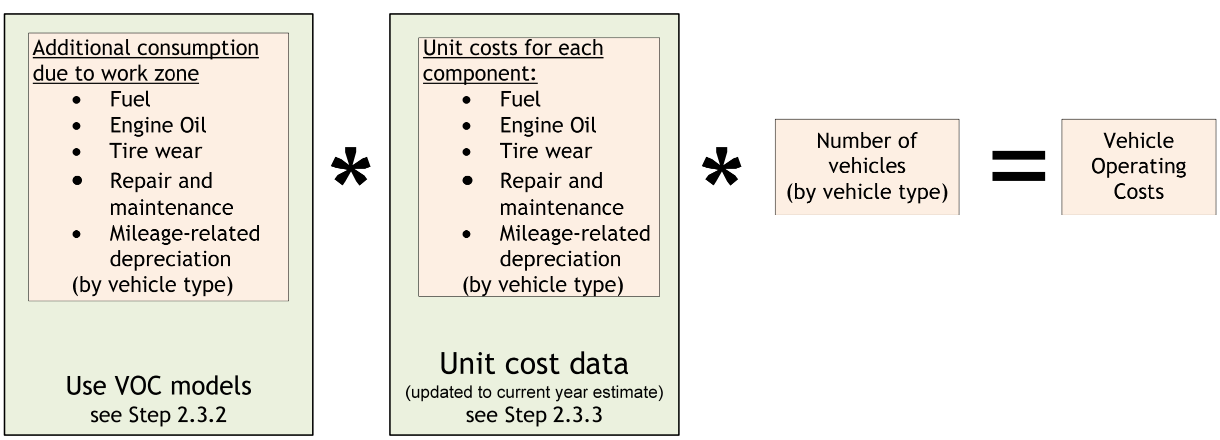

Figure 3. Schematic illustrating the components of VOC.

The resource consumption is a function of prevailing roadway and traffic characteristics and can vary significantly with factors such as roadway geometry, traffic volume and composition, travel delay, and speed. Table 11 presents a matrix showing how each resource is influenced by various roadway factors.

Table 11. Roadway factors affecting vehicle operating costs.

Roadway Factor	Fuel	Oil	Tire Wear	Maintenance and Repair	Depreciation (mileage-related)
Vehicle Class	X	X	X	X	X
Vehicle Speed	X	X	X	X	X
Road Grade	X	X	X	X	
Surface Type	X	X	X	X	X
Surface Condition	X	X	X	X	X
Road Curvature	X		X	X	

Source: NCHRP Synthesis 269.[31]

For WZ RUC analysis, the VOC is estimated for the traffic flowing through the work zone as well as those diverted through detour routes (if applicable). Traffic flowing through the work zone undergoes acceleration/deceleration cycles, stopping and idling depending on the flow condition (i.e. unrestricted or restricted). VOC models can be used to account for the effect of change in flow condition changes on resource consumption.

Traffic diverted through the detour routes may or may not experience change in flow conditions depending on the detour route capacity and diverted traffic volume. If there is forced flow condition, a detailed traffic analysis using VOC models is required for detour routes at the network or route level (depending on the impact and site-specific factors). Otherwise, a simple per-mile estimate can be used in VOC estimation for free flow conditions. VOC models provide per-mile estimates for constant-operating conditions with due consideration to travel speed, grade, and pavement conditions. Alternate cost sources such as AAA or ATRI can also be used for simpler, flat-rate per-mile estimates.

2.3.2 VOC Models

VOC models provide a detailed methodology for quantifying the additional resources consumed due to change in traffic flow conditions. Three methods are used commonly in the U.S. for determining VOC:

- National Cooperative Highway Research Program (NCHRP) Report 133 method.[32]
- Texas Research and Development Foundation method.[33]
- HERS-ST method.[20]
- U.S. Environmental Protection Agency (EPA)'s Motor Vehicle Emission Simulator (MOVES) —Only fuel consumption costs can be estimated using this tool (see section 2.5.1.2 for more discussion)

[31] Lewis, D. L. *Road User and Mitigation Costs in Highway Pavement Projects*, NCHRP Synthesis 269, National Cooperative Highway Research Program, Transportation Research Board, Washington DC, 1996.

[32] Curry, D. A. and D. G. Anderson, *Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects*, National Cooperative Highway Research Program Report 133, Transportation Research Board, Washington, DC, 1972.

[33] Zaniewski, J. P., B. C. Butler, G. Cunningham, G. E. Elkins, M. S. Paggi, and R. Machemehl. *Vehicle Operating Costs, Fuel Consumption and Pavement type and Condition Factors*, Final Report # DOT-FH-11-9678, Prepared by Texas Research and Development Foundation, Federal Highway Administration, Washington, DC, 1982.

This document presents a detailed discussion of VOC models commonly used in the U.S. Some of the International sources of VOC models include:

- The World Bank's Highway Design and Maintenance Standards (HDM-IV) model.
- The British Cost Benefit Analysis Program (COBA).
- The Australian Road Research Board's Road Fuel Consumption model.
- The National Association of Australian State Road Authorities' Improved Model for Project Assessment and Costing (NIMPAC).
- The Swedish National Road and Transport Research Institute (VTI) Vejstandard og transportomkostninger (VETO) model.

2.3.2.1 NCHRP Report 133 Method

NCHRP Report 133 provides relationships to calculate VOC consumption for work zone conditions. These relationships were based largely on earlier work by Winfrey and Claffey.[34,35] Since these earlier studies were published, there have been improvements in fuel efficiency standards, vehicle technologies, and tire technologies; therefore, the accuracy of these relationships is questionable for current vehicle standards.

The NCHRP Report 133 relationships were utilized in RealCost for computing work zone VOC.[36] Table 12 presents the additional time and operating costs in 2010 dollars resulting from vehicle stopping, idling, and speed changes in work zones. Both time and cost factors are presented as a function of vehicle traveling speed. Reproduced from the RealCost technical bulletin, the cost table was adjusted from 1996 to 2010 rates using the Consumer Price Index (CPI) (transportation component).

Table 12. Added time and vehicle running cost/1,000 stops and idling cost in 2010 dollars.

Initial Speed (mph)	Added Time (Hr/1000 Stops)			Added Cost ($/1000 Stops)		
	Passenger Cars	Single-Unit Truck	Combination Truck	Passenger Cars	Single-Unit Truck	Combination Truck
0	0.00	0.00	0.00	$0.00	$0.00	$0.00
5	1.02	0.73	1.10	$3.66	$12.53	$45.53
10	1.51	1.47	2.27	$11.96	$28.06	$104.95
15	2.00	2.20	3.48	$20.53	$45.90	$176.02
20	2.49	2.93	4.76	$29.44	$65.55	$257.40
25	2.98	3.67	6.10	$38.83	$86.64	$347.44
30	3.46	4.40	7.56	$48.89	$108.66	$444.50
35	3.94	5.13	9.19	$59.67	$131.21	$546.93
40	4.42	5.87	11.09	$71.37	$154.35	$653.06
45	4.90	6.60	13.39	$84.06	$176.17	$761.31
50	5.37	7.33	16.37	$97.93	$197.68	$870.02

[34] Winfrey, R., *Economic Analysis of Highways*, International Textbook Company, Scranton, Pennsylvania, 1969.
[35] Claffey, P. J., *Running Costs of Motor Vehicles as affected by Road Design and Traffic*, National Cooperative Highway Research Program Report 111, Transportation Research Board, Washington, DC, 1971.
[36] Walls III, J. and M. R. Smith, Life-Cycle Cost Analysis in Pavement Design — Interim Technical Bulletin, Report No. FHWA-SA-98-079, Federal Highway Administration, Washington, DC, 1998.

Table 12. Added time and vehicle running cost/1,000 stops and idling cost in 2010 dollars.

Initial Speed (mph)	Added Time (Hr/1000 Stops)			Added Cost ($/1000 Stops)		
	Passenger Cars	Single-Unit Truck	Combination Truck	Passenger Cars	Single-Unit Truck	Combination Truck
55	5.84	8.07	20.72	$113.04	$217.90	$977.50
60	6.31	8.80	27.94	$129.61	$242.40	$1,082.08
65	6.78	9.53	31.61	$147.65	$265.23	$1,150.68
70	7.25	10.27	39.48	$167.41	$283.13	$1,247.36
75	7.71	11.00	47.90	$188.97	$304.54	$1,344.05
80	8.17	11.73	57.68	$212.42	$325.96	$1,440.75
Idling Cost ($/veh-hr.)				$0.94	$1.04	$1.12
Source: FHWA's RealCost and NCHRP Report 133. Original CPI: 142.8 (year 1996) Current year CPI: 193.396 (year 2010)						

Speed change VOC is calculated by subtracting the cost factors at the work zone speed from those at the upstream speed. This difference is then multiplied by the number of vehicles traversing the work zone under the unrestricted flow scenario. Similarly, for calculating the stopping VOC of vehicles, the difference in cost factors at the upstream speed and stopping is then multiplied by the number of vehicles traversing the work zone under the restricted flow scenario. The idling VOC is calculated by multiplying the idling cost factors by the number of delayed vehicles and their queuing/idling time. For additional miles resulting from detour, the RealCost software recommends the use of flat, mileage-based rates under normal vehicle operating conditions. Sources of mileage-based VOC are presented in section 2.3.3.

2.3.2.2 Texas Research and Development Foundation Method

In 1982, the Texas Research and Development Foundation (TRDF) developed relationships to incorporate the effects of highway design and pavement condition on VOC for FHWA. This study provided a VOC model as a function of vehicle speed, grade, and vehicle class. This model was developed based on highway, vehicle technology, operation, and economic conditions typical of the 1970s. Table 13 presents a sample relationship showing the TRDF estimates of VOC resource consumption for vehicle idling.

Table 13. TRDF estimates of VOC consumption during idling.

Vehicle	Fuel (gallon /l000 hrs)	Oil (quart/ 1000 hrs)	Tire (% of wear /1000 hrs)	Depreciation (% of new veh. price/l000 hrs)	Maint. & Repairs (% of avg. cost per 1000 miles/1000 hrs)
Small Passenger Car	271	5.8	0	0.81	57
Medium/Large Passenger Car	563	5.8	0	0.81	58
Pickup/Van	756	3.5	0	0.5	60
Buses	398	3.46	0	1.1	26
2-Axle Single Unit	198	3.2	0	1.1	23
3-Axle Single Unit	398	3.46	0	1.1	26
2-S2 Semis	470	3.46	0	0.38	24
3-S2 Semis	470	3.46	0	0.38	24

TRDF VOC data have been used in many highway planning and project evaluation models, including HERS-ST, MicroBENCOST (a benefit-cost analysis tool for highway applications), and the Canadian Highway User Benefit Assessment. However, this method, like the NCHRP Report 133 method, falls short of taking changing vehicle standards and technologies into account.[37]

Example 2.9: Computing VOC using the NCHRP Report 133 method

This example illustrates the use of the NCHRP Report 133 method with the I-00 work zone scenario.

Speed Change VOC:
Time: 05-06 am
Upstream speed = 55 mph WZ speed = 45 mph
Total vehicles = 988

Initial Speed (mph)	Added Cost ($/1000 Stops)		
	Passenger Cars	Single Unit Truck	Combination Truck
55	$113.04	$217.90	$977.50
45	$84.06	$176.17	$761.31
55-45-55	$28.98	$41.73	$216.19
Speed Delay VOC at 05-06 am	=988*0.88*$28.98/1000	=988*0.08*$41.73/1000	=988*0.04*$216.19/1000
	$25.2	$3.30	$8.5
	Total = $37.0		

Stopping VOC:
Time: 08-09 am
Total vehicles = 2964

Initial Speed (mph)	Added Cost ($/1000 Stops)		
	Passenger Cars	Single Unit Truck	Combination Truck
55	$113.04	$217.90	$977.50
Stopping	$0	$0	$0
55-Stopping-55	$28.98	$41.73	$216.19
Stopping VOC at 08-09 am	=2964*0.88*$28.98/1000	=2964*0.08*$41.73/1000	=2964*0.04*$216.19/1000
	$294.84	$51.67	$115.89
	Total = $462.42		

Idling VOC:
Time: 08-09 am
Number of vehicles in queue = 410
Queuing Time = 23.81 minutes = 0.397 hr

Queued Vehicles	Queuing Time	Idling Cost per vehicle-hour		
		Passenger Cars	Single Unit Truck	Combination Truck
410	0.397hr	$0.94	$1.04	$1.12
Idling VOC at 08-09 am		=410*0.88*0.397*$0.94	=410*0.08*0.397*$1.04	=410*0.04*0.397*$1.12
		$134.32	$13.54	$7.27
		Total = $155.13		

Speed Delay VOC at 05-06 am = $37.00
Stopping VOC at 08-09 am = $462.42
Idling VOC at 08-09 am = $155.13

[37] Bein, P., and D. C. Biggs, Critique of Texas Research and Development Foundation Vehicle Operating Cost Model, Transportation Research Record No.1395, Journal of the Transportation Research Board, Washington, DC, 1993.

Example 2.9: Computing VOC using the NCHRP Report 133 method (continued)

The various components of VOC for the 24-hour cycle are illustrated in the following table:

Time	Mainline Traffic Volume	Queued Vehicles	Queue Time	Stopped Vehicles	Speed Change VOC	Stopping VOC	Idling VOC	Total VOC
00-01	304	0	0	0	$11.40	$0.0	$0.0	$11.4
01-02	304	0	0	0	$11.40	$0.0	$0.0	$11.4
02-03	304	0	0	0	$11.40	$0.0	$0.0	$11.4
03-04	456	0	0	0	$17.10	$0.0	$0.0	$17.1
04-05	646	0	0	0	$24.22	$0.0	$0.0	$24.2
05-06	988	0	0	0	$37.04	$0.0	$0.0	$37.0
06-07	1558	0	0	0	$58.41	$0.0	$0.0	$58.4
07-08	2964	410	23.81	2964	$0.0	$462.4	$155.1	$617.5
08-09	3610	1466	23.81	3610	$0.0	$563.2	$554.7	$1,117.9
09-10	2470	1382	23.81	2470	$0.0	$385.3	$522.9	$908.2
10-11	1786	614	23.81	1786	$0.0	$278.6	$232.3	$511.0
11-12	1710	0	23.81	1244	$17.47	$194.1	$470.69	$682.2
12-13	1634	0	0	0	$61.26	$0.0	$0.0	$61.3
13-14	1710	0	0	0	$64.11	$0.0	$0.0	$64.1
14-15	1862	0	0	0	$69.81	$0.0	$0.0	$69.8
15-16	2470	0	0	0	$92.60	$0.0	$0.0	$92.6
16-17	3002	448	23.81	3002	$0.0	$468.3	$169.5	$637.9
17-18	3534	1428	23.81	3534	$0.0	$551.3	$540.3	$1,091.6
18-19	2432	1306	23.81	2432	$0.0	$379.4	$494.1	$873.6
19-20	1482	234	23.81	1482	$0.0	$231.2	$88.5	$319.7
20-21	1254	0	23.81	226	$38.55	$35.2	$85.40	$159.2
21-22	684	0	0	0	$25.64	$0.0	$0.0	$25.6
22-23	456	0	0	0	$17.10	$0.0	$0.0	$17.1
23-24	380	0	0	0	$14.25	$0.0	$0.0	$14.2
Total vehicle operating costs of mainline through traffic								=$7,434.6

The VOC for the northbound through traffic =$7,434.6/day.

2.3.2.3 HERS-ST Method

FHWA's HERS-ST model provides a comprehensive method to compute VOC resource components for various vehicle types, roadway conditions, and traffic characteristics. For every cost component, HERS-ST provides separate VOC models for calculating each resource component based on:

- Constant-speed operating conditions as a function of average effective speed, average grade, and pavement serviceability rating.
- Excess resource consumption due to speed-change cycles.
- Excess resource consumption due to roadway curvature.[38]

The HERS-ST VOC estimation models are derived based on the TRDF VOC relationships, with some adjustments made based on the findings of Claffey and Daniels.[33, 35,39] In addition, HERS-ST facilitates adjustments for commodity cost fluctuations and improvements in vehicle fuel efficiency.

The HERS-ST model contains numerous equations for VOC estimation based on the combinations of VOC resource components, vehicle types, and influencing factors (e.g., average effective speed, speed change, horizontal curves, and vertical grade). The HERS-ST software package facilitates the analysis of VOC estimation using a set of equations.[40] Tables 14 and 15 present sample HERS-ST estimates of VOC for each resource component estimated using constant speed and speed variability submodels, respectively. These tables were estimated for a given set of influencing factors.

The overall equation for estimating VOC is presented as follows:

$$CSOPCST_{vt} = CSFC*PCAFFC*COSTF_{vt}/FEAF_{vt} + CSOC*PCAFOC*COSTO_{vt}/OCAF_{vt} + 0.01*CSTW*PCAFTW*COSTT_{vt}/TWAFvt + 0.01*CSMR*PCAFMR*COSTMR_{vt}/MRAF_{vt} + 0.01*CSVD*PCAFVD*COSTV_{vt}/VDAF_{vt}$$

where,

CSOPCSTvt = constant speed operating cost for vehicle type
CSFC = constant speed fuel consumption rate (gallons/1000 miles)
CSOC = constant speed oil consumption rate (quarts/1000 miles)
CSTW = constant speed tire wear rate (% worn/1000miles)
CSMR = constant speed maintenance and repair rate (% of average cost/1000 miles)
CSVD = constant speed depreciation rate (% of new price/ 1000 miles)
PCAFFC = pavement condition adjustment factor for fuel consumption
PCAFOC = pavement condition adjustment factor for oil consumption
PCAFTW = pavement condition adjustment factor for tire wear
PCAFMR = pavement condition adjustment factor for maintenance and repair
PCAFVD = pavement condition adjustment factor for depreciation expenses
COSTFvt = unit cost of fuel for vehicle type
COSTOvt = unit cost of oil for vehicle type

[38] Additional vehicle operating costs incurred due to the effects of roadway curvature is not required for WZ RUC analysis, as the differential costs between the normal operating and work zone conditions are only considered.
[39] Daniels, C. *Vehicle Operating Costs in Transportation Studies*, E.S.U. Technical Series, No. 1, Spencer House, London (1974).
[40] Equations of HER-ST VOC models are presented in Appendix E of the HERS-ST Technical Report.

COSTTvt = unit cost of tires for vehicle type
COSTMRvt = unit cost of maintenance and repair for vehicle type
COSTVvt = depreciable value for vehicle type
FEAFvt = fuel efficiency adjustment factor for vehicle type
OCAFvt = oil consumption adjustment factor for vehicle type
TWAFvt = tire wear adjustment factor for vehicle type
MRAFvt = maintenance and repair adjustment factor for vehicle type
VDAFvt = depreciation adjustment factor for vehicle type.

Table 14. Sample HERS-ST estimates of constant speed VOC in 2010 dollars.

Average Effective Speed (mph)*	Small Autos	Medium/ Large Auto	4-Tire Truck	6-Tire Truck	3+Axle Single Unit	3-4 Axle Combination	5+ Axle Combination
40	$0.36	$0.43	$0.45	$1.20	$1.38	$0.91	$1.09
45	$0.36	$0.43	$0.45	$1.20	$1.38	$0.90	$1.09
55	$0.37	$0.43	$0.45	$0.83	$1.37	$0.91	$1.08

Note: These estimates were developed for an assumed roadway grade of 1 percent and a pavement serviceability rating of 2.5

Table 15. Sample HERS-ST estimates of speed variability VOC in 2010 dollars.

Maximum Speed in a Speed Change Cycle (mph)	Small Autos	Medium/ Large Auto	4-Tire Truck	6-Tire Truck	3+Axle Single Unit	3-4 Axle Combination	5+ Axle Combination
5	$0.04	$0.04	$0.14	$0.26	$0.26	$0.12	$0.13
10	$0.08	$0.09	$0.17	$0.33	$0.50	$0.29	$0.32
15	$0.14	$0.15	$0.22	$0.44	$0.81	$0.52	$0.58
20	$0.21	$0.22	$0.30	$0.59	$1.17	$0.80	$0.90
25	$0.29	$0.31	$0.39	$0.79	$1.59	$1.15	$1.29
30	$0.38	$0.42	$0.50	$1.04	$2.08	$1.54	$1.75
40	$0.59	$0.66	$0.76	$1.66	$3.21	$2.50	$2.86
50	$0.83	$0.95	$1.09	$2.46	$4.55	$3.66	$4.26
60	$1.10	$1.27	$1.47	$3.45	$6.10	$5.02	$5.96
70	$1.39	$1.60	$1.91	$4.63	$7.85	$6.58	$7.98

2.3.3 Unit Cost Data Sources for VOC Estimation

Unit cost data are required to compute the costs of additional resources consumed due to work zone activity. Several unit cost data sources are available for VOC estimations, and commonly cited U.S. cost sources include:

Passenger cars only

- AAA - *Your Driving Costs* (published annually) – see Table 16.

Trucks only

- American Transportation Research Institute (ATRI)-see Table 17.

All vehicles

- Barnes and Langworthy (2004)[41] – see Table 18.
- Sinha and Labi (2005) – see Table 19.
- HERS-ST – see Table 20.

Table 16. AAA estimates of VOC for passenger cars in 2010 dollars (cents/vehicle mile).

Cost Component	Small Sedan	Medium Sedan	Large Sedan	4WD Sport Utility Vehicle	Minivan
Fuel	9.24	11.97	12.88	16.38	13.7
Maintenance and oil	4.21	4.42	5	4.95	4.86
Tires	0.65	0.91	0.94	0.98	0.75
Depreciation @ 15000 miles/year	15.89	23.01	32.19	33.35	26.63

Table 17. ATRI estimates of VOC for trucks in 2008 dollars (cents/vehicle mile).

Cost Component	Trucks
Diesel Fuel (@ $4.69/gallon)	
No surcharge	63.4
With surcharge	21.9
Fuel taxes	6.2
Maintenance	9.2
Tires	3.0
Depreciation	N.A.

Table 18. Barnes and Langworthy estimates of VOC in 2003 dollars (cents per vehicle mile).

Cost Component	Automobile		Pickup/SUV/Van		Trucks	
	Highway	City	Highway	City	Highway	City
Fuel @ $1.50/gallon	5.0	7.0	7.8	10.1	21.4	28.0
Maintenance	2.1	2.5	2.4	2.8	10.5	12.1
Repair	1.1	1.3	1.3	1.5		
Tires	0.9	0.9	1.0	1.0	3.5	3.5
Depreciation	6.2	7.4	7.0	8.1	8.0	9.2
Total	15.3	19.1	19.5	23.6	43.4	52.9

Table 19. Average VOC (cents/vehicle mile) in 2005 dollars.

Cost Component	Small Autos	Medium-sized Autos	Large Autos	SUVs	Vans	Trucks
Fuel and Oil	5.4	6.44	7.5	8.34	7.5	21.41
Maintenance and Repair	3.5	4.12	4.33	4.33	4.12	11.09
Tires	0.5	1.58	1.9	1.58	1.69	3.7
Depreciation	13.9	12.5	12.5	12	12	10.6
Total	20.59	20.59	22.17	22.7	21.75	44.64

Note: This table is a compilation of cost data from several sources:
Non-trucks: fuel, maintenance and repair, and tires from AAA Your Driving Costs 2005);
Trucks: fuel, maintenance and repair, and tires from Barnes and Langworthy (2003); and,
Depreciation estimations and projections from the HERS-ST Technical Report (2002).

[41] Barnes, G and P. Langworthy, *The Per-Mile Costs of Operating Automobiles And Trucks*, Report No. MN/RC 2003-19, Submitted to Minnesota Department of Transportation, St. Paul, 2004. http://www.lrrb.org/pdf/200319.pdf

Table 20. HERS-ST unit costs of VOC resource components in 2004 dollars.

Cost Component	Small Autos	Medium/ Large Auto	4-Tire Truck	6-Tire Truck	3+Axle Single Unit	3-4 Axle Combination	5+ Axle Combination
Fuel ($/gal)	$1.93	$1.93	$1.93	$1.93	$1.84	$1.84	$1.84
Oil ($/quart)	$4.48	$4.48	$4.48	$1.79	$1.79	$1.79	$1.79
Tires ($/tire)	$45.89	$72.55	$79.96	$193.00	$477.90	$477.90	$477.90
Maintenance & Repair ($/1000 miles)	$103.50	$125.60	$159.60	$298.70	$422.50	$437.60	$437.60
Depreciation ($/vehicle)	$19,717	$23,255	$25,061	$37,448	$82,386	$95,432	$103,767

2.3.3.1 Updating Cost Data Sources for VOC Estimation

Unit cost data shown in Tables 16 through 20 do not reflect the current year prices. To update the cost of individual resource components to current year prices, adjustments using standard price indices, such as CPI and PPI, are recommended. Table 21 presents the guidelines on using the price indices for price adjustment. The information presented in the parentheses indicates the appropriate items codes of CPI or PPI data for each combination of resource and vehicle type. To estimate current year prices, multiply the existing year prices by a ratio of CPI (current year) to CPI (existing year), or PPI values as appropriate.

Table 21. Price adjustments for VOC components.

Resource	Automobile	Pickup/SUV/ Van	Single-unit Trucks	Combination Trucks
Fuel	Consumer Price Index-All Urban Consumers			
	Gasoline (SETB01)	Gasoline (SETB01)	Gasoline (SETB01) for 2-axle 6-tire truck. Other motor fuels for Diesel (SETB02) for 3-axle truck	Other motor fuels for Diesel (SETB02)
Oil	Consumer Price Index-All Urban Consumers			
	Motor oil, coolant, and fluids (SS47021)	*Motor oil, coolant, and fluids (SS47021)*	*Motor oil, coolant, and fluids (SS47021)*	*Motor oil, coolant, and fluids (SS47021)*
Maintenance and Repair	Consumer Price Index-All Urban Consumers			
	Motor vehicle maintenance and repair (SETD)	*Motor vehicle maintenance and repair (SETD)*	*Motor vehicle maintenance and repair (SETD)*	*Motor vehicle maintenance and repair (SETD)*
Tires	Consumer Price Index-All Urban Consumers			
	Tires (SETC01)	*Tires (SETC01)*	*Tires (SETC01)*	*Tires (SETC01)*
Depreciation	Producer Price Index - Commodity Data Transportation Equipment (14)			
	Passenger cars (1101)	*Trucks with GVW under 14,000 lbs (1105)*	*Trucks with GVW over 14,000 lbs (1106)*	*Truck trailers (1406)*

To illustrate, the HERS-ST estimates of unit costs presented in Table 20 reflect the prices in 2004. To convert the 2004 prices to 2010 prices, the ratio of 2010 CPI or PPI value to 2004 CPI or PPI value for each of the codes presented in Table 21 are first computed (see Table 22). The 2004 prices in Table 20 are then multiplied by the appropriate price adjustment factors presented in Table 22 to estimate the unit costs of various resource components in 2010 dollars (see Table 23).

Table 22. 2004 to 2010 price adjustment factors for VOC components.

Resource	Automobile	Pickup/SUV / Van	6-tire Single-unit Trucks	3-axle Single-unit Trucks	Combination Trucks
Fuel	1.497	1.497	1.497	1.539	1.539
Oil	1.847	1.847	1.847	1.847	1.847
Maintenance and Repair	1.214	1.214	1.214	1.214	1.214
Tires	1.239	1.239	1.239	1.239	1.239
Depreciation	0.979	1.013	1.257	1.257	1.226

Table 23. HERS-ST unit costs of VOC resource components in 2010 dollars.

Cost Component	Small Autos	Medium/Large Auto	4-Tire Truck	6-Tire Truck	3+Axle Single Unit	3-4 Axle Combination	5+ Axle Combination
Fuel	$2.89	$2.89	$2.89	$2.89	$2.84	$2.84	$2.84
Oil	$8.27	$8.27	$8.27	$3.31	$3.31	$3.31	$3.31
Tire (single)	$55.70	$88.07	$97.06	$234.28	$580.11	$580.11	$580.11
Maintenance and Repair	$128.21	$155.59	$197.71	$370.03	$523.39	$542.09	$542.09
Depreciation	$19,303	$23,569	$25,399	$47,069	$103,551	$116,979	$127,196

2.4 CRASH COSTS

Crash costs associated with work zones and work zone-related detours are a function of the expected change in the crash rates due to the presence of work zones. Required crash-related inputs for WZ RUC analysis include:

- Crash rate and /frequency at work zones.
- Crash severity rating.
- Unit cost of crashes.

2.4.1 Work Zone Crash Rate

Crash statistics often are reported in terms of crash rate and crash frequency. Crash rate is the number of crashes expected or observed along a roadway segment during a time period normalized to the roadway segment length and the traffic volume over the same period. Crash rate typically is expressed as “crashes per VMT” or “crashes per million VMT (MVMT)” for roadway sections and “crashes per million entering vehicles (MEV)” for intersection locations. The formula for calculating the crash rate for a roadway segment is presented as follows:

$$CR = \frac{A * 10^6}{T * L * AADT * 365}$$

where,

CR = number of crashes per million vehicle miles of travel
A = average number of crashes along the roadway segment for the analysis period
T = duration of the analysis period (years)
L = length of roadway segment (miles)
AADT = annual average daily traffic (in both directions)

Crash frequency is the number of crashes normalized to the roadway segment length and time period. It typically is expressed as "crashes per mile per year".

The presence of a work zone increases the likelihood of crashes in a given location. Therefore, the work zone crash rates typically are estimated by applying a multiplicative factor, called crash modification factor (CMF), to the pre-work zone crash rates at the project location. Crash records collected over a typical 3-year period are considered in determining pre-work zone crash rates.

Numerous studies indicate that the pre-work zone crash rates are likely to increase by 20 to 70 percent when there is a work zone in place. For active work with temporary lane closure on freeway and expressway facilities, Ullman et al (2008). found that the crash risk increased by about 66 percent during the day and by 61 percent at night for a motorist traveling through the work zone; however, the actual change in crash risk varied significantly when the crash data was examined on the basis of time of work (daytime or nighttime work) and work conditions (no work activity, active work with lane closures, or active work with no lane closures).[42]

Work zone CMFs are available on the *CMF Clearinghouse* website, a repository established and maintained by the FHWA Office of Safety.[43] This site contains the best available information on the crash modification factors for a variety of scenarios, including countermeasure strategies to address specific work zone safety issues. Table 24 presents typical work zone CMFs for temporary lane closure on freeways and expressways.

There are no statistically accepted values of CMFs, as they were found to vary from study to study. Furthermore, numerous factors pertaining to the operational and physical characteristics of the facility influence the likelihood of increase in crash rates at work zones:

- Roadway functional class (e.g., freeways vs. two-lane highways).
- Location (e.g., urban vs. rural).
- Work zone configuration (e.g., work zone length, number of open lanes).
- Traffic volume.
- Exposure period (e.g., number of days, night vs. daytime).
- MOT strategy (e.g., partial lane closure vs. crossover).

[42] Ullman, G. L., M.D. Finley, J. E. Bryden, R. Srinivasan, and F. M. Council, *Traffic Safety Evaluation of Nighttime and Daytime Work Zones*, NCHRP Report 627, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2008.
[43] CMF Clearinghouse: http://www.cmfclearinghouse.org/index.cfm

- Traffic management strategies (e.g., flagger vs. non-flagger).
- Weather conditions.

Therefore, agencies could consider establishing their own CMFs reflecting local trends using historical data. Other approaches such as historical averages, regression-based models involving key influencing variables, and crash reduction factors also can be employed. Table 25 presents an example showing the difference in work zone and pre-work zone crash rates observed in various work zone sites in Indiana.[44] This table also illustrates how the work zone conditions, such as lane closure strategies and number of available lanes, influence the likelihood of increase in crash rates at work zones. Table 26 presents an example of the CMFs calculated for Ohio's work zones. [45]

Table 24. Typical work zone crash modification factors for temporary lane closure on freeways.

Crash Types	Crash Severity	CMF
All	All	1.77
All	Property damage only (PDO)	1.9
All	Serious injury, Minor injury	1.6
Nighttime	All	1.57
Nighttime	Property damage only (PDO)	1.63
Nighttime	Serious injury, Minor injury	1.34

Note: Reported for work zones with active work and temporary lane closure.

Table 25. Average crash rates at Interstate work zones in Indiana.

Sites	Crash Rate (per 10 Million VMT)		
	Without Work Zone	With Work Zone	CMF
Sites Using Cross-over (2 lanes in each direction)	6.0329	8.0431	1.33
Sites Using Partial Lane Closure (2 lanes in each direction)	5.5916	7.4528	1.33
Sites Using Cross-over (3 lanes in each direction)	5.8278	9.3544	1.61
Sites Using Partial Lane Closure (3 lanes in each direction)	7.5166	10.1006	1.34

Table 26. Work zone crash rates in Ohio.

Year	Crash Rate (per Million VMT)		CMF
	Before Work Zone	With Work Zone	
2002	1.04	1.68	1.62
2003	1.19	2.02	1.69
2004	1.34	1.71	1.28
2005	1.29	1.23	0.95
2006	1.51	1.51	0.0

[44] Pal, R., and K. Sinha, *An Evaluation of Lane Closure Strategies for Interstate Work Zones*, Report No. FHWA/IN/JHRP-95/1, Joint Transportation Research Program, Purdue University, West Lafayette, IN, 1995.
[45] Presented by Mr. Holstein, State Traffic Engineer of Ohio DOT, 2008 Work Zone Rule Virtual Workshop. http://ops.fhwa.dot.gov/wz/resources/final_rule/ohio_ppt/ohio.htm

In addition to the elevated crash related risks due to work zone, the pre-work zone crash rates should be adjusted for:

- Influence Zone (or Analysis Area) — The influence zone is the area or roadway segments that are adversely impacted by the work zone hazards. The safety impacts of the work zone are evaluated not only in the immediate work zone area but also on the adjacent roadways, and are duly accounted in the crash cost computations.
- Traffic Volume and Length of the Influence Zone — The variable "VMT" is a measure of exposure expressed in terms of traffic volume and section length. When computing the expected or actual work zone crash rate, the traffic volume exposed during the work zone period as well as the length of the influence zone should be taken into account.
- Work Zone Safety Improvement— Appropriate crash reduction factors should be included in the crash rate computations to account for future safety improvement countermeasures to be implemented in the work zone. For instance, See et al. reported that the work zone crash rate in Arkansas highways fell by 46 percent when the conventional right-hand lane closure was replaced with the Iowa weave lane closure (i.e., lane closure with a left-hand merge and lane shift) strategy was implemented.[46]

2.4.2 Crash Severity Rating

Roadway crashes are commonly identified in one of the following categories on the basis on their severity:

- Fatal crash is one where the crash results in at least one death.
- Injury crash results in non-fatal bodily injury.
- Property damage only (PDO) involves damage to property but does not result in bodily injury /fatality.

The National Highway Traffic Safety Administration (NHTSA) uses the following scale to report the extent of a roadway crash or the severity of an associated injury:

- **KABCO injury scale**: KABCO is a coding scheme designed for police officers assessing the crash scene. The scale requires no medical training for police officers at the crash scene to assess the severity level of the injury/trauma. This scale has been criticized for coding inconsistencies. See Table 27 for guidelines on KABCO coding.
- **Abbreviated injury scale (AIS)**: AIS is an anatomically based severity scoring scheme that classifies each injury in every region of human body according to its relative severity on a six-point adjectival scale. AIS is often used with the KABCO scale in NHTSA reporting. See Table 28 for guidelines on AIS coding.

[46] See, C.F., S.D. Schrock, and K. McClure, "Crash Analysis of Work-Zone Lane Closures with Left-Hand Merge and Downstream Lane Shift," Paper #09-0979, DVD Compendium, Proceedings of 88th Annual Meeting, Transportation Research Board, Washington, DC, 2009.

Table 27. KABCO injury scale.

Code	Severity	Description
K	Fatal	Any injury that results in death within 30 days of crash occurrence
A	Incapacitating	Any injury other than a fatal injury which prevents the injured person from walking, driving, or normally continuing the activities the person was capable of performing before the injury occurred (e.g., severe lacerations, broken limbs, damaged skull)
B	Injury evident	Any injury other than a fatal injury or an incapacitating injury that is evident to observers at the scene of the crash in which the injury occurred (e.g., abrasions, bruises, minor cuts)
C	Injury possible	Any injury reported that is not a fatal, incapacitating, or non-incapacitating evident injury (e.g., pain, nausea, hysteria)
O	Property damage only	Property damage to property that reduces the monetary value of that property

Table 28. Abbreviated injury scale.

Code	Severity	Description
AIS 6	Fatal	Loss of life due to decapitation, torso transaction, massively crushed chest, etc.
AIS 5	Critical	Spinal cord injury, excessive second- or third-degree burns, cerebral concussion (unconscious more than 24 hours)
AIS 4	Severe	Partial spinal cord severance, spleen rupture, leg crush, chest wall perforation, cerebral concussion (unconscious less than 24 hours)
AIS 3	Serious	Major nerve laceration; multiple rib fracture, abdominal organ contusion; hand, foot, or arm crush/amputation
AIS 2	Moderate	Major abrasion or laceration of skin, cerebral concussion finger or toe crush/amputation, close pelvic fracture
AIS 1	Minor	Superficial abrasion or laceration of skin, digit sprain, first-degree burn, head trauma with headache or dizziness
AIS 0	Uninjured	No injury

2.4.3 Monetary Value of Crashes

There are two approaches in assigning a monetary value for roadway crashes:

- **Human capital costs:** Include those "hard dollar" costs related directly to the crash such as property damage, medical care, compensations and legal costs. Primary sources include NHTSA and the National Safety Council (NSC) bulletins.
- **Comprehensive costs**: Include the intangible nonmonetary losses or consequences to individuals, families and the society, in addition to the human capital costs. Examples include the risk of loss of life, physical and mental suffering, diminished quality of life, and permanent cosmetic damage. Primary sources include USDOT estimates[47] of "Treatment of Value of Life and Injuries in Preparing Economic Evaluations" based on the economic value of a statistical life and the FHWA Technical Advisory (T 7570.2)[48], "Motor Vehicle Accident Costs."

[47] USDOT, Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses-Revised Departmental Guidance, Memorandum, Office of the Secretary of Transportation, U.S. Department of Transportation, Washington, DC. 2009. http://ostpxweb.dot.gov/policy/reports/080205.htm

[48] FHWA, Motor Vehicle Accident Costs, Technical Advisory T 7570.1, Federal Highway Administration, Washington, DC, 1994. http://safety.fhwa.dot.gov/facts_stats/t75702.cfm

The FHWA report, *Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries*, serves a comprehensive resource for obtaining both human capital and comprehensive costs.[49] This report provides cost estimates for 22 scenarios of crash geometries, 2 vehicle speeds (≤ 45 mph, ≥ 50 mph), and 6 levels of KABCO crash severity rating combinations. Table 29 presents a sample of FHWA crash cost estimates for a given crash geometry in 2001 dollars. [49] To convert the cost estimates from 2001 dollars to the current year, human capital costs are adjusted using the CPI (all items). The adjustment to comprehensive cost is a two-step process: (1) the human capital cost portion of the comprehensive cost is adjusted using the CPI (all items), and (2) the remaining portion of the comprehensive cost is adjusted using the ECI (not seasonally adjusted, total compensation, total private industry).

Table 29. Sample FHWA crash cost estimates in 2001 dollars.

Crash Geometry	Speed Limit (mph)	Max. Injury Severity in Crash	Max. Injury Severity Code	Human Capital Cost per Crash		Comprehensive Cost per Crash	
				Mean	Std. Err	Mean	Std. Err
Single vehicle struck human , at intersection	<=45	No injury	0	$8,512	997	$10,249	1,408
	<=45	B or C	1.5	$33,369	4,561	$60,333	9,021
	<=45	A	3	$163,157	15,153	$316,380	33,532
	<=45	K	4	$975,643	30,468	$3,234,016	114,015
	<=45	Injured, severity unknown	5	$67,342	22,127	$129,418	42,249
	<=45	Unknown	9	$14,386	-	$22,841	-
	>=50	No injury	0	$3,672	-	$4,015	-
	>=50	B or C	1.5	$54,605	32,590	$101,712	61,756
	>=50	A	3	$116,545	26,407	$189,805	36,182
	>=50	K	4	$1,022,983	1,695	$3,404,944	2,819
	>=50	Injured, severity unknown	5	$61,573	-	$146,281	-
	<=50	Unknown	N.A.	N.A.	N.A.	N.A.	N.A.

[49] Council, F., E. Zaloshnja, T. Miller and B. Persaud, *Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries*, Report No. FHWA-HRT-05-051, Submitted to the Office of Safety Research and Development, Federal Highway Administration, 2005.

Example 2.10: Computing crash costs

Assume that a highway agency is planning to reconstruct a 3-mile section of Route 101, a four-lane principal arterial in Green County, in 2012. The agency estimates that the work zone of the proposed project is expected to serve a two-directional annual average daily traffic (ADT) of 20,000 vehicles in 2010, while the historic AADT values were 18000, 19000, and 19500 in 2007, 2008, and 2009. The speed limit of the roadway segment is 55 miles per hour. The estimated work zone duration is 60 days.

The agency's office of safety reports that there were 50 PDO incidents and 20 incidents involving injuries (no fatalities), as well as 2 fatalities over a 12-mile section of Route 101 in the past 4 years. No data are available on the crash geometry and severity of injury. Traffic estimates indicate that the roadway segment has carried more than 20 million vehicles in the past 3 years.

The agency is planning to implement a single lane closure in each direction; however, to improve work zone safety, all fixed objects such as signs will be moved 10 feet away from the edge line. The agency typically uses the risk escalation factors reported in the CMF Clearinghouse. Assume that the agency applies 56 percent risk escalation for single lane closures and 62 percent risk reduction for relocating fixed objects. Estimate the work zone crash costs.

Solution:

Step 1. Compute the pre-construction crash rate

$$CR = \frac{A * 10^6}{T * L * AADT * 365}$$

Length of roadway section (L) = 12 miles

Analysis period (T) = 4 years (2007-2010)

AADT in 2007 = 18,000

AADT in 2008 = 19,000

AADT in 2009 = 19,500

AADT in 20010 = 20,000

Total traffic volume (T*AADT) = 18,000+ 19,000+19,500+20,000 = 76,500

Fatalities:

Number of fatalities (A_F) = 2

Pre-construction crash rate – fatalities (Pre-CR_F) = $2*10^6$/(76,500*12*365) = 0.00597/MVMT

Number of injuries (A_{INJ}) = 20

Pre-construction crash rate – injuries (Pre-CR_{INJ}) = $20*10^6$/(76,500*12*365) = 0. 05969/MVMT

Number of property damage only (A_{PDO}) = 50

Pre-construction crash rate – PDO (Pre-CR_{PDO}) = $50*10^6$/(76,500*12*365) = 0.14922/MVMT

Step 2. Estimate the crash modification factor for single lane closure

Risk escalation for work zone crashes = 56%

Crash modification factor for single lane closure (CMF_{SLC}) = 100% + 56% = 156% or 1.56

Step 3. Estimate the crash modification factor for safety improvement counter measures (relocating fixed objects)

Risk reduction in work zone crashes = 62%

Crash modification factor for countermeasures (CMF_{CM}) = 100% - 62% = 38% or 0.38

Step 4. Compute the work zone crash rate

Apply adjustment factors to pre-work zone crash rates to account for elevated risks resulting from work zone hazards and work zone safety improvement countermeasures.

Work zone crash rate = pre-work zone crash rate * CMF_{SLC} * CMF_{CM}

Work zone crash rate involving fatalities ($WZ\text{-}CR_F$)= 0.00597 * 1.56 * 0.38 = 0.003538/MVMT

Work zone crash rate involving injuries ($WZ\text{-}CR_{INJ}$)= 0.05969 * 1.56 * 0.38 = 0.035384/MVMT

Work zone crash rate for PDO ($WZ\text{-}CR_{PDO}$)= 0.14922 * 1.56 * 0.38 = 0.088459/MVMT

Step 5. Estimate the measure of work zone exposure

Work zone duration = 60 days

ADT in 2010 = 20,000 vehicles per day

Work zone traffic volume = 60 * 20,000 = 1,200,000 vehicles or 1.2 million vehicles

Length of influence zone = 3.0 mile

Million Vehicle Miles Traveled = 1.2 * 3 = 3.6 MVMT

Step 6. Estimate the unit crash costs

Refer to FHWA crash estimates (Council et al., 2005) for crash costs.

As the crash geometry is unknown, select Levels 5 and 6 for which cost estimates are provided with no regard to crash geometry.

From Tables 12 and 14 of Council et al. report, estimate the human capital and comprehensives cost for a single crash.

Severity	Human Capital Cost (2001 dollars)	Comprehensive Cost (2001 dollars)
Fatalities (Level 5, speed ≥ 50 mph & K)	\$ 1,277,640	\$ 4,106,620
Injuries (Level 6, speed ≥ 50 mph & A/B/C)	\$ 52,569	\$ 98,752
PDO (Level 5, speed ≥ 50 mph & No injury)	\$ 6,497	\$7,800

Step 7. Adjust unit crash costs from 2001 dollars to 2010 dollars

To convert the comprehensive cost estimates from 2001 dollars to current year, use Consumer Price Index (all items) and Employment Cost Index (ECI - not seasonally adjusted, total compensation, total private industry) from BLS website. Note that region-specific ECI statistics can be obtained for BLS geographic regions (i.e. Midwest or South Atlantic region).

CPI Index Number in December 2001 = 177.1

CPI Index Number in December 2010 = 218.056

Adjustment Factor = CPI(2010)/ CPI(2001) = 1.2313

ECI Index Number in December 2001 = 85.95

ECI Index Number in December 2010 = 112.55

Adjustment Factor = ECI(2010)/ ECI(2001) = 1.3095

The comprehensive cost for a given crash type is adjusted as follows:

Adjusted comprehensive cost = human capital cost * CPI(2010)/ CPI(2001) + (comprehensive – human capital cost) * ECI(2010)/ ECI(2001)

The calculations are shown below:

Severity	Adjustment Factor		Comprehensive Cost (2010 dollars)
	CPI	ECI	
Fatalities	1.2313	1.3095	= ($1,277,640 * 1.2313) + ($4,106,620 -1,277,640)* 1.3095 = $5,277,707
Injuries	1.2313	1.3095	= ($52,569 * 1.2313) + ($98,752 -$52,569)* 1.3095 =$125,205
PDO	1.2313	1.3095	= ($6,497 * 1.2313) + ($7,800 -$6,497)* 1.3095 =$9,706

Step 8. Compute work zone crash costs for the project
The work zone crash costs are computed by multiplying the work zone crash rate (by crash severity) with vehicle miles traveled and the corresponding cost per event.

Severity	Crash rate/ MVMT	MVMT	Cost/event	Crash cost
Fatalities	0.003538	3.6	$5,277,707	$67,221
Injuries	0.035384	3.6	$125,205	$15,949
PDO	0.088459	3.6	$9,706	$3,091

Total estimated crash costs for the project = $67,221 + $15,949 + $3,091 = $86,261
Work zone crash costs for the Route 101 reconstruction project are $86,261 (in 2010 dollars).

2.5 Emission Costs

Work zone activities have adverse effects on the environment through additional vehicle emissions resulting from reduced speeds and queuing. Vehicle emissions generally are categorized as:

- **Air Pollutant Emissions** – Include those emitted directly into the atmosphere, such as carbon monoxide (CO), volatile organic compounds, particulate matter (PM10), oxides of nitrogen (NOX), oxides of sulfur (SOX), and those formed in the atmosphere from the directly emitted pollutants, such as ozone and acidic depositions.
- **Greenhouse Gases** – Include those direct emissions that are not yet recognized as an air pollutants but trap heat within the atmosphere and thus contributing undesirable climatic effects, such as carbon dioxide (CO_2).

Table 30 presents the list of major factors affecting the level and type of vehicular emissions.[50,51]

[50] Thompson, M., A. Unnikrishnan, A. J. Conway and C. M. Walton, *A Comprehensive Examination of Heavy Vehicle Emission Factors*, Report No. SWUTC/10/476660-00067-1, Southwest Region University Transportation Center, College Station, TX, 2010.
[51] Nesamani, K. S., *Estimating Vehicle Emissions in Transportation Planning Incorporating the Effect of Network Characteristics on Driving Patterns*, Ph.D. Dissertation, University of California, Irvine, 2007.

In WZ RUC analysis, the expected increase in emissions (ton/mile) by emissions type is estimated as a function of vehicle type, reduced work zone speed, and increased congestion due to queuing and detours. Once the emission rates for different types of vehicles are estimated, the emissions cost is calculated as a function of vehicles miles traveled (VMT) and unit costs ($/ton) by emissions type. The emissions cost component of WZ RUC is the differential between emissions cost resulting from work zone activities and the pre-construction emissions costs

Emissions Cost = ∑ (VMT x Emissions Rate x Cost/ton) by Emissions Type
WZ RUC Emissions Cost = Emission Cost (work zone) - Emission Cost (pre-construction)

Procedures for estimating emission rates and cost per ton values are presented in sections 2.5.1 and 2.5.2, respectively.

Table 30. Factors affecting vehicular emissions.

Roadway Characteristics	Traffic Characteristics	Driver Characteristics	Vehicle Characteristics	Weather Characteristics
• Number of lanes • Lane width • Sight distance • Horizontal curves • Vertical curves • Grades • Roadway type • Speed limits • Pavement quality • Signal coordination • Other traffic control measures	• Volume • Capacity • Volume/ Capacity ratio • Vehicle composition • Vehicle Speed	• Attitude • Experience • Gender • Age • Aggressiveness • Driving modes	• Age • Mileage • Weight • Fuel type • Engine size • Engine type and cycle characteristic • Air to fuel mass ratio • Catalyst • Maintenance • Aerodynamics • Emission control devices • Acceleration and deceleration characteristics	• Temperature • Humidity • Visibility

2.5.1 Estimating Emissions Rates

There are several models for estimating roadway emissions. Based on the input parameters and the methodology used, these models are broadly classified into:

- Static emission factor models.
- Dynamic instantaneous emission models.

2.5.1.1 Static Emission Factor Models

Static emission factor models use emission factors (i.e., amount of pollutants released to the atmosphere for a given activity) to calculate emissions based on average operation conditions. These models typically include separate emission factors for a given speed and the type of vehicle (passenger cars, buses, light-duty trucks, medium-duty trucks, etc). These models generally are suitable for estimating emissions in large-scale planning studies where the estimations based on average speed are highly accurate; however, these models are not sensitive enough to capture the actual driving conditions such as acceleration, deceleration, idling, and cruising cycles in a work zone. For instance, an emission factor model will estimate the same quantity of emission for a vehicle that traveled smoothly at 15 mph speed in a non-work zone free flow condition and a vehicle that traveled across the work zone at an average speed of 15 mph speed under queuing and forced flow conditions. This limitation is due to the fact that the models lack sophisticated algorithms and data to account for variations in speed and acceleration profiles.

Notable examples include:

- **Mobile 6.2**: This model, developed by the EPA, is used in most of the U.S. except California. It provides estimates of criteria pollutants, toxic pollutants, and particulate matter by vehicle class (covering 28 vehicle types), roadway type (freeways, arterial, ramp and locals), time of day, fuel options, vehicle operating parameters, and other characteristics. It accounts separately for start emissions and running emissions. Mobile 6.2 can be used as a standalone program, while an earlier version of Mobile (version 5.0) is implemented in QUEWZ-98.

- **EMFAC model**: This model, developed by the California Air Resource Board (CARB), is used in California to estimate the emission rates for HC, CO, NO_x, PM, SO_2, lead, and CO_2, as well as fuel consumption. The model provides rates for each emission type as a function of vehicle speed. The latest version of the EMFAC model includes low emission vehicle standards and EPA Tier II standards. The California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C) version 3.2, a spreadsheet, uses EMFAC emission factors to estimate highway emissions cost. Table 31 provides a sample of EMFAC emission factors used in the Cal-B/C program for automobiles and trucks.

Table 31. EMFAC emissions factors (g/mi) used in Cal-B/C program – model year 2003.

Speed	Auto					Trucks				
	CO	NO_X	PM_{10}	SO_X	VOC	CO	NO_X	PM_{10}	SO_X	VOC
5	16.97	1.39	0.10	0.01	1.97	31.44	16.57	0.71	0.12	3.60
10	14.25	1.21	0.07	0.01	1.48	26.81	15.19	0.63	0.12	3.18
15	12.23	1.07	0.06	0.01	1.18	20.51	13.11	0.51	0.11	2.58
20	10.79	0.97	0.05	0.01	0.99	16.68	11.70	0.42	0.11	2.19
25	9.75	0.90	0.04	0.01	0.88	14.29	10.80	0.36	0.11	1.93
30	8.98	0.86	0.04	0.00	0.80	12.78	10.28	0.31	0.11	1.74
35	8.42	0.83	0.04	0.00	0.75	11.83	10.08	0.28	0.11	1.62
40	8.02	0.81	0.03	0.00	0.72	11.27	10.18	0.25	0.11	1.53
45	7.77	0.81	0.03	0.00	0.71	11.00	10.59	0.23	0.11	1.47
50	7.66	0.82	0.03	0.00	0.70	10.98	11.35	0.22	0.11	1.42
55	7.71	0.84	0.03	0.00	0.71	11.19	12.54	0.21	0.11	1.40
60	7.97	0.88	0.03	0.00	0.73	11.69	14.30	0.20	0.11	1.38
65	8.51	0.94	0.03	0.00	0.76	12.55	16.87	0.20	0.11	1.38

2.5.1.2 Dynamic Instantaneous Emission Models

Dynamic emission factor models, otherwise called modal emission models, incorporate the effects of instantaneous changes in vehicle operating conditions in emission estimations. These models typically require extensive data for different operating scenarios at second-by-second intervals (Nesamani, 2007). Unlike emission factor based models, the dynamic models can accommodate changes in speed and acceleration profiles, and thus are suitable for applications at a micro-scale level. Many of these models have been integrated with traffic simulation models for evaluating the emission impacts of various traffic management strategies (Thompson et al., 2010). Notable examples of dynamic instantaneous emission models include:

- **Motor Vehicle Emission Simulator (MOVES)**: This model is the new generation, state-of-the-art modeling tool, developed by the EPA, for estimating emissions from highway vehicles at a detailed level. The current version of this model, MOVES 10a, replaces Mobile 6.2 as the approved tool for use in transportation conformity analyses outside of California (EPA, 2010).[52] This model is capable of estimating emissions on both a macro-scale (e.g., county level) and a micro-scale (e.g., work zone level). The model also can calculate emissions for the time aggregation level chosen (year, month, day, or hour). For example, if the user selects the hour option, the model will estimate emissions for each hour of a day based on the specific inputs for that hour (temperature, speed distribution, etc.). The model accounts for running, start, extended idle, evaporative, crank case, tire wear, brake wear, and life cycle process.

  The vehicle classification used in MOVES10a is consistent with the classification used in the Highway Performance Monitoring System (HPMS). This model uses five different road types: off-network (parking lots, rest areas), rural highways with restricted access (i.e., can only be accessed by an on-ramp), rural highways with unrestricted accesses (arterials, connectors and local streets), urban highways with restricted access, and urban highways with unrestricted access.

- **Comprehensive Model Emission Model (CMEM):** This model, developed under NCHRP Project 25-11, can estimate emissions of cars and small trucks produced as a function of the vehicle's operating mode with high precision(Barth et al., 2000).[53] This model is suitable for applications in project-level or corridor-specific transportation control measures (such as high-occupancy vehicle lanes), intelligent transportation systems (ITS) implementations (such as electronic toll collection), and traffic flow improvements (such as traffic signal coordination).

- **Mobile Emission Assessment System for Urban and Regional Evaluation (MEASURES):** This model, developed at Georgia Institute of Technology and North Carolina DOT, estimates emissions using an approach based on geographic information system (GIS) data.

[52] EPA, *Technical Guidance on the Use of MOVES2010 for Emission Inventory Preparation in State Implementation Plans and Transportation Conformity*, Report No. EPA-420-B-10-023, Office of Transportation and Air Quality, United States Environmental Protection Agency, April, 2010. http://www.epa.gov/otaq/models/moves/420b10023.pdf

[53] Barth, M., F.An, T. Younglove, G. Scora, C. Levine, M. Ross and T. Wenzel, *Development of a Comprehensive Modal Emissions Model*, Final Report, NCHRP Project 25-11, National Cooperative Highway Research Program, Transportation Research Board, Washington DC, 2000. http://www.cert.ucr.edu/cmem/docs/NCHRP_Final_Report.pdf

2.5.2 Monetary Value of Emissions

Emission costs are social costs that are not borne directly by the road users but are estimated based on the impacts borne by the society in general. There is no consensus on how to assign a dollar value to quantify the impacts of each pollutant type. Unit costs of emissions typically used in practice are derived based on the economic analysis of health impacts caused by air pollutants and greenhouse gases.

Furthermore, the unit costs of emissions vary widely with source-related factors such as population density and land cover of the work zone location. Metropolitan areas with high population densities are affected more strongly by adverse health impacts of emissions than rural areas, and hence, higher unit costs are used. Therefore, practitioners should use emission costs that reflect region-specific values developed by the regional planning agency for each emission type. Examples of unit cost sources of emissions include:

- California Department of Transportation (Caltrans) estimates[54] - See Table 32.
- HERS-ST Technical Report (2005) – See Table 33. In addition, Appendix F of the HERS-ST report provides dollar cost estimates per vehicle mile as a function of vehicle speed, vehicle type, and roadway functional class.

There is no consensus on guidelines on updating the existing year dollars to current year prices. The commonly used approach is to adjust the emission costs using Implicit Price Deflators for Gross Domestic Product-Goods.[55, 56]

Table 32. Caltrans estimates ($/U.S. ton) of health cost of transportation emissions in 2010 dollars.

Pollutant	L.A./South Coast	CA Urban Area	CA Rural Area
Carbon Monoxide	$135	$70	$65
Nitrogen Oxide (NOx)	$55,700	$16,300	$12,100
Particular Matter (PM10)	$456,500	$131,800	$94,000
Sulfur Oxide (SOx)	$171,500	$65,800	$47,500
Volatile Organic Compounds	$3,465	$1,140	$895
Greenhouse Gases (CO2)*		$37	

Note: (*) Federal Register 74 FR 28759 (06-17-2009) suggests that the estimate of $33 per metric ton of carbon cited on page VIII-45 of National Highway Traffic Safety Administration (NHTSA)'s analysis may be used as a placeholder to measure the global benefits of reducing U.S. CO2 emissions.[57]

[54] http://www.dot.ca.gov/hq/tpp/offices/ote/benefit_cost/eab-econ-valuations.html

[55] California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C) Technical Supplement to User's Guide, Prepared by Booz Allen & Hamilton Inc., California Department of Transportation, Sacramento, 1999.

[56] Implicit Price Deflators for GDP can be obtained from Table 1.1.9 of the National Income and Product Account (NIPA) published by the Bureau of Economic Analysis. Using GDP deflators for adjustment treats emission costs as an economic product and will not capture the quality of life or well being. http://www.bea.gov/national/nipaweb/SelectTable.asp

[57] NHTSA Final Regulatory Impact Analysis, *Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks*, published March 2009. http://www.nhtsa.gov/DOT/NHTSA/Rulemaking/Rules/Associated%20Files/CAFE_Final_Rule_MY2011_FRIA.pdf

Table 33. HERS-ST estimates of air pollutant damage costs in 2000 dollars.

Pollutant	Damage Costs ($/ton)	Adjustment Factors	
		Urban	Rural
Carbon Monoxide	$100	1	0.5
Volatile Organic Compounds	$2,750	1.5	1
Nitrogen Oxides	$3,625	1.5	1
Sulfur Dioxide	$8,400	1.5	1
Fine Particulate Matter (PM2.5)	$4,825	1	0.5
Road Dust	$4,825	1	0.5

2.6 NETWORK/CORRIDOR LEVEL IMPACTS OF NEARBY PROJECTS

Work zone can have more pronounced impacts at the corridor, network, and regional level than at the immediate work zone itself, particularly for significant projects. Hence, the analysis of work zone impacts and associated WZ RUC computation should extend beyond the immediate work zone area. Practitioners can use the guidance provided in the FHWA Traffic Analysis Toolbox Volume IX in selecting a work zone modeling program or approach to quantify impacts on a wider scale.[58] The impact assessment and associated WZ RUC at the corridor, network, and regional level can help an agency to coordinate transportation management strategies within and outside the agency.

2.7 NON-MONETARY QUANTITATIVE AND QUALITATIVE FACTORS

In addition to monetary components, other work zone effects that impact the community at-large are also taken into consideration. These factors are generally hard to monetize and therefore should be considered as non-monetary or qualitative factors in the decision-making process. The key non-monetary and qualitative factors include:

- Noise
- Business and societal impacts

2.7.1 Noise

Excessive noise resulting from work zone construction activities can have adverse effects on road users and other stakeholders. Noise can be a significant issue, especially with nighttime construction in residential and business areas, and may violate compliance of local ordinance requirements. Apart from general nuisance, excessive noise can pose health problems. Therefore, it is essential for highway agencies to estimate the work zone noise level and employ appropriate noise mitigation and work schedule strategies. Additional costs associated with noise mitigation strategies, such as the installation of noise barriers, should be considered in the MOT alternative analysis.

Practitioners can utilize the FHWA Roadway Construction Noise Model (RCNM) in predicting noise for highway construction projects of varying complexity. The RCNM is a Windows-based

[58] Hardy, M. and K. Wunderlich, *Traffic Analysis Tools Volume IX: Work Zone Modeling and Simulation—A Guide for Analysts*, Report No. FHWA-HOP-09-001, Office of Operations, Federal Highway Administration, Washington, DC, 2009.
http://ops.fhwa.dot.gov/wz/traffic_analysis/tatv9_wz/index.htm

computer program that enables the prediction of construction noise levels for various construction operations while requiring no additional effort of collecting extensive project-specific input data. The RCNM is based on a compilation of empirical data and the application of acoustical propagation formulas. The RCNM provides the estimation of maximum, average, and percentile statistics of sound level at a work zone event over a given period of observation time for up to 10 receptor locations and 20 pieces of construction equipment.

Little information is available on monetizing the damage caused by construction noise. Delucchi and Hsu (1998) provide a theoretical basis and cost estimates for monetizing the external damage caused by noise emitted from motor vehicles under normal operating conditions.[59] FHWA's highway cost allocation study uses noise damage costs in estimating the share of highway costs that various highway users pay; however, these costs provide per mile rates (cents per mile) based on highway functional classification and vehicle type under normal operating conditions and do not account for work zone effects.

2.7.2 Business and Local Community Impacts

Work zones can affect accessibility to local business premises, thus adversely impacting local commerce. Many business owners are concerned about the potential negative impacts on their businesses, which may include:[60]

- Customer access and parking, and delivery access.
- Parking issues.
- Utility outages and disruptions.
- Congestion and traffic pattern changes.
- Temporary loss of customers.
- Decrease in gross sales revenue and net profits.
- Adverse impacts on full time and part time employment.
- Decrease in property and land values.

Highway agencies address the concerns of individual business owners by conducting business impact studies in the project development phase to identify critical needs and priorities of different types of businesses. Agencies then implement management strategies in the construction phase to mitigate these impacts.

Wolffing et al. (2004) conducted a survey to identify how State highway agencies gather information and manage business owners' concerns.[61] This study found that most State agencies involve the business owners and other stakeholders early in the project development process through public information meetings/hearings. In some cases, agencies may involve local government officials or hire facilitators/liaison officers in the process before scheduling public information meetings.

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[59] Delucchi, M. and S. Hsu, The External Damage Cost of Noise Emitted from Motor Vehicles, Journal of Transportation and Statistics, Bureau of Transportation Statistics, 1998. http://ntl.bts.gov/lib/9000/9100/9106/1deluc.pdf

[60] Wildenthal, M.T. and J.L. Buffington, "Estimated Construction Period Impact of Widening State Highway 21, in Caldwell, Texas," Transportation Research Record No. 1559, Journal of the Transportation Research Board, Washington, D.C, 1996.

[61] Wolffing, C., J. Liesman, R. Young and K. Ksaibati, *Highway Construction Related Business Impacts: Phase I Report*, Report No. FHWA-WY-04/01F, Wyoming Department of Transportation, Cheyenne, WY, March 2004.

In addition to public meetings, agencies use strategies such as surveys with business managers and door-to-door visits with residents and business owners to gather information of local community and business impacts. The purpose of these meetings is to provide project information to business owners, answer questions about the project, and solicit inputs regarding potential concerns and impacts. The inputs gathered at these meetings often are incorporated as mitigation strategies in devising MOT alternatives.

Local communities have similar concerns, such as issues related to resident access, decrease in property and land values, noise, and air pollution. The strategies used for gathering information of societal impacts are similar to those for gathering information on business impacts. Some agencies, such as Florida DOT, have a community awareness program for every project to involve with adjacent communities early in the process and address local conditions during construction.

2.8 DATA REQUIREMENTS FOR WZ RUC MOBILITY ANALYSIS

This section presents a discussion of the input data required for conducting work zone mobility impact analysis. The following inputs are required to estimate or assess work zone mobility impacts for WZ RUC computation:

- Hourly traffic demand.
- Traffic composition.
- Work zone capacity.
- Travel speed.
- Work zone configuration.
- MOT strategy.

2.8.1 Hourly Traffic Demand

Hourly traffic demand is the 24-hour hourly distribution of vehicles passing through the work zone in a single direction under normal operating conditions. The hourly variations can be obtained from actual traffic count measurements at the work zone site or estimated from the projected ADT using hourly distribution factors (percent of ADT during the specific hour). In determining hourly demand, distinctions should be made among weekday, weekend, and seasonal traffic patterns. The hourly demand also may vary between urban and rural roadways, by location, and among various functional classes.

Hourly distribution factors can be determined by analyzing traffic data obtained from data collection devices such as WIM systems, automatic vehicle recorders (ATR), and accumulative count recorders (ACR). In the absence of such site-specific data, regional estimates, typical, or default hourly patterns can be used. Table 34 presents an example of hourly distribution factors used in MicroBENCOST for urban and rural highways. Using default hourly traffic patterns may not be representative of the actual project conditions and can be appropriate for preliminary analyses.

Table 34. Sample hourly traffic distribution factors.

Hour of the Day	Urban			Rural		
	Hourly Factors	Percent Inbound Direction	Percent Outbound Direction	Hourly Factors	Percent Inbound Direction	Percent Outbound Direction
0 - 1	1.20	47.0	53.0	1.80	48.0	52.0
1 - 2	0.80	43.0	57.0	1.50	48.0	52.0
2 - 3	0.70	46.0	54.0	1.30	45.0	55.0
3 - 4	0.50	48.0	52.0	1.30	53.0	47.0
4 - 5	0.70	57.0	43.0	1.50	53.0	47.0
5 - 6	1.70	58.0	42.0	1.80	53.0	47.0
6 - 7	5.10	63.0	37.0	2.50	57.0	43.0
7 - 8	7.80	60.0	40.0	3.50	56.0	44.0
8 - 9	6.30	59.0	41.0	4.20	56.0	44.0
9 - 10	5.20	55.0	45.0	5.00	54.0	46.0
10 - 11	4.70	46.0	54.0	5.40	51.0	49.0
11 - 12	5.30	49.0	51.0	5.60	51.0	49.0
12 - 13	5.60	50.0	50.0	5.70	50.0	50.0
13 - 14	5.70	50.0	50.0	6.40	52.0	48.0
14 - 15	5.90	49.0	51.0	6.80	51.0	49.0
15 - 16	6.50	46.0	54.0	7.30	53.0	47.0
16 - 17	7.90	45.0	55.0	9.30	49.0	51.0
17 - 18	8.50	40.0	60.0	7.00	43.0	57.0
18 - 19	5.90	46.0	54.0	5.50	47.0	53.0
19 - 20	3.90	48.0	52.0	4.70	47.0	53.0
20 - 21	3.30	47.0	53.0	3.80	46.0	54.0
21 - 22	2.80	47.0	53.0	3.20	48.0	52.0
22 - 23	2.30	48.0	52.0	2.60	48.0	52.0
23 - 24	1.70	45.0	55.0	2.30	47.0	53.0

2.8.2 Traffic composition

A traffic stream typically includes various vehicle types—passenger cars, buses, single-unit trucks, tractor-trailers, and multi-trailer trucks. These vehicle types are associated with different usage, operating characteristics, and performance, and thus, have different vehicle operating costs and monetary values of time. Furthermore, heavy vehicles occupy more roadway space than passenger cars, affecting roadway capacity. Inputs for traffic composition can be categorized broadly as:

- Number of passenger cars (vehicle classes 1 through 3 as defined in the FHWA TMG)[62]
  - Small automobiles[63]
  - Medium/large automobiles
  - Pickups & vans
- Number of single-unit trucks (FHWA TMG vehicle classes 4 through 7)
  - Six-tire trucks
  - Three or more axle single-unit trucks

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[62] Traffic Monitoring Guide, Report No FHWA-PL-01-021, Office of Highway Policy Information, Federal Highway Administration, Washington, DC, 2001. http://www.fhwa.dot.gov/ohim/tmguide/index.htm
[63] Highway Economic Requirement System (HERS) considers small automobiles as smaller cars as opposed to FHWA vehicle class 1 (i.e. motorcycles).

- Number of combination trucks (FHWA TMG vehicle classes 8 through 13)
  - Three/four axle combination trucks
  - Five or more axle combination trucks

Typical sources of data include an agency's traffic monitoring programs and HPMS data inventories; in the absence of location-specific data, typical values representative of project conditions can be substituted.

2.8.2.1 Passenger Car Units

As heavy vehicles in the traffic stream occupy more physical space than passenger cars, these vehicles affect the number of vehicles that can be served on a roadway segment. Therefore, to allow a consistent measure of traffic flow in demand-capacity analysis, each heavy vehicle is converted into an equivalent number of passenger cars using a heavy vehicle adjustment factor called passenger-car equivalents (E_T). This conversion depends on the proportion of heavy vehicles in the traffic stream as well as the geometric alignment of the roadway.

Chapters 11 and 14 of the HCM 2010 present E_T values for multilane highways and highways respectively, for various terrain types and grade geometries.[7,64]

2.8.3 Work Zone Configuration

Work zone configuration inputs required for WZ RUC analysis typically include:

- Number of lanes in each direction.
- Number of open lanes through the work zone in each direction.
- Length of the lane closure.
- Lane width.
- Lateral clearance restrictions.
- Turn restrictions.
- Layout of project sequencing.
- Availability and traffic characteristics of alternative routes.
- Hours of lane closure (begin and end time).
- Hours of work activity (begin and end time).
- Signalization
- Segment information – network information

2.8.4 Work Zone Capacity

Work zone capacity is defined as the maximum sustainable flow rate at which vehicles can pass a given point or uniform segment of a lane or roadway in a work zone during a specified period under prevailing roadway, traffic, and control conditions. Capacity usually is expressed as passenger cars per hour per lane (pcphpl) or vehicles per hour per lane (vphpl).

The vehicle capacity of a facility is a function of roadway and traffic characteristics; the capacity is at the maximum under base conditions and uninterrupted traffic flow. The base

[64] Highway Capacity Manual 2010, Transportation Research Board, Washington DC, 2010.

conditions of a facility represent best possible characteristics at which no further improvements would increase vehicle capacity. Base conditions include factors such as the criteria for minimum lane width and lateral clearance, level terrain (less than 2 percent), free-flow speed, flow of passenger cars only, no direct access points along the segment, and a good, rideable surface.

The capacity values (at base conditions) for various highway types are recommended in the HCM 2010. HCM 2010 also presents guidelines to determine reduction in capacity resulting from work zone activities. The suggested values are 1,600 pcphpl for short-term work zones and a range of 1,550 to 2,060 pcphpl for long-term work zones.

As the prevailing conditions of a facility deviate from the base conditions, appropriate adjustments to the capacity must be made. Factors that warrant adjustments to the work zone capacity estimates include:

- Work zone configuration.
  - Number of opened lanes.
  - Number of closed lanes.
  - Location of closed lanes (left or right).
  - Work zone grade.
  - Work zone length.
  - Lane width.
  - Area type (rural/urban).
  - Presence of ramps.
- Traffic characteristics.
  - Effect of heavy vehicles.
  - Driver population.
  - Entrance ramp volume.
  - Lateral distance to the open travel lanes.
  - Work zone speed.
  - Platoon factor (i.e., fluctuation in capacity utilization).
- Intensity of work activity.
- Work zone duration (short term or long term).
- Weather condition.
- Work time (day or night).

In addition to the HCM 2010 guidelines, there are numerous work zone capacity models available. Notable examples include (presented in chronological order):

- Weng and Meng (2011)[65] – Presents a decision tree model based on 16 influencing factors and 182 data sets from 14 States and cities.
- Benekohal et al (2004)[66] – Presents a methodology based on data from 11 work zone sites in Illinois.

[65] Weng, J. and Q. Meng, A Decision Tree-based Model for Work Zone Capacity Estimation, Paper No. 11-0865, DVD Compendium, Proceedings of 90th Annual Meeting, Transportation Research Board, Washington, DC, 2011.
[66] Benekohal, R. F. A. Kaja-Mohideen, M. V. Chitturi, A Methodology for Estimating Operating Speed and Capacity in Work Zones, Transportation Research Record No. 1883, Journal of the Transportation Research Board, Washington, DC, 2004.

- Sarasua et al. (2004)[67] – Presents a prediction model based on data from 22 short-term work zone sites along South Carolina's Interstate system.
- Al-Kaisy & Hall (2002)[68] – Presents a prediction model based on data from 7 long-term work zone sites in Toronto, Ontario.
- Kim's model (2001)[69] – Presents a prediction model based on data from 12 work zone sites in Maryland.
- Jiang, Y (1999)[70] – Presents the findings of work zone capacity studies of 12 data sets from 4 work zone sites in Indiana.
- Dixon et al. (1996)[71] – Presents the findings of capacity studies of 24 short-term freeway lane closures in North Carolina.
- Krammes & Lopez (1992)[72] – Adopted in QUEWZ-98, Cited in HCM 2000 for short-term work zone capacity.
- Dudek & Richards (1981)[73] – Adopted in 1984 version of QUEWZ. Presents the findings of work zone capacity studies conducted in Houston and Dallas, Texas.

2.8.5 Travel Speed

Two key inputs required for delay-capacity analysis are the free-flow speed (adjusted to roadway conditions) and the work zone speed limit. Free-flow speed is the operating speed at which the traffic travels under normal operating conditions (when there is no work zone). Work zone speed limit is the posted speed limit in a work zone. At this speed, the vehicles are expected to travel the work zone with no queuing and reduction in posted speed limit. As the demand/capacity ratio approaches 1.0 (i.e., the demand reaches saturation levels), the travel speed decreases. When the demand exceeds available capacity, queuing can result.

NOTE

Average travel speed can be measured using radar, roadside detectors, travel-time runs, etc. Recently, agencies have also started using private sector data for this purpose.[74]

[67] Sarasua, W. A., W. J. Davis, D. B. Clarke, J. Kottapally, P. Mulukutla, Estimating Interstate Highway Capacity for Short-Term Work Zone Lane Closures: Development of Methodology, Transportation Research Record No. 1877, Journal of the Transportation Research Board, Washington, D.C., 2004.

[68] Al-Kaisy, A. and F. Hall, Guidelines for Estimating Freeway Capacity at Long-Term Reconstruction Zones, CDROM Compendium, Proceedings of 81th Annual Meeting, Transportation Research Board, Washington, DC, 2002.

[69] Kim, T., D. J. Lovell, and J. Paracha, A New Methodology to Estimate Capacity for Freeway Work Zones, Paper No. 01-0566, CDROM Compendium, Proceedings of 80th Annual Meeting, Transportation Research Board, Washington, DC, 2001.

[70] Jiang, Y. Traffic capacity, Speed and Queue-discharge rate for Indiana's Four-lane Freeway Work Zones. Transportation Research Record No. 1657, Journal of the Transportation Research Board, Washington, D.C.,1999

[71] Dixon, K. K., Hummer, J. E. and Lorscheider, A. R. Capacity for North Carolina Freeway Work Zones. Transportation Research Record No. 1529, Journal of the Transportation Research Board, Washington, D.C., 1996.

[72] Krammes, R. A. and G. O. Lopez, Updated Short-Term Freeway Work Zone Lane Closure Capacity Values, Report No. FHWA/TX-92/1108-5, Texas Department of Transportation, Austin, TX, 1992.

[73] Dudek, C. L. and S. H. Richards. Traffic Capacity through Work Zones on Urban Freeways. Report FHWA/TX-81/228-6, Texas Department of Transportation, Austin, TX, 1981.

[74] Eisele, B., Schrank, D. and T. Lomax, 2011 Congested Corridors Report - Appendix B, Texas Transportation Institute, College Station, TX, 2011. http://mobility.tamu.edu/corridors/methodology/

2.8.6 Maintenance of Traffic Strategy

MOT is a set of coordinated strategies to meet the traffic mobility and safety needs within a work zone. MOT traditionally has included temporary traffic control strategies and devices for managing work zone traffic; however, with the implementation of the FHWA Final Rule on Work Zone Safety and Mobility, the scope of MOT has expanded to include strategies for addressing public information and transportation operations needs for all projects with significant work zone impacts including Federal-aid projects.[75, 76]These strategies are grouped taxonomically as follows:

- Temporary traffic control (TTC) strategies.
  - Traffic control strategies – include various traffic control approaches to accommodate road users within the work zone or the adjoining corridor in an efficient and safe manner, while providing adequate access to construction activities.
  - Traffic control devices – include various traffic control devices installed for maintaining work zone traffic as outlined in the MUTCD standards.
  - Project coordination, contracting, and innovative construction strategies – include coordination strategies with other projects and infrastructure elements (e.g., railroad, utilities).
- Transportation operations strategies
  - Demand management strategies - include various strategies intended to reduce the volume of traffic traveling through the work zone.
  - Corridor/network management strategies- include various traffic operations techniques and technologies to optimize traffic flow through the work zone and adjacent roadways.
  - Work zone safety management strategies – include various devices, features, and management procedures to address work zone safety concerns.
  - Traffic/incident management and enforcement strategies – include various strategies to monitor traffic conditions and make adjustments as required to traffic operations based on changing conditions.
- Public information strategies
  - Public awareness strategies - include various methods to educate and reach out to the public, businesses, and the community on the upcoming/ongoing project work zones and potential impacts.
  - Motorist information strategies – provide current and/or real-time information to road users regarding the project work zone.

Tables 35 through 37 presents specific strategies classified under each of these groups.[77]

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[75] A significant project is one that, alone or in combination with other concurrent projects nearby is anticipated to cause sustained work zone impacts (or high level of disruption) that are greater than what is considered tolerable based on the respective agency's policy and/or engineering judgment. The agency's work zone policy provisions, the project's characteristics, and the magnitude and extent of the anticipated work zone impacts should be considered when determining if a project is significant or not.

[76]Frequently Asked Questions for the Work Zone Safety and Mobility Rule
http://www.ops.fhwa.dot.gov/wz/resources/final_rule/rule_faqs.htm

[77] Jeannotte, K., and A. Chandra, Developing and Implementing Transportation Management Plans for Work Zones, Report No. FHWA-HOP-05-066, Office of Transportation Operations, Federal Highway Administration, Washington, DC, 2005.
http://www.ops.fhwa.dot.gov/wz/resources/publications/trans_mgmt_plans/trans_mgmt_plans.pdf

Table 35. Work zone management strategies by category – temporary traffic control.

Traffic Control	**Traffic Control Devices**	**Project Coordination, Contracting, and Innovative Construction**

• Construction phasing/staging
• Full roadway closures
• Lane shifts or closures
  o Reduced lane widths to maintain number of lanes (constriction)
  o Lane closures to provide worker safety
  o Reduced shoulder width to maintain number of lanes
  o Shoulder closures to provide worker safety
  o Lane shift to shoulder/median to maintain number of lanes
• One-lane, two-way operation
• Two-way traffic on one side of divided facility (crossover)
• Reversible lanes
• Ramp closures/relocation
• Freeway-to-freeway interchange closures
• Night work
• Weekend work
• Work hour restrictions for peak travel
• Pedestrian/bicycle access improvements
• Business access improvements
• Off-site detours/use of alternate routes
	• Temporary signs
	  o Warning
	  o Regulatory
	  o Guide/ information
	• Changeable message signs
	• Arrow panels
	• Channelizing devices
	• Temporary pavement markings
	• Flaggers and uniformed traffic control officers
	• Temporary traffic signals
	• Lighting devices
		• Project coordination
		  o Coordination with other projects
		  o Utilities coordination
		  o Right-of-way coordination
		  o Coordination with other transportation infrastructure
		• Contracting strategies
		  o Design-build
		  o A+B bidding
		  o Incentive/disincentive clauses
		  o Lane rental
		• Innovative construction techniques (pre-cast members, rapid cure materials)

Source: Jeannotte and Chandra (2005)[77]

Table 36. Work zone management strategies by category – transportation operations.

Demand Management	Corridor/ Network Management	Work Zone Safety Management	Traffic/ Incident Management and Enforcement
• Transit service improvements • Transit incentives • Shuttle services • Ridesharing/carpooling incentives • Park-and-ride promotion • High-occupancy vehicle lanes • Toll/congestion pricing • Ramp metering • Parking supply management • Variable work hours • Telecommuting	• Signal timing/ coordination improvements • Temporary traffic signals • Street/ intersection improvements • Bus turnouts • Turn restrictions • Parking restrictions • Truck/heavy vehicle restrictions • Separate truck lanes • Reversible lanes • Dynamic lane closure system • Ramp metering • Temporary suspension of ramp metering • Ramp closures • Railroad crossings controls • Coordination with adjacent construction site(s)	• Speed limit reduction/ variable speed limits • Temporary traffic signals • Temporary traffic barrier • Movable traffic barrier systems • Crash-cushions • Temporary rumble strips • Intrusion alarms • Warning lights • Automated flagger assistance devices • Project task force/committee • Construction safety supervisors/inspectors • Road safety audits • TMP monitor/ inspection team • Team meetings • Project on-site safety training • Safety awards/incentives • Windshield surveys	• ITS for traffic monitoring/ management • Transportation management center • Surveillance • Helicopter for aerial surveillance • Traffic Screens • Call boxes • Mile-post markers • Tow/freeway service patrol • Total station units • Photogrammetry • Coordination with media • Local detour routes • Contract support for incident management • Incident/emergency management coordinator • Incident/emergency response plan • Dedicated (paid) police enforcement • Cooperative police enforcement • Automated enforcement • Increased penalties for work zone violations

Source: Jeannotte and Chandra (2005)[77]

Table 37. Work zone management strategies by category – public information.

Public Awareness	Motorist Information
• Brochures and mailers • Press releases/media alerts • Paid advertisements • Public information center • Telephone hotline • Planned lane closure web site • Project web site • Public meetings/hearings • Community task forces • Coordination with media/schools/ businesses/emergency services • Work zone education and safety campaigns • Work zone safety highway signs • Rideshare promotions • Visual information (videos, slides, presentations) for meetings and web	• Traffic radio • Changeable message signs • Temporary motorist information signs • Dynamic speed message sign • Highway advisory radio • Extinguishable signs • Highway information network (web-based) • 511 traveler information systems (wireless, handhelds) • Freight travel information • Transportation management center

Source: Jeannotte and Chandra (2005)[77]

2.9 Tools for WZ RUC Computation

Available WZ RUC computation tools can be categorized into two groups: work zone traffic analysis and economic analysis tools.

2.9.1 Work Zone Traffic Impact Analysis Tools

Traffic analysis tools help practitioners to understand and assess the mobility impacts of work zone strategies prior to deployment and monitor performance during construction. While the traffic analysis tools focus on quantifying the mobility impacts, a robust mobility analysis is often instrumental in the assessment of factors such as safety, economic, environmental and other work zone related impacts.[78] The mobility impacts form the core for aggregating user delay costs, VOC, impacts to local businesses, and costs to the local agency.

Various traffic analysis tools are available for analyzing work zone related mobility impacts at various stages of a project. The FHWA Traffic Analysis Toolbox (TAT) provides detailed guidance on using various traffic analysis methodologies and tools.[79] FHWA TAT organizes currently available tools into six categories:

- Sketch-planning/HCM based methods.
- Travel demand models.
- Traffic signal optimization.
- Macroscopic simulation.
- Mesoscopic simulation.
- Microscopic simulation.

The following section limits the discussion to sketch-planning and HCM based tools.

> NOTE
>
> Selection of an appropriate traffic analysis tool for work zone impact analysis depends on factors such as project size, level of details needed, geographic scale, work zone configuration, and so on. More detailed guidance on tool selection is presented in *Traffic Analysis Tools Volume IX: Work Zone Modeling and Simulation —A Guide for Analysts.*[58]

2.9.1.1 Sketch-Planning and HCM Methodologies

These tools utilize hourly traffic demand data and capacity analyses to estimate and quantify work zone impacts. These estimates may be less precise, owing to the simplistic approach adopted by these tools, and thus often are considered more appropriate for use in the early stages of a project.

Some tools have advanced functionalities. For example, Quick Zone can handle delay impacts at the corridor level and facilitates tradeoff analyses between construction costs and delay costs, while CA4PRS is equipped to handle “what if” scenarios for highway rehabilitation to

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[78] Hardy, M., and K. Wunderlich, *Traffic Analysis Tools Volume VIII: Work Zone Analysis - A Guide for Decision-Makers*, Report No. FHWA-HOP-08-029, Office of Operations, Federal Highway Administration, Washington, DC, 2008.

[79] FHWA Traffic Analysis Toolbox, http://ops.fhwa.dot.gov/trafficanalysistools/index.htm

identify solutions that balance on-schedule construction production, traffic inconvenience, and agency costs. Commonly used sketch-planning and HCM based tools are listed in Appendix A, Volume I of the TAT.[80] Notable examples include:

- Spreadsheet-based tools.
- QUEWZ-98.
- Quick Zone.
- CA4PRS.

Spreadsheet-based Tools

Several State DOTs have developed spreadsheet-based tools to analyze the traffic impacts at work zones. Typical examples include those developed by Arizona, Florida, Idaho, Illinois, Maryland, Michigan, Missouri New Jersey, Ohio, Pennsylvania, and Virginia. While most spreadsheet-based tools use analytical equations and HCM procedures, some tools use only simple mathematical formulae.

In addition to these general capabilities, some spreadsheet-based tools possess unique functionalities tailored to a particular agency's needs. Some of the salient features are summarized as follows:

- Maryland's Loss of Public Benefit (LOPB) spreadsheet can estimate crash costs and has a separate module for temporary signal and flagging operations.
- Florida's spreadsheet can perform demand-capacity analysis for two-lane, two-way operations, and urban streets. This tool includes formulae for calculating crash costs and a general impact factor to adjust the overall WZ RUC results.
- Illinois's tool is equipped with an improved queuing analysis methodology calibrated using field data from 13 work zones. This approach includes separate speed-flow curves for work zones with speed limit of 45 mph and a flagger, work zones with speed limit of 45 mph and without a flagger, and work zones with speed limit of 55 mph.
- Highway User Benefit-Cost Analysis Program (HUB-CAP), a Virginia DOT benefit-cost analysis spreadsheet tool, includes a comprehensive crash cost estimation tool based on the KABCO crash severity scale. This tool also includes look-up tables of source information used for deriving unit costs.
- The Construction Congestion Cost (CO3) tool, developed for Michigan DOT, has an additional module for analyzing the impact of different construction methods on construction costs. This module includes individual components for calculating project costs associated with labor, equipment, materials, traffic control, and project-related agency costs. Notable among them is the labor cost component, which takes the fixed mobilization costs and productivity-based variable labor wage costs into account for standard and overtime conditions.
- Oregon DOT has replaced its spreadsheet-based package with a web-based tool, Work Zone Traffic Analysis Tool (WZTA), that allows users to access location-specific traffic data, free flow capacity, and vertical and horizontal geometric features of the work zone location and generate delay times and queue length for a user-specified lane closure period.

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[80] Alexiadis, V., K. Jeannotte and A. Chandra, *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*, Report No. FHWA-HRT-04-038, Office of Operations, Federal Highway Administration, Washington, DC, 2004. http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol1/sectapp_a.htm

- Colorado DOT uses a standalone program, Work Zone-RUC that possesses typical capabilities of a spreadsheet-based tool. This tool contains productivity rates (number of estimated days to complete a specific unit of work) for typical highway construction related activities. It also allows adjustments to lane capacity based on the activity type, lateral distance to obstruction, and geometric features of the work zone location. It allows only two types of MOT strategies: crossovers and single lane closures.

Figures 04 through 07 present screenshots of some spreadsheet tools.

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 Delay (Added Time)	CAR	90	27,900		0.109	12.75	34,897
	TRUCK	10	27,900		0.109	21.25	6,462
Queue Idling VOC (Added Cost)	CAR	90	27,900		0.109	0.6821	1,867
	TRUCK	10	27,900		0.109	0.7845	239
Work Zone Delay (Added Time)	CAR	90	50,000		0.012	12.75	6,885
	TRUCK	10	50,000		0.012	21.25	1,275
Circuity Delay (Added Time)	CAR						
	TRUCK						
Circuity VOC (Added Cost)	CAR						
	TRUCK						
Total Vehicles that Travel Queue:			27,900		Daily Road User Cost		51,625
Total Vehicles that Travel Work Zone:			50,000		Calculated Road User Cost (CRUC)		25,813
Total Vehicles that Travel Detour:			0		Number of Work Zone Days		75
Percent Passenger Cars:			90%		Total Road User Cost		1,935,938
Percent Trucks:			10%				
Project: EXAMPLE #1						Date:	July 1999
Description: 24 Hour Lane Reduction							

Figure 4. Sample screenshot from the New Jersey DOT spreadsheet tool.

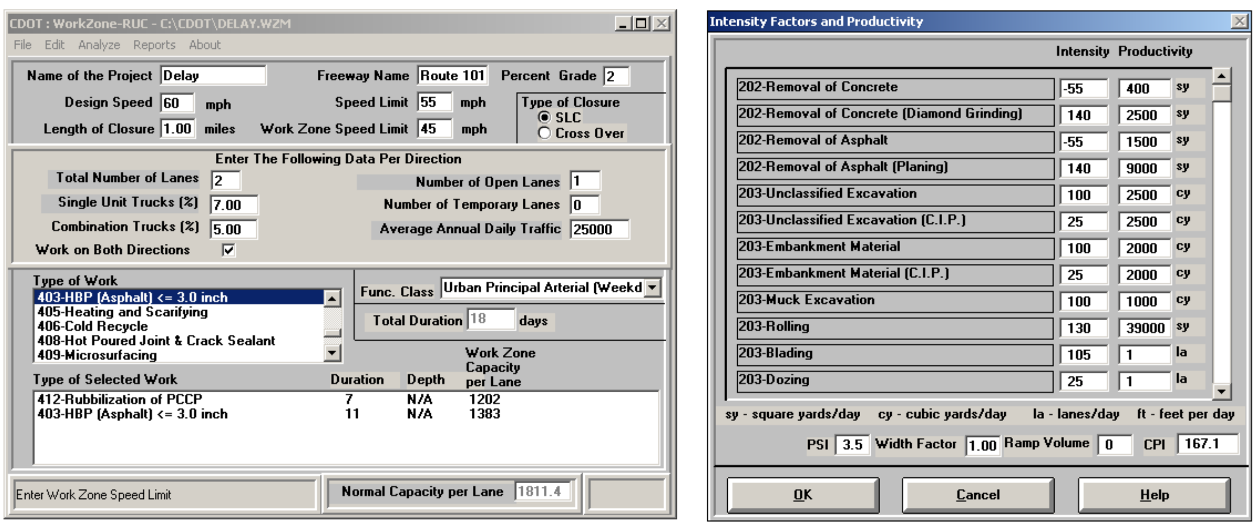


Figure 5. Sample screenshot from the Colorado WZ RUC program with input screens (left) and the productivity rates for various highway construction activities and the corresponding lane capacity adjustment values (right).

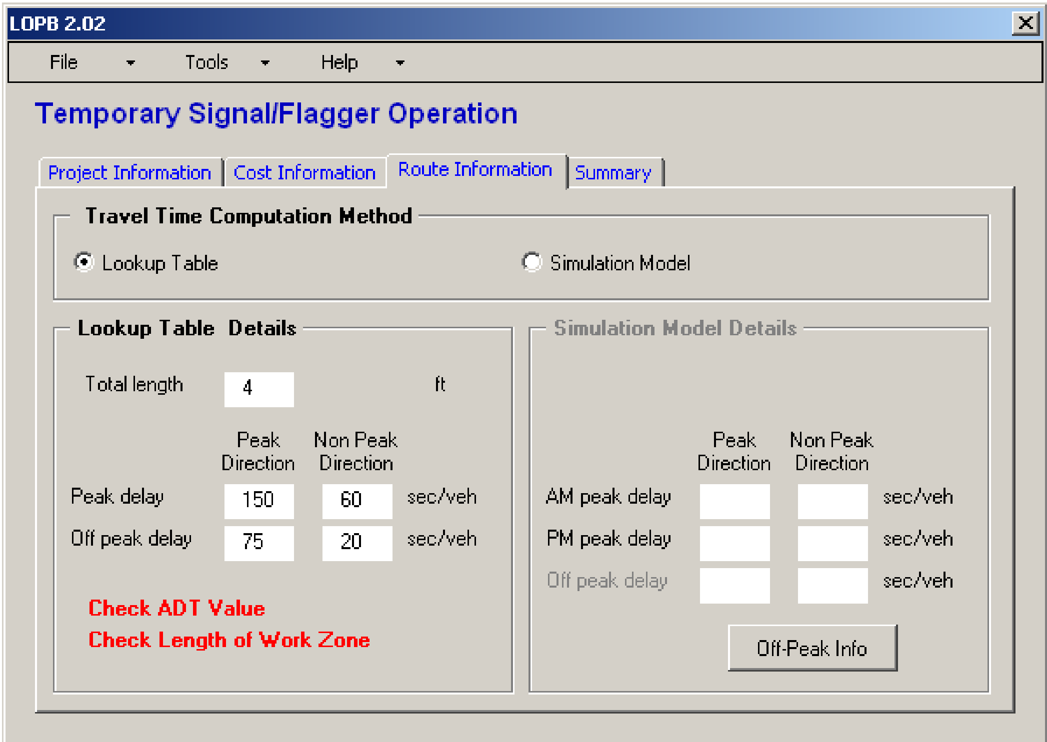
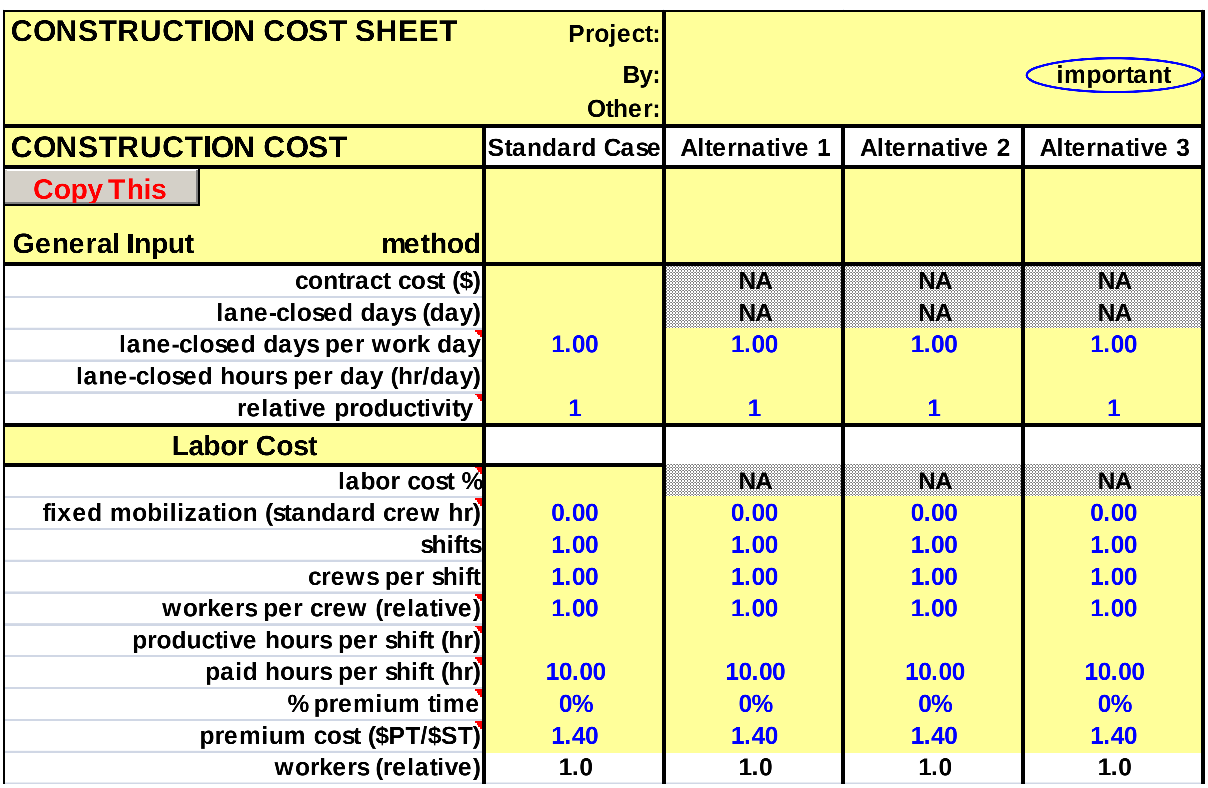


Figure 6. Sample screenshot from the Maryland LOPB tool, showing work zone flagger operation inputs.



CONSTRUCTION COST SHEET				
Project:				
By:				important
Other:				
CONSTRUCTION COST	Standard Case	Alternative 1	Alternative 2	Alternative 3
Copy This				
General Input method				
contract cost ($)		NA	NA	NA
lane-closed days (day)		NA	NA	NA
lane-closed days per work day	1.00	1.00	1.00	1.00
lane-closed hours per day (hr/day)				
relative productivity	1	1	1	1
Labor Cost				
labor cost %		NA	NA	NA
fixed mobilization (standard crew hr)	0.00	0.00	0.00	0.00
shifts	1.00	1.00	1.00	1.00
crews per shift	1.00	1.00	1.00	1.00
workers per crew (relative)	1.00	1.00	1.00	1.00
productive hours per shift (hr)				
paid hours per shift (hr)	10.00	10.00	10.00	10.00
% premium time	0%	0%	0%	0%
premium cost ($PT/$ST)	1.40	1.40	1.40	1.40
workers (relative)	1.0	1.0	1.0	1.0

Figure 7. Sample screenshot from the Michigan CO3 spreadsheet, showing the construction cost module.

Inputs and Outputs
The basic inputs required for spreadsheet-based tools are:

- Work zone configuration- total number of lanes, number of closed lanes, lane width, normal and work zone speed, period of lane closure, normal and work zone lane capacity, etc.
- Traffic – hourly traffic demand, percent trucks, etc.
- Unit costs - hourly cost of travel delay, VOC for various vehicle types, etc.

The typical outputs reported by spreadsheet-based tools are travel delay time, number of queued vehicles, queue lengths, and in some cases, crash costs and emission estimates.

QUEWZ-98

Developed for the Texas DOT, QUEWZ-98 is a DOS-based analysis tool for evaluating freeway work zone lane closures. This tool simulates traffic conditions on a freeway segment with and without a lane closure in place and provides estimates of the queue lengths and additional road user costs resulting from work zone lane closures. The computed WZ RUC include travel time costs, VOC, and excess emissions. QUEWZ-98 can be used to identify time schedules for lane closures that will not produce excessive queue lengths and delays.

QUEWZ-98 has two output options:

- RUC option - this option analyzes a user-specified lane closure configuration and schedule of work activities. The outputs include estimates of traffic volumes, capacities, speeds, queue lengths, emissions, and additional road user costs for each hour affected by the lane closure.
- Lane closure schedule option - this option summarizes the hours of the day for a given number of closed lanes without causing user-defined excessive queuing.

QuickZone

Developed by FHWA, QuickZone is a sketch-planning tool for analyzing work zone mobility impacts such as traffic delays, queuing, and associated delay costs. The tool uses a link-node system for network layout and configuration and a deterministic delay estimation algorithm to estimate traffic delays and queuing.
This tool can be used in quantifying delay at the corridor level resulting from work zone related mobility constraints, identifying the mobility impacts of alternative project phasing plans, evaluating the impacts of various construction staging strategies, and supporting tradeoff analyses between construction costs and delay costs.

Capabilities

QuickZone can estimate travel delay time, queuing, and delay costs per vehicle hour for not only the roadway segment under work zone but also all available alternative segments of the roadway network defined in the program. This tool can be used in estimating traffic delays, potential backups, and associated delay costs for both an average day of work and for the whole life cycle of construction.

Inputs and Outputs

QuickZone requires the following data for evaluating mobility impacts in work zones:

- Network (Nodes and Links) - a network of nodes and links, segment (link) capacity, segment length, free-flow speed, and jam density.
- Traffic volume - hourly demand for each link and each day of a week.
- Project Information - project description, start date, project duration, yearly demand increase, yearly capacity decrease.
- Construction Phase Data - phase description, duration, infrastructure cost.
- Work Zone Plan - work zone start and end times, links and nodes affected by work zone, mitigation strategies, travel behavior (mode change, trip cancellation).

QuickZone reports the following outputs:

- Delay Graph - delay graphs comparing up to six phases of the project for the whole or any day of the week or delay graph for just a single phase.
- Travel Behavior Summary - a summary of the number of vehicles that choose one of the four travel behaviors determined for each phase: cancel trip, mode shift, hour time shift, and takes detours.
- Life Cycle Costing Graph - a summary of both delay and infrastructure costs for the project by year.
- Summary Table - provides estimates of queue length, delay, travel behavior, and costs. The table provides average, total, or maximum values for each phase as well as for the individual work zone plans within each phase.

Advantages and Disadvantages

Unlike similar spreadsheet based tools, QuickZone is capable of modeling the entire network for work zone mobility impact analysis. In addition, the tool evaluates traveler behavior to prevailing traffic conditions such as route changes, peak-spreading, mode shifts, and trip losses. While the interface is simple and easier to use, it may require more time and effort than similar spreadsheet-based tools.[81]

CA4PRS

CA4PRS is a construction schedule, staging, and traffic analysis tool that helps to identify optimal rehabilitation strategies by balancing project duration, lane closure strategies, and road user impacts. The traffic analysis module quantifies the impact of various work zone lane closure strategies on the traveling public in terms of WZ RUC and travel delay time, while the scheduling module estimates the required number of lane closures for project completion by taking into account the alternative strategies for pavement designs, lane closure tactics, and contractor logistics. The tool employs “what if scenarios” to determine which rehabilitation strategies maximize production without creating unacceptable traffic delays.[82]

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[81] Edara, P., Estimation of Traffic Impacts at Work Zones: State of the Practice, Report No. VTRC 06-R25, Virginia Department of Transportation, Richmond, VA, 2006.

[82] Lee, E. B., and C. W. Ibbs, Computer Simulation Model: Construction Analysis for Pavement Rehabilitation Strategies, ASCE Journal of Construction Engineering and Management, Vol. 131, No. 4, 2005.

Capabilities

The CA4PRS tool can be used in establishing schedules, developing staging construction plans, estimating cost (A) + schedule (B) contracts, and calculating incentive and disincentive specifications for contracts. CA4PRS uses an HCM-based demand-capacity algorithm for quantifying mobility impacts; this tool also can be integrated with macro and microscopic traffic simulation tools to estimate road user delay costs arising from construction.

Inputs and Outputs

CA4PRS uses the following input variables in evaluating "what-if" scenarios:

- Work zone constraints - number of lanes before and during construction, number of partial or full lane closures, roadway capacity, traffic composition, hourly demand, unit costs for delay time and VOC, lane width, lateral clearance.
- Construction window - nighttime closures, weekend closure, continuous closure, or combinations of the above.
- Pavement strategy – portland cement concrete (PCC) reconstruction, asphalt overlay of crack and seat PCC, or full-depth asphalt concrete replacement.
- Material constraints - concrete mix design and curing time or asphalt cooling time for asphalt
- Pavement cross section - thickness of new concrete or asphalt concrete, concrete pavement base types.
- Contractor's logistical resource constraints - location, capacity, and numbers of rehabilitation equipment available (paver, batch plant, delivery and hauling trucks).
- Scheduling interfaces - mobilization/demobilization time, traffic control time, and activity lead-lag time relationships (e.g., lag time from demolition to PCC pavement installation), and buffer sizes.

The outputs reported by CA4PRS include:

- Mobility impacts - maximum delay time and queue length before and during construction.
- Road user costs - daily, per closure and total road user costs.
- Project costs - pavement, non-pavement and indirect costs.
- Traffic handling and management costs - daily traffic handling, extra TMP and incident management costs.

Figure 8 presents a sample screenshot showing lane closure analysis of I-80 pavement rehabilitation project using CA4PRS.[83]

Advantages and Disadvantages

The primary advantage of CA4PRS is its capability to perform comprehensive analysis for WZ RUC computations by integrating traffic mobility analysis with construction scheduling, constructability and logistics, and pavement rehabilitation alternatives. It supports decision making by identifying the resource bottleneck limiting the project acceleration and allows users to specify the type of operations, concurrent or sequential. Another advantage is its

[83] Pyeon, J. H., and E. B. Lee, "CA4PRS Application for Determination of Incentive/Disincentive Dollar Amount," CA4PRS Peer Exchange Workshop, St. Louis, MO, 2010.

ability to verify contractor submitted schedules. This tool can be used in conjunction with macroscopic or microscopic simulation tools for wider coverage of work zone influence and more in-depth impact analysis.

The current version of CA4PRS (version 2.5) is limited to pavement rehabilitation activities. Future versions of this tool plan to extend its scope to roadway widening, bridge and interchange replacement and include life-cycle cost analysis. WZ RUC computation using this tool is limited to travel delay costs and VOC; it does not compute emission or crash costs.

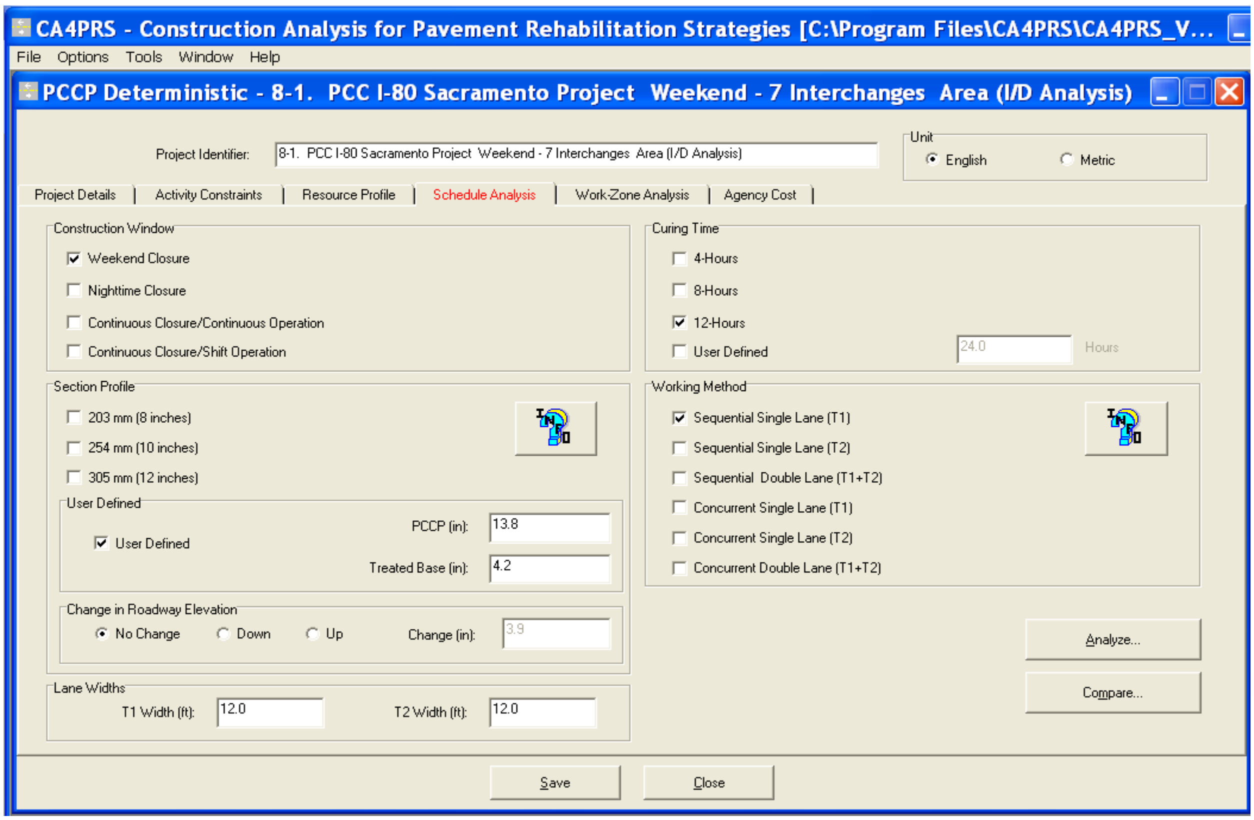

Figure 8. Sample screenshot showing lane closure analysis using CA4PRS.

2.9.1.2 Work Zone Traffic Analysis Tools used by State DOTs

State DOTs typically use more than one tool for evaluating work zone impacts. These agencies typically use sketch-planning and HCM-based tools for projects where:

- The work zone mobility, safety, and economical impacts are expected to be low to moderate.
- The proposed work zone has limited impacts on the network.
- The agency resources are limited.
- The project completion time is not a major factor.
- Rough estimation of performance measures is sufficient.

State agencies also use sophisticated traffic analysis tools, such as microscopic and mesoscopic simulation tools, for projects where:

- The work zone mobility, safety, and economical impacts are expected be high.
- The work zone impacts are expected over a large geographic area.
- The project completion time is a critical factor.
- Accurate estimation of performance measures is a requirement.

Table 38 provides a partial list of traffic analysis tools used by various State DOTs. [84,85]

Table 38. Traffic analysis tools used by State DOTs.

State	RUC-specific	Non-RUC Specific (traffic analysis only)
California	CA4PRS[86]	HCM, SYNCHRO
Colorado	WorkZone RUC	N.A.
Delaware	N.A.	HCS, spreadsheet , Quick Zone, SYNCHRO
District of Columbia	QuickZone, QUEWZ-98,	SYNCHRO/SimTraffic, CORSIM
Florida	FDOT RUC	N.A.
Hawaii	N.A.	HCM
Illinois	DOT-specific spreadsheet, Quickzone	N.A.
Iowa	QuickZone	N.A.
Kansas	N.A.	HCM, Travel Demand Models, Simulations
Maryland	LOPB, LCAP	HCS, SYNCHRO, CORSIM
Massachusetts	N.A.	HCS, SYNCHRO, SIDRA, Transyt-7F, TSIS-CORSIM, GDOT Roundabout Analysis Tool, VISSIM
Michigan	CO3	HCM, SYNCHRO
Missouri	QuickZone	MoDOT Work Zone Impact Analysis Spreadsheet, VISSIM, CORSIM, SYNCHRO
New Hampshire	QuickZone	HCM, SYNCHRO
New Mexico	N.A.	HCM and Simulation
New Jersey	DOT-specific spreadsheet	N.A.
New York State	QuickZone, AASHTO User Benefit Analysis	CORSIM
North Carolina	QUEWZ-98	in-house detour and flagging programs
Ohio	DOT-specific spreadsheet	
Oklahoma	N.A.	HCM-based spreadsheet
Oregon	N.A.	Work Zone Traffic Analysis Tool
Pennsylvania	DOT-specific spreadsheet	
Rhode Island	N.A.	HCM, QuickZone
Texas	RUC Tables	PASSER V
Utah	N.A.	HCM, SYNCHRO, VISSIM
Virginia	HUB-CAP	N.A.
Washington	QUEWZ-98	SYNCHRO
Wisconsin	N.A.	HCM w/spreadsheet, Quadro, SYNCHRO
Tennessee	N.A.	HCM, Web-based Queue/Delay Prediction Model
Wyoming	N.A.	HCM, SYNCHRO

AASHTO = American Association of State Highway and Transportation Officials.

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[84] http://www.mhd.state.ma.us/downloads/trafficMgmt/TrafficAnalysisToolsGuide.pdf

[85] Work Zone Traffic Analysis Strategies Webinar, Recording, FHWA/National Transportation Operations Coalition, July 9, 2008. http://www.ops.fhwa.dot.gov/wz/traffic_analysis/index.htm

[86] CA4PRS has been used in several other States, such as Minnesota, Oklahoma, Utah, Virginia, and Washington State.

2.9.2 Economic Analysis Tools

Economic analysis tools help decision makers to identify and quantify the value of economic costs and benefits of highway projects/programs over a multi-year period. These tools allow highway agencies to utilize the available resources to their best for maximizing benefits to the public.[87] Notable examples of economic analysis tools are discussed below.

RealCost

RealCost is a tool for conducting life cycle cost analysis in pavement design. Developed by the FHWA, this tool can be used for selecting a cost-effective pavement alternative among competing alternatives that offer essentially identical benefits. RealCost has a built-in tool for capacity flow analysis and for calculating road user costs associated with establishing a work zone. The capacity flow analysis is based on the traffic flow concepts presented in the 1994 edition of the HCM.

RealCost version 2.5 allows users to compute travel delay costs and VOC. Though illustrated in the interim technical bulletin, the computation of crash costs is not yet implemented in the software. RealCost has adopted the approach presented in NCHRP Report 133 for computing travel delay costs and VOC. Figure 9a presents a RealCost screenshot illustrating the hourly traffic demand and capacity analysis, lane closure timings, and resulting queue conditions for a typical work zone project. Figure 9b presents an example of various WZ RUC components computed for that project.

HERS-ST

HERS-ST is a benefit-cost analysis tool for selecting an economically efficient highway investment alternative among competing alternatives based on their potential impacts on highway condition, performance, and users. The benefits include reductions in user costs, agency maintenance costs, and externalities over the life of the improvement, while the costs include initial capital costs of the improvement. HERS-ST is designed to select only those projects where benefits will exceed initial costs. Developed by FHWA, HERS-ST has a suite of comprehensive submodels for computing various cost components of WZ RUC, including crash and emission costs.

MicroBENCOST

MicroBENCOST, developed under NCHRP Project 7-12, is an economic analysis tool for calculating road user benefit and costs of highway investments on a wide range of projects from individual intersection improvements to major road upgradings and construction of new roads. MicroBENCOST allows computation of travel delay costs, VOC, safety costs, and emission costs (considers the estimation of carbon monoxide only) for various work zone lane closure scenarios. Figure 10 presents a screenshot of work zone impact analysis functionalities of MicroBENCOST for use in WZ RUC computation.

BCA.Net

BCA.Net is the FHWA's web-based benefit-cost analysis tool to support the highway project decision making process. The tool evaluates the economic merits of investment alternatives by comparing their relative costs and benefits. BCA.Net takes the capital costs, physical and performance characteristics, and forecast travel demand for the evaluation of a highway project.

[87] Economic Analysis Primer, Office of Asset Management, Federal Highway Administration, U.S. Department of Transportation, August 2003.

The user specifies strategies for improvements and maintenance for a base case and an alternate case. The tool performs traffic impact analysis and calculates the agency and user costs and benefits for each case. The expected benefits and costs are compared on a time scale (i.e., discounted using the time value of money concept) to calculate the net benefits. The results of the simulation include various measures of economic worth such as the net present value, benefit-cost ratio, and internal rate of return for both base and alternate cases. For user costs, the BCA.Net tool is capable of calculating the following components: delay costs, VOC, crash and emission costs. Figure 11 presents a screenshot of RUC analysis functionalities of BCA.Net.

Work Zone User Cost: Inbound Traffic

Step 2. Build hourly demand and capacity matrix						Step 3. Quantify vehicles affected						Step 4. Determine work zone operating condition
		Hourly Traffic Demand and Roadway Capacity (vph)					Vehicles That:					
Hour	Work Zone	% AADT	Demand	Capacity	Queue Rate	Number of Queued Vehicles	Change Speed	Traverse WZ	Traverse Queue	Stop for the Queue	Slow Down for the WZ	
0 - 1	Yes	0.7%	1215	2100	(885)	0	1215	2010	1886	1091	124	Work Zone, Queue Dissipating
1 - 2	Yes	0.4%	738	2100	(1362)	0	738	738	0	0	738	Work Zone, No Queue
2 - 3	Yes	0.3%	585	2100	(1515)	0	585	585	0	0	585	Work Zone, No Queue
3 - 4	Yes	0.3%	459	2100	(1641)	0	459	459	0	0	459	Work Zone, No Queue
4 - 5	Yes	0.3%	459	2100	(1641)	0	459	459	0	0	459	Work Zone, No Queue
5 - 6	No	0.7%	1170	6750	(5580)	0	0	0	0	0	0	No Work Zone, No Queue
6 - 7	No	1.6%	2880	6750	(3870)	0	0	0	0	0	0	No Work Zone, No Queue
7 - 8	No	2.2%	3870	6750	(2880)	0	0	0	0	0	0	No Work Zone, No Queue
8 - 9	No	2.4%	4320	6750	(2430)	0	0	0	0	0	0	No Work Zone, No Queue
9 - 10	No	2.5%	4410	6750	(2340)	0	0	0	0	0	0	No Work Zone, No Queue
10 - 11	No	2.4%	4320	6750	(2430)	0	0	0	0	0	0	No Work Zone, No Queue
11 - 12	No	2.7%	4770	6750	(1980)	0	0	0	0	0	0	No Work Zone, No Queue
12 - 13	No	2.9%	5130	6750	(1620)	0	0	0	0	0	0	No Work Zone, No Queue
13 - 14	No	3.1%	5490	6750	(1260)	0	0	0	0	0	0	No Work Zone, No Queue
14 - 15	No	3.4%	6120	6750	(630)	0	0	0	0	0	0	No Work Zone, No Queue
15 - 16	No	3.7%	6660	6750	(90)	0	0	0	0	0	0	No Work Zone, No Queue
16 - 17	No	3.9%	6930	6750	180	180	6930	0	6750	6930	0	No Work Zone, Queue
17 - 18	No	3.7%	6660	6750	(90)	90	6660	0	6750	6660	0	No Work Zone, Queue
18 - 19	No	3.4%	6120	6750	(630)	0	874	0	964	874	0	No Work Zone, Queue Dissipating
19 - 20	No	3.0%	5400	6750	(1350)	0	0	0	0	0	0	No Work Zone, No Queue
20 - 21	No	2.2%	3870	6750	(2880)	0	0	0	0	0	0	No Work Zone, No Queue
21 - 22	No	1.9%	3429	6750	(3321)	0	0	0	0	0	0	No Work Zone, No Queue
22 - 23	Yes	1.7%	2979	2100	879	879	2979	2100	2100	2979	0	Work Zone, Queue
23 - 24	Yes	1.1%	2016	2100	(84)	795	2016	2100	2100	2016	0	Work Zone, Queue
Daily Totals		50.0%	90000	129450			22915	8451	20551	20551	2365	

a. An example of work zone traffic analysis illustrating lane closure timings and queuing conditions.

Step 7 - Sum User Costs

Cost Component	Cost ($1000)	Percent
WZ Speed Change VOC	$3.90	0%
WZ Speed Change Delay	$1.67	0%
WZ Reduced Speed Delay	$3.66	0%
Queue Stopping Delay	$22.73	2%
Queue Stopping VOC	$40.49	4%
Queue Added Travel Time	$921.75	86%
Queue Idle Time	$77.00	7%
Total Cost	$1,071.20	100%

b. An example showing computed RUC components for a typical work zone project.

Figure 9. Screenshot showing the WZ RUC analysis in RealCost version 2.5.

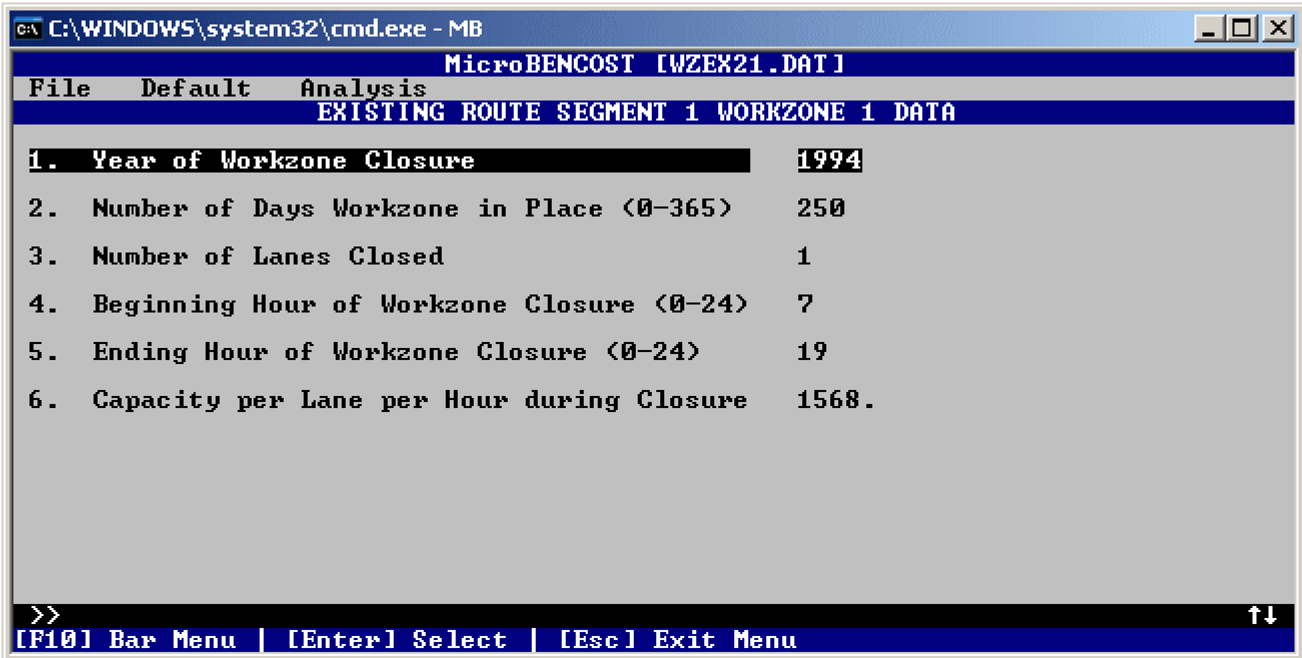

Figure 10. Screenshot showing the work zone analysis functionalities of MicroBENCOST.

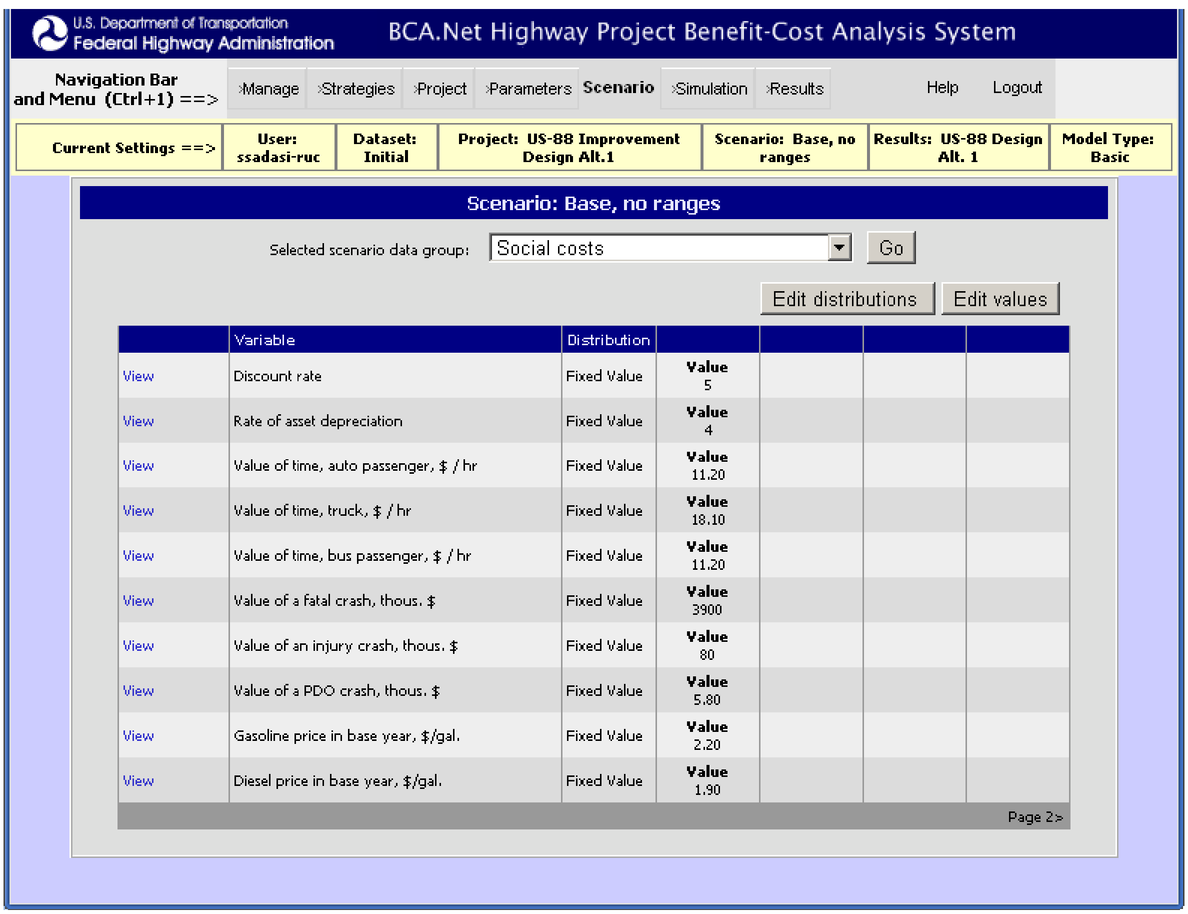

Figure 11. Screenshot showing the RUC analysis functionalities of BCA.Net.

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CHAPTER 3. APPLICATION OF WZ RUC DURING MOT ALTERNATIVE ANALYSIS

3.1 OVERVIEW

A MOT strategy is a temporary application of traffic control measures and devices to facilitate road users through work zones. The functions of a MOT strategy are to (1) provide reasonably safe and effective movement of traffic through or around the work zones, (2) reasonably protect road users, workers, responders to traffic incidents, and equipment, and (3) facilitate the efficient completion of the highway construction activities.

A temporary traffic control strategy can be enhanced into a comprehensive TMP by adding features such as construction staging, phasing, safety improvements, enforcement of traffic regulations, incident management, public involvement and outreach programs, traffic operations at the corridor or network level, non-traditional contractual arrangements, and innovative construction techniques.

MOT alternative analysis is an assessment of competing strategies to determine one that best mitigates the adverse mobility, safety, environmental, business, and community impacts of a construction work zone at reasonable agency and WZ RUC. The analysis considers potential benefits, costs, and constraints associated with each feasible alternative and their effectiveness in managing work zone impacts.

The selection of an MOT alternative for a project depends on factors such as the significance of mobility and safety impacts, project type and complexity, urban/rural location, construction factors, constructability constraints, agency and road user costs, agency policies, and aspects of the surrounding area (e.g., availability of alternate routes, nearby businesses). Therefore, to devise an effective MOT strategy, it is imperative to take these influencing factors into consideration in a systematic manner on a project-by-project basis.

3.2 MAINTENANCE OF TRAFFIC ALTERNATIVE ANALYSIS

The MOT alternative analysis evolves over the various stages of project development. In the planning stage, the agency conducts a cursory qualitative assessment to evaluate the criticality of the proposed work zone impacts as well as the system needs, constraints, and deficiencies (e.g., agency policies or resource availability). Based on the impact assessment, a decision is made whether there is a need for conducting a detailed MOT alternative analysis. For projects with low to moderate impacts, the agency may find conventional strategies adequate (e.g., permitted lane closure timings), while the projects with significant impacts may require a more detailed impact assessment and MOT alternative analysis.

In the preliminary engineering stage, candidate MOT strategies are identified based on the potential design, construction techniques, phasing, and contracting strategies. Quantitative analysis of work zone impacts is conducted at this point using sketch-planning tools and deterministic tools to analyze the effectiveness of each candidate strategy. For projects with low to moderate impacts, this level of analysis would suffice. For more complex projects with significant impacts, simulation tools can be employed.

The agency sets performance goals (threshold values) for each performance measure based on agency policies and project-specific needs to ensure a minimum acceptable level of work zone performance. The expected benefits, costs, and constraints associated with each candidate alternative are evaluated against the performance thresholds, and against each other, and ranked to determine the preferred alternative. Based on this evaluation, an alternative that best meets the criteria is selected as the preferred alternative using decision analysis tools.

In the design stage, a further work zone impacts assessment is conducted, if required, to finalize the preferred MOT strategy. The design and construction details are refined as the project progresses from preliminary engineering and design stages, and therefore, inputs and assumptions used in the MOT alternative analysis will have to be revised accordingly.

In the construction stage, unforeseen situations such as a change in the original construction schedule, construction technique, or the TMP may warrant reassessing the selected MOT strategy or reanalyzing the work zone impacts. The contractor also may propose value engineering solutions to the selected MOT strategy.

The steps involved in the MOT alternative analysis process are listed below and discussed in greater detail in the following sections:

1. Perform preliminary analysis of work zone impacts using available project information.
2. Identify the need for MOT alternative analysis based on preliminary analysis of work zone impacts. If there is a need for MOT alternative analysis, go to Step 3.
3. Identify candidate strategies for MOT alternative analysis.
4. Identify performance measures and thresholds.
5. Conduct detailed analysis of work zone impacts when the final design is complete.
6. Use Kepner-Tregoe method to select a preferred MOT strategy.

3.2.1 Preliminary Assessment of Work Zone Impacts (Step 1)

MOT alternative analysis typically begins with a cursory assessment of work zone impacts in the early planning stages of the project. The available information on project scope and duration, roadway/traffic characteristics, and other contributing factors (local communities, businesses, traveling public, etc.) is compiled and evaluated. More detailed discussion can be found in the FHWA's guidance on the work zone impact assessment.[9]

Though qualitative in nature, this assessment evaluates how the proposed work zone will affect the mobility, safety, and economical impacts of the traveling public and the community at large. It provides a general sense on the magnitude of work zone impacts, which are in turn used to establish the significance of the project type and the need for conducting a detailed MOT alternative analysis.

The assessment helps to identify issues relating to project scheduling, potential construction approaches and contractual arrangements, funding constraints, availability of agency resources and analysis tools, agency policies, concurrent projects and coordination issues, and their potential effects on work zone impacts. The findings of this assessment are used in identifying candidate strategies for the MOT selection process. Early impact assessment helps to limit the number of candidate strategies considered in the MOT alternative analysis and to develop a better end product.[88]

Some of the typical factors that would be considered in the preliminary evaluation include:

- Facility type: freeway, principal arterial, collector, local etc.
- Area type: rural or urban.
- Project type and complexity.
- Expected construction duration.
- Need for early completion.
- Strategic importance of the roadway.
- Traffic volume.
- Level of service – the adequacy of roadway capacity to accommodate traffic demand.
- Peak hour traffic demand.
- Commuter traffic.
- Availability of detour alternatives.
- Ability of detour routes to accommodate diverted traffic volume.
- Likelihood of getting lost in detours.
- Adequacy of lane shoulder width.
- Interference with contractor access to work zone.
- Need to consider business impacts.
- Level of public interest.
- Need to consider local ordinances on noise for night work.
- Safety risks to motorists and construction workers.
- High incidence areas.

3.2.2 Identifying the Significance of Projects (Step 2)

The next step in the MOT alternative analysis process is to determine the relative impact based on the project size and complexity, expected duration of construction, traffic volume affected, and the magnitude of mobility, safety, and economical impacts. The purpose of this step is to identify the level of effort and resources required for MOT alternative analysis commensurate with the magnitude of work zone impacts.

Based on this guidance, FHWA specifies the following criteria for designating a project as "significant":

> All Interstate system projects that occupy a location for more than three days with either intermittent or continuous lane closures, and located within the boundaries of a designated Transportation Management Area (TMA). A TMA is an urbanized area with a population of over 200,000 individuals.

The FHWA Work Zone Mobility and Safety Self-Assessment Guide presents another scheme for categorizing work zone projects based on the expected impact levels.[89] Under this

[88] Bourne, J. S. et al, *Best Practices In Work Zone Assessment, Data Collection, and Performance Evaluation*, NCHRP Project 20-68A Scan 08-04, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2010.

classification, projects are categorized into Types I, II, III, and IV (see Table 39). Projects classified as Types I and II may require MOT alternative analysis.

Table 39. Classification of project types based on work zone impacts.

Type	Characteristics
Type I	• Affects the traveling public at the metropolitan, regional, intrastate, and possibly interstate level. • Very high level of public interest. • Directly affects a very large number of travelers. • Significant user cost impacts. • Very long duration.
Type II	• Affects the traveling public predominantly at the metropolitan and regional level. • Moderate to high level of public interest. • Directly affects a moderate to high number of travelers. • Moderate to high user cost impacts. • Duration is moderate to long.
Type III	• Affects the traveling public at the metropolitan or regional level. • Low to moderate level of public interest. • Directly affects a low to moderate level of travelers. • Low to moderate user cost impacts. • May include lane closures for a moderate duration.
Type IV	• Affects the traveling public to a small degree. • Low public interest. • Duration is short to moderate. • Work zones are usually mobile and typically recurring.

In addition, State and local highway agencies have developed their own criteria to define whether a project is "significant." Some of the typical criteria include:

- Volume/capacity ratio exceeding a specified value.
- Work zone travel time delay exceeding a specified value.
- Queue length exceeding a specified value.
- Reduction in level of service exceeding a specified level.
- Estimated project cost exceeding a specified value.
- Projects based on functional classification.
- Projects on the safety improvement list.
- Worker safety considerations.
- Traffic volume.
- Restrictions on emergency vehicle access.
- Impacts on public/private access.
- Early completion goal.
- Time of work.
- High level of public interest.
- Regional significance.
- Network/corridor level significance.
- Anticipated performance not meeting thresholds.

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[89] FHWA *Work Zone Mobility and Safety Self-Assessment Guide*, Office of Operations, Federal Highway Administration, Washington, DC, 2004. http://ops.fhwa.dot.gov/wz/docs/wz-sa-docs/sa_guide_s1.htm.

Table 40 presents a sample of criteria used by the North Carolina DOT for defining significant projects.[90]

3.2.3 Identifying the Need for MOT Alternative Analysis (Step 3)

The need for an MOT alternative analysis is established based on the significance of the project size and complexity, project duration, traffic volume, and severity of work zone impacts.

Highway agencies typically use partial width reconstruction for low volume, low-impact roads as the baseline MOT strategy where the partial lane closure is in effect during weekday, daytime, or off-peak hours for lane-by-lane construction until the corresponding phase of construction is completed. The closure timings typically are determined based on the latest traffic data, actual field operation experience, and highway capacity calculations. These pre-determined strategies can be effective when the hourly traffic demand does not exceed the work zone capacity. In such cases, the MOT alternative analysis may not be warranted.

When the hourly demand exceeds the agency-estimated work zone capacity values, it is necessary to check whether the projected work zone performance exceeds the allowable targets using quantitative impact analysis. If the projected performance exceeds the allowable targets, a MOT alternative analysis is required to select a strategy that projects work zone performance below the thresholds.

In practice, the requirement for a MOT alternative analysis is waived for non-significant projects with moderate work zone impacts if:

- The hourly traffic demand does not exceed the work zone capacity during lane closure.
- The measured work zone performance does not exceed agency-specified thresholds.

Similar to the approach mentioned above, Figure 12 presents a schematic of lane closure process adopted by the Maryland State Highway Administration (SHA) for arterial highways.

MOT alternative analysis is required for all significant projects where moderate to high impacts are anticipated on work zone traffic and the local area. For such projects, the traffic demand is likely to exceed the lane capacity of the proposed work zone. In such cases, a quantitative analysis is required to model the expected mobility and safety impacts using sketch-planning or deterministic tools. If the estimated impacts do not meet the agency's thresholds, an alternative analysis should be conducted to select the preferred MOT strategy.

[90] NCDOT, Guidelines for Implementation of the Work Zone Safety and Mobility Policy, Draft, 2007. http://www.ncdot.org/doh/preconstruct/wztc/final%20rule/ImportantDocs/WZSafety&MobilityDraftGuidelines07_23_2007.pdf.

Table 40. North Carolina DOT criteria for determining level of project significance.

Level		USE FOR DIVISION ACTIVITIES AND TIP PROJECTS					USE FOR TIP ONLY	
		Level On an interstate within a TMA? Has intermittent or continuous lane closures for 3 days or longer?	**Existing AADT (Also may use Anticipated AADT if available)**	**Total Truck Traffic**	**Anticipated Additional Travel Times**	**Anticipated Level Adverse Impacts to existing transportation infrastructure and/or high volume traffic generators**	**Duration of Traffic Impacts(change this to include corridors, etc.) (using conventional estimating/letting methods)**	**User Value and/or User Cost 1 meets ANY of these criteria**
SIGNIFICANT	**1 meets ANY of these criteria**	Yes to both questions, project/ activity is significant Yes to one, refer to remaining columns in chart	AADT per lane > 15,000	> 20%	Exceeding 15 minutes	High	> 3 Years	> $50,000/day
SIGNIFICANT	**2 meets at least TWO of these criteria**	Yes to both questions, project/ activity is significant Yes to one, refer to remaining columns in chart	AADT per lane > 10,000 but < 15,000	> 15% but < 20%	> 10 minutes but < 15 minutes	Moderate	2 Years but < 3 Years	> $25,000/day but <$50,000/day
3 meets at least TWO of these criteria		No to one question refer to remaining columns in the chart	AADT per lane > 7,500 but < 10,000	> 10% but < 15%	> 5 minutes but < 10 minutes	Low	> 1 Year but < 2 Years	> $12,500/day but < $25,000/day
4 meets ANY of these criteria		No to one question refer to remaining columns in the chart	AADT per lane < 7,500	< 10%	< 5 minutes	N/A	< 1 Year	< $12,500/day

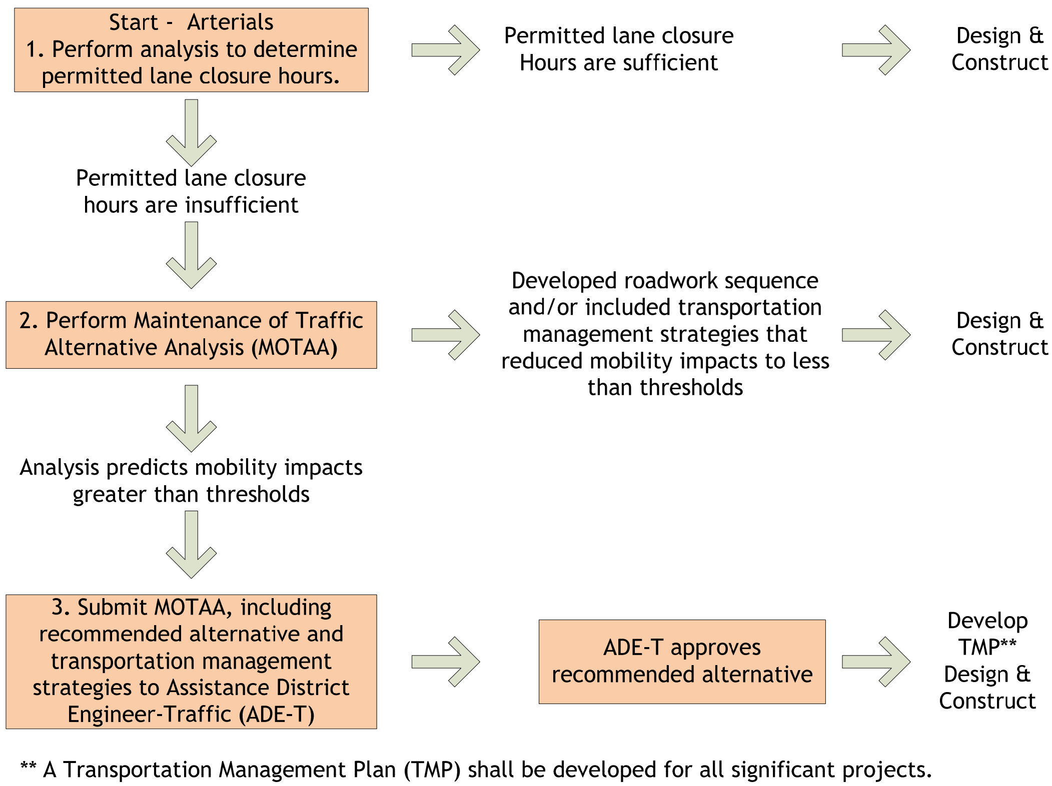

Figure 12. Maryland SHA's lane closure process for arterials.

3.2.4 Work Zone Performance Measures and Thresholds (Step 4)

Work zone performance measures are defined, quantifiable, outcome-based conditions or response times that are used to evaluate success of work zone policies, procedures, and performance. Performance measures focus on what to achieve, not how to achieve it.[91] There are four key measures of work zone performance: mobility (or construction congestion), safety, construction efficiency and effectiveness, and public perception and satisfaction. Table 41 presents a list of performance measures recommended for use in the MOT alternative analysis for each performance category.

At the project level, performance measures are used in evaluating the projected performance of proposed work zone strategies in the pre-construction stages and monitoring the actual performance of those strategies during construction. At the agency level, performance measures are used in evaluating the performance of work zone policies, management strategies, practices, and techniques. In the MOT alternative analysis, the performance measures quantify the impacts outcomes associated with each MOT alternative to determine what would work for the given work zone conditions.

[91] Work Zone Safety Performance Measures Guidance Booklet, Prepared by American Traffic Safety Services Association (ATSSA), Fredericksburg, VA, 2010. http://www.workzonesafety.org/files/documents/training/fhwa_wz_grant/atssa_performance_measures_guide.pdf

Table 41. Performance measures for MOT alternative analysis.
(Sources: HfL,[92] Ullman et al.,[93] and Sankar et al.[9])

Performance Category	Element	Performance Measure
Mobility	Overall	• RUC estimates for travel time, delays and vehicle operating costs.
	Queue length	• Average length per hour of lane closure. • Percent of lane closure hours creating a queue. • Percent of lane closure hours creating a queue exceeding L mile.
	Capacity	• Percent difference between pre-construction capacity and work zone capacity.
	Delay or travel time	• Average total delay time (vehicle-hours) per hour of lane closure. • Percent of total delays occurring when average vehicle delay exceeds T minutes per vehicle. • Percent of total delays occurring when lane closure queue lengths exceed L mile. • Average delay per vehicle per hour of lane closure. • Percent of lane closure hours when average delays exceed T minutes per vehicle.
	Incident clearance time	• Average time to clear non-injury incidents. • Average number of non-injury incidents cleared within T minutes.
	Buffer index[94]	• Average change in buffer index.
Safety (includes workers as well as motorists)	Overall	• Crash-related WZ RUC estimates.
	Injuries	• Increase in crash rates per million vehicle miles for injuries. • Increase in crash rates for million vehicle miles for fatalities.
	Vehicle crashes	• Increase in crash rates for million vehicle miles for PDO.
Construction Efficiency and Effectiveness[95]	Time	• Percent savings in the estimated project schedule. • Reduction in the number of days used WZ RUC computation (i.e., number of days * daily WZ RUC)
	Cost	• Percent savings in the estimated overall project costs. • Percent savings in WZ RUC estimates.
	Needs satisfaction	• Adjectival rating whether the construction related issues were addressed.
Public perception and	Pre-construction	• Number/frequency of complaints

[92] Highways for Life, *Performance Contracting Framework*, Prepared by Science Applications International Corporation, Federal Highway Administration, Washington, DC, 2006. http://www.fhwa.dot.gov/hfl/framework/framework.pdf
[93] Ullman, G. L., R. J. Porter, and G. J. Karkee, *Monitoring Work Zone Safety and Mobility Impacts in Texas*, Report No. FHWA/TX-09/0-5771-1, Submitted to Texas Department of Transportation, Austin, TX, 2009. http://tti.tamu.edu/documents/0-5771-1.pdf
[94] Buffer Index is a measure of the reliability of travel service calculated as the ratio between the difference of the 95th percentile travel time and the average travel time divided by the average travel time.
[95] Quality as a performance measure is typically used to evaluate the post-construction performance of work zones, and therefore not considered in the MOTAA.

Table 41. Performance measures for MOT alternative analysis.
(Sources: HfL,[92] Ullman et al.,[93] and Sankar et al.[9])

Performance Category	Element	Performance Measure
satisfaction	public surveys	• Customer satisfaction index
	Historic surveys on projects with similar strategies	• Number/frequency of complaints • Customer satisfaction index

Performance thresholds set the benchmark of minimum acceptable level for comparing candidate alternatives and further determine what would work best for the given work zone conditions. These values are set by the agency based on the institutional policies and may vary with individual project needs. Table 42 presents a summary of performance thresholds used by various highway agencies for managing work zone impacts.

Table 42. Performance thresholds used by various agencies.
(Sources: HfL[92] and NCHRP 20-68A Scan 08-04[88])

Agency	Category	Performance Threshold
FHWA HfL	Safety	• Work zone crash rate during construction—≤ than the preconstruction rate. • Incident rate for worker injuries during construction—< 4.0, based on incidents reported via Occupational Safety and Health Administration (OSHA) Form 300.
FHWA HfL	Mobility	• Trip time during construction—< 10 percent increase in trip time compared to the average preconstruction speed, using 100 percent sampling. • Queue length during construction—A moving queue length of < 0.5 mile in a rural area or < 1.5 mi in an urban area
FHWA HfL	Construction Time	• 50 percent reduction in the time highway users are impacted, compared to traditional methods.
FHWA HfL	Public perception	• User satisfaction - measurement of 4-plus on a 7-point Likert scale.
California DOT	Mobility	• 0-minute delay for most freeway projects. • < 15-minute delay if aggressive TMP is being used. • < 30-minute delay on complex projects. • On other highways, < 20-min delay for flagging operations.
Florida DOT	Mobility	• Lane closures shall not exceed 2 miles in length on interstates or highways with speed limits >55mph.
Indiana DOT	Mobility	• Queues cannot be present > 6 continuous hours or 12 hours total per day. • 0.5 mile < queues < 1.0 miles limited to four continuous hours. • 1.0 mile < queues < 1.5 miles limited to two continuous hours. • Queues > 1.5 miles are not permitted.
Maryland SHA	Mobility	• Queues < 1.0 miles acceptable on freeways. • 1.0 < queues < 1.5 miles limited to two hours on freeways. • Queues > 2.0 miles not acceptable on freeways. • Delays < 15 minutes on arterials. • Level of Service (LOS) - Signalized Intersections: o C < LOS < A, loss of LOS to D, maximum control delay of 30 seconds. o LOS = D, maximum control delay increase is 30%. o LOS = E, maximum control delay increase is 30% up to 50 seconds.

Table 42. Performance thresholds used by various agencies.
(Sources: HfL[92] and NCHRP 20-68A Scan 08-04[88])

Agency	Category	Performance Threshold
		o LOS = F, no control delay increase is acceptable. • LOS - Unsignalized Intersections: o C < LOS < A, loss of LOS to D, maximum control delay of 45 seconds. o LOS = D, maximum control delay increase is 30%LOS = E, maximum control delay increase is 30% up to 80 seconds. o LOS = F, no control delay increase is acceptable.
Michigan DOT	Mobility	• Delays < 10 minutes. • Volume/capacity ratio < 0.8. • Drop in LOS < 2 levels. • LOS no worse than D.
Missouri DOT	Mobility	• Delays > 15 minutes are considered excessive.
New Hampshire DOT	Mobility	• 0 < delays < 5 minutes are acceptable. • 5 < delays < 10 minutes are not preferable. • Delays > 10 minutes are undesirable; field staff will consider suspending work.
New Jersey DOT	Mobility	• Delays < 15 minutes.
Ohio DOT	Mobility	• Queues < 0.75 miles acceptable. • 0.75 < queues < 1.5 miles limited to two hours. • Queues > 1.5 miles are not acceptable.
Pennsylvania DOT	Mobility	• Delays < 15 minutes are acceptable. • 15 minutes < delays < 30 minutes limited to two consecutive hours.
Oregon DOT	Mobility	• Project delays < 10% of the peak travel times • Corridor delays (all projects combined) < 10% of peak travel times.
Wisconsin DOT	Mobility	• Maximum of 15 minutes of added delay between major city nodes (all potential projects along route combined).

3.2.5 Candidate Strategies for MOT Alternative Analysis (Step 5)

Tables 35 and 36 in Chapter 2 provide an array of candidate strategies for work zone management for consideration in the MOT alternative analysis. FHWA's TMP Matrix[77] provides a brief description of the strategies listed in these tables, their pros and cons, what project characteristics may trigger their inclusion in the TMP, and their contributions toward possible improvements in mobility and motorist and worker safety. This information can be used as guidance in the selection of candidate MOT alternatives.

The candidate selection depends largely on the expected mobility and safety impacts, economical impacts to local business and the community, construction phasing and staging, traffic control costs, capacity reduction, feasibility of full lane closure (necessary in some cases), and the distance to feasible detour routes. The findings of the initial assessment conducted in Step 1 should be taken into consideration in identifying the candidate strategies for the MOT alternative analysis. In addition, it is necessary to review the constructability options of the candidate strategies for inclusion in the MOT alternative analysis.

The following factors, used by Maryland SHA for identifying possible work zone constraints, can be used as additional factors for candidate selection:

- Ability to meet performance thresholds.
- Ability to maintain access (businesses, communities, etc.).
- Ability to provide required ramp merge distances.
- Right-of-way impacts.
- Environmental impacts.
- Bridge widths.
- Significant impacts on construction duration.
- Significant impacts to earthwork, retaining walls, pier clearances, profile differences, etc.
- Ability to maintain existing drainage, utility and lighting systems.
- Constructability and construction equipment access.
- Impacts on pedestrian and bicycle facilities.
- Impacts on emergency services (fire, ambulance, police, hospitals).
- Safety (of traveling public and workers).
- Ramp capacity.
- Construction and MOT costs.

Table 43 presents a list of possible strategies for identifying possible candidate strategies based on the preliminary assessment.

Table 43. Candidate strategies for MOT alternative analysis.

Objective	Strategy
Baseline (traditional strategy)	• Partial lane closure
To reduce overall work zone impacts	• Construction phasing/staging • Continuous full road closure • Business access improvements
To restrict work zone operational time	• Lane rental • Off-peak/night/weekend/intermittent full road closure • Night work – lane shift/full or partial width closure • Weekend work – lane shift/full or partial width closure • Work hour restrictions for peak travel
To reduce or divert work zone traffic demand	• Truck/heavy vehicle restrictions • Off-site detours/use of alternate routes • Ramp closures/relocation • Freeway-to- freeway interchange closures
To maintain/add work zone capacity	• Street/intersection improvements • Reduced lane widths to maintain number of lanes • Reduced shoulder width to maintain number of lanes • Lane shift to shoulder/median
To manage work zone capacity constraints	• One-lane, two-way operation • Crossover • Reversible lanes
To manage traffic flow within work zone	• Signal timing/coordination improvements • Temporary traffic signals • Speed limit reduction/variable speed limits • Separate truck lanes • Dynamic lane closure system

3.2.6 Detailed Assessment of Work Zone Impacts (Step 6)

In this step, a more rigorous reassessment of work zone impacts and issues, qualitative as well as quantitative, is conducted to facilitate the selection of preferred MOT strategy. The level of detail varies depending on the significance of the impacts and the project itself. More detailed discussion can be found in the FHWA's guidance on work zone impact assessment.[9]

During the detailed assessment, the performance impacts are quantified for each candidate strategy and qualitative criteria, if any, are reconfirmed. Specific issues pertinent to mobility, safety, construction, and coordination (e.g., right-of-way, utility) are identified and addressed. At this stage, the use of work zone impact analysis tools is considered more suitable for a detailed quantitative analysis. Section 2.9 provides a detailed discussion on the available work zone impact analysis tools, their advantages, and their disadvantages.

Example 3.1: Identifying alternatives for MOT analysis

US 00 serves as a major arterial road connecting the regional industrial hub with the twin metros located in Polk County, District 1. The existing pavement between mileposts 100 and 110 has reached the end of its useful life and needs reconstruction. The route carries significant amounts of commuter and truck traffic. The alternative routes for detour have limited lane capacity and can accommodate only a portion of the work zone traffic volume. This industrial hub is paramount to the economic vitality of the metro region, so long delays are not acceptable. This route also serves a hurricane evacuation route connecting the twin metros to interstate highways. The construction is expected to be scheduled in late summer and early fall seasons.

For the US 00 pavement reconstruction project, the following candidate alternatives can be considered for MOT alternative analysis:

- Alternatives that restrict the operational time of work zones to off-peak hours
    - Off-peak full closure.
    - Nighttime full closure.
    - Weekend full closure.
    - Reversible lanes.
    - Nighttime partial width closure.
    - Weekend partial width closure.
    - Work hour restrictions for peak travel.
- Alternatives that divert work zone traffic demand
    - Diverting trucks to alternative routes during peak hours.
    - Restricting truck travel through the work zone during peak hours.

3.2.7 Decision Analysis for MOT Strategy Selection (Step 7)

The MOT alternative analysis involves the consideration of both qualitative and quantitative factors. Recognizing that the possibility for an ideal MOT strategy is impractical, the selection process should focus on identifying an option that more or less meets the project goals. Selecting a meaningful and justifiable option involves weighing both quantifiable performance metrics and policy directives to ensure that both agency and project-specific needs are incorporated in decision making. Decision analysis tools provide a structured, systematic framework for gathering, organizing, and evaluating information to make informed choices.

While any appropriate decision analysis tool can be used, the Kepner-Tregoe (K-T) decision analysis method is recommended here for MOT alternative analysis.[96] Not only does this tool allow combining quantitative and qualitative criteria of work zone road user impacts, but it also provides flexibility to make project-specific choices. The steps include:

1. Prepare decision statement.
2. Define MUST and WANT objectives.
3. Assign weights to WANT objectives.
4. Identify candidate MOT alternatives.
5. Summarize the findings of work zone impact assessment.
6. Evaluate alternatives against MUST objectives.
7. Evaluate alternatives against WANT objectives.
8. Calculate the weighted scores of alternatives.
9. Evaluate adverse consequences.
10. Select the preferred MOT strategy.

Example 3.2: Illustrating the K-T decision analysis method

The "US 00 Pavement Rehabilitation" example presented in Example 3.1 has been selected for illustrating the K-T decision analysis method.

Step 7.1 Prepare Decision Statement

The K-T decision analysis process begins with a precise statement of what needs to be done and how it will be done. This statement provides the focus for all other steps that follow and sets the limits on the range of alternatives that would be considered in the decision analysis. This statement must be defined consistent with the agency's work zone related policies and project-specific needs.

The decision statement for the project presented in Example 3.2 is as follows:

The purpose of the decision analysis is to identify the most appropriate strategy for maintaining traffic on US 00 during the reconstruction of the pavement segments between mileposts 100 and 110.

Step 7.2 Define Objectives

Objectives are the decision criteria that describe the required and desired attributes of the resulting choice, and the explicit limits imposed on the decision process. The objectives include:

- **MUSTS**: These are the mandatory attributes required for an alternative to be considered in the decision process. These attributes are considered mandatory to guarantee a successful decision. Any alternative that cannot comply with a MUST objective is eliminated for further consideration, while those comply with all the MUST objectives qualify as feasible alternatives. The MUST objectives should be measurable, and all MUST objectives are assigned with GO and NO GO options.

[96] Kepner, C. H., and B. B. Tregoe, *The New Rational Manager*, Princeton Research Press, Princeton, NJ, 1981.

- **WANTS**: These are the desired attributes based on which a preferred alternative is selected from the pool of feasible alternatives (i.e., alternatives that fulfill all the MUST objectives). A mandatory or high-priority objective can be considered as a WANT objective, if that objective is not measurable or a relative assessment is preferred over an absolute GO/NO GO judgment. A MUST objective can also be considered as a WANT objective by rephrasing the objective statement for relative assessment of feasible alternatives. Numerical weights indicating their relative importance are assigned.

In other words, "the MUSTS decide who gets to play, but the WANTS decide who wins."[97]

A list of MUST objectives for Example 3.2 is as follows:

1.	Maintain a minimum of one lane each direction for work zone traffic during weekdays	Go/No Go
2.	No lane closure from 7a.m. to 10 a.m. and 4 p.m. to 8 p.m. on weekdays	Go/No Go
3.	Queue length not more than 0.75 for more than 1 hour	Go/No Go
4.	Delay time not more than 30 minutes	Go/No Go
5.	Available detour routes exceed capacity?	Go/No Go
6.	MOT alternative has no constructability issues	Go/No Go

A list of WANT objectives for Example 3.2 is presented as follows:

1. Minimize daily road user costs ($)
2. Minimize number of days for project completion
3. Minimize traffic control & construction engineering costs ($)
4. Minimize length of detour (miles)
5. Minimize queue length (lane-miles)
6. Minimize average delay time per vehicle (min.)
7. Minimize percent motorist traveling at a speed 15 mph less than the posted limit
8. Minimize average time to clear a non-injury incidence (min.)
9. Maintain emergency services (adjectival ratings—poor, average, good)
10. Reduce environmental impacts (adjectival ratings—low, moderate, severe)

Selection of Objectives

One of the commonly cited concerns with decision analysis is the interdependency among objectives. It is a phenomenon where two or more objectives are highly correlated. The presence of interdependence among objectives in decision analysis can produce erroneous or misleading outcomes. Interdependence leads to lead to double counting and tend to weigh heavily toward the interdependent factors, while diminishing the significance of other factors in the analysis. Therefore, it is imperative that a decision analyst screen for interdependency among the objectives and validate them.

For example, consider the list of WANT objectives presented above. The factor "daily road user costs" is highly correlated with the following factors: length of detour, maximum queue length, average delay time, average time to clear non-injury incidence, percent traveling at a speed 15 mph less than the posted speed limit. The factors all contribute to the computation of daily road user cost value. Similarly, the factors "the number of days for project completion" and "traffic control & construction engineering costs" are highly correlated.

[97] Kepner, C. H., and B. B. Tregoe, The New Rational Manager, Princeton Research Press, Princeton, NJ, 1981.

One common technique used in screening the interdependency among objectives is sensitivity analysis. A sensitivity analysis can be conducted formally or informally to evaluate the effects of varying one objective (numerical or adjectival) on other objectives and final outcomes. The results of the sensitivity analysis will help to identify correlations among analysis factors. Both the degree of correlation and the logical dependency between the factors should be taken into account while identifying the dependent pairs. The purpose here is to avoid double counting rather than eliminating all correlated factors.

Consider the dependency between two pairs:

- Average delay time vs. daily road user cost. In this case, considering both factors in the analysis will lead to double counting, as the factor “daily road user cost” is a monetized aggregation of various impacts including the factor “average delay time.” Any change in the average delay time will result in a proportional change in the daily road user cost. In such cases, it is suggested that the analyst eliminate the factor “average delay time” or break the factor “daily road user cost” into individual components.
- Average delay time vs. average time to clear a non-injury incident. In this case, the factor “the change in average time to clear a non-injury incidence” also causes a proportional change in the average delay time, and hence is highly correlated. However, considering the probability of a non-injury incident and the importance of clearing the incident, the analyst may prefer to list both factors to emphasize the effectiveness on traffic incident management in MOT alternative selection and distinguish it from other traffic delay control strategies. Therefore, it is imperative to use engineering judgment and experience in selecting the objectives so that the intended purpose of the analysis and the complexity of the problem are not diluted.

The problem of interdependency may occur if one objective is defined at the aggregate/generic level while another is defined at the component/specific level. For example, in the list of WANT objectives presented above, the interdependency between the factor “daily road user cost” and other factors is a result of mixing up the factors from different hierarchical order, as illustrated in Figure 13. This figure presents the relationship between “daily road user costs” and only those delay-related WANT objectives listed in the example. All the factors listed on the left (queue length, average time to clear a non-injury incidence etc) contribute in determining the average delay time, which in turn, is used in the daily road user cost computation.

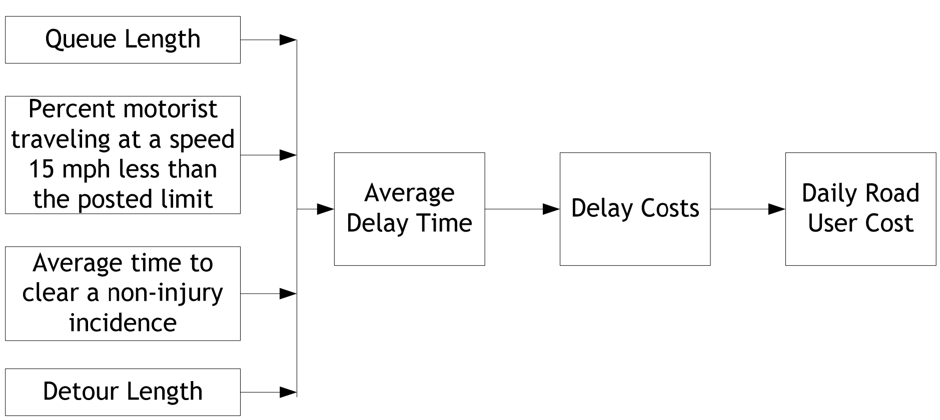

Figure 13. Illustration of relationships among factors.

A modified list of WANT objectives for Example 3.2 is presented as follows:

1. Minimize delay costs
2. Minimize vehicle operating costs
3. Minimize number of days for project completion
4. Minimize traffic control and associated construction costs (e.g., shoulder widening, temp bridges)
5. Minimize average time to clear a non-injury incidence (min.)
6. Maintain emergency services (adjectival ratings—poor, average, good)
7. Reduce environmental impacts (adjectival ratings—low, moderate, severe)

Step 7.3 Assign Weights to WANT Objectives

The WANT objectives are not all equally important. Therefore, it is necessary to allocate weights to the items listed in Step 7.2 to reflect their relative priority in the decision. A simple approach is to give the most important criterion a weight of 10 and then assign weights to the rest against that standard.

In this way, each WANT objective is weighted on a scale of 1 to 10 based on its relative importance in the decision process, with 1 indicating "least preferable" and 10 indicating "most preferable" or "equally preferable." The weights assigned to the WANT objectives should reflect the agency's policies, results of work zone impact assessment, and project-specific needs. The contribution of the WANT objective to the overall work zone impacts should be taken into account while assigning weights. In addition, the following issues should be evaluated while assigning the weights:

- Too many high weights may indicate unrealistic expectations or a faulty perception of which objectives can guarantee success.
- Too many low weights suggest the possible inclusion of unimportant details in the analysis.
- Biased objectives may produce an ineffective analysis.

Sensitivity analysis can be used in screening such issues.

The following illustrates the assigning of weights to each of the WANT objectives considered in Example 3.2:

No.	WANT Objective	Assigned Weight
1.	Delay costs	10
2.	Vehicle operating costs	8
3.	Number of days for project completion	10
4.	Traffic control & associated construction costs ($)	8
5.	Average time to clear a non-injury incidence (min.)	4
6.	Maintenance of emergency services (adjectival ratings—poor, average, good)	6
7.	Environmental impacts (adjectival ratings—low, moderate, severe)	3

Step 7.4 Identify Candidate MOT Alternatives

Identify all potential alternatives to be evaluated and measured as MUST and WANT objectives. The viable alternatives that could succeed in identifying the preferred MOT strategy are listed herein. Use the alternatives identified in Step 5 as candidate alternatives for decision analysis. No attempt is made in this step to evaluate these alternatives, only to list them.

The candidate alternatives for Example 3.2 are as follows:

Alternative A.	Daytime partial lane closure -closed between 7 a.m. and 5 p.m.
Alternative B.	Nighttime partial lane closure -closed between 8 p.m. and 6 a.m.
Alternative C.	Nighttime partial lane closure -closed between 9 p.m. and 7 a.m.
Alternative D.	Nighttime full lane closure -closed between 9 p.m. to 7 a.m.
Alternative E.	Truck traffic diverted through detour routes during peak hours.

Step 7.5 Summarize the Findings of Work Zone Impact Assessment

A detailed work zone impact assessment for each candidate alternative should be done to evaluate both MUSTs and WANTs. Use the findings of the preliminary and detailed impact assessments conducted in Step 1 and Step 5, respectively, for evaluation. The assessment findings must be summarized for each alternative against the objectives.

The following summarizes the impact assessment findings of all alternatives against the MUST objectives considered in Example 3.2:

MUST Objective	Alternative Evaluation				
	A	B	C	D	E
1. Maintain a minimum of one lane each direction for work zone traffic during weekdays	No	Yes	Yes	Yes	Yes
2. No lane closure from 7 a.m. to 10 a.m. and 4 p.m. to 8 p.m. on weekdays	No	Yes	Yes	Yes	Yes
3. Average delay time per vehicle (min)	19.0	6.0	3.0	10.0*	20.0**
4. Maximum queue length (mi.)	1.6	0.0	0.0	0.5*	0.5**
5. Available detour route exceed capacity?	No	No	No	No	Yes
6. MOT alternative has no constructability issues	No	No	No	No	No
Note: (*) Calculated for the selected detour route. (**) Weighted average for both mainline and detour routes.					

The following summarizes the impact assessment findings of all alternatives against the WANT objectives considered in Example 3.2:

WANT Objective	Alternative Evaluation				
	A	B	C	D	E
1. Delay costs	$5,300	$3,125	$2,800	$4,700	$6,800
2. Vehicle operating costs	$1,484	$656	$728	$1,175	$1,836
3. Number of days for project completion	150	84	84	60	90
4. Traffic control & associated construction costs ($)	$55,000	$94,000	$75,000	$109,000	$85,000
5. Average time to clear a non-injury	20	25	25	15	10

WANT Objective	Alternative Evaluation				
	A	B	C	D	E
incidence (min.)					
6. Maintenance of emergency services (adjectival ratings—poor, average, good)	moderate	moderate	moderate	good	good
7. Environmental impacts (adjectival ratings—low, moderate, severe)	moderate	severe	severe	low	low

Step 7.6 Evaluate Alternatives against MUST Objectives

Evaluate all available alternatives against each of the MUST objectives identified in the earlier step. Any alternative is eliminated from further consideration if it fails to satisfy one or more of the MUST objectives; only those satisfying all the objectives are considered as feasible alternatives.

For Example 3.2, the results obtained from the evaluation of alternatives against MUST objectives are presented as follows:

MUST Objective	Alternatives				
	A	B	C	D	E
1. Maintain a minimum of one lane each direction for work zone traffic during weekdays	Go	Go	Go	*Go*	*Go*
2. No lane closure from 7 a.m. to 10 a.m. and 4 p.m. to 8 p.m. on weekdays	No-Go	Go	Go	*Go*	*Go*
3. Queue length not more than 0.75 miles for more than 1 hour	No-Go	Go	Go	*Go*	*Go*
4. Delay time not more than 30 min.	Go	Go	Go	*Go*	*Go*
5. Alternative detour route exceeds capacity?	Go	Go	Go	*Go*	*No-Go*
6. MOT alternative has no constructability issues	Go	Go	Go	Go	Go
Outcome: Alternatives A and E are eliminated. Alternatives B, C and D qualify as feasible alternatives					

Based on the evaluation results, Alternatives A and E are eliminated from further consideration, as these alternatives did not satisfy all the required attributes. Alternatives B, C, and D are carried into the next step.

Step 7.7 Evaluate Alternatives against WANT Objectives

In this step, each alternative is assigned with a score of 1 to 10 against each WANT objective based on how well the alternative meets that objective. This step involves assessing each alternative individually against each WANT objective and comparing the alternatives with each other against each WANT objective.

For Example 3.2, the results obtained from the evaluation of alternatives against WANT objectives are presented as follows:

WANT Objective	Weight	Alternative Score				
		A	B	C	D	E
1. Delay costs	10		9	10	6	
2. Vehicle operating costs	8		10	8	7	
3. Number of days for project completion	10		7	7	10	
4. Traffic control & associated construction costs ($)	8		8	8	10	
5. Average time to clear a non-injury incidence	4		6	6	10	
6. Maintenance of emergency services	6		6	6	10	
7. Environmental impacts	3		3	3	10	

Step 7.8 Calculate the Weighted Scores of Alternatives

The weighted score of each feasible alternative should be computed to determine the relative performance of the alternatives. The weighted score is the score of an alternative multiplied by the weight of the WANT objective to which the score refers. For example, the weight of the objective "length of detour" is 7, and the score of Alternative D against this objective is 2. Therefore, the weighted score of Alternative D on that objective is 14. For each alternative, all the weighted scores are added up to calculate the total weighted score for that alternative.

The total weighted score of an alternative indicates how well an alternative stack up against each of the other alternatives on overall performance against WANT objectives. In other words, the total weighted scores indicate the comparative performance of the alternatives.

For Example 3.2, the individual and the total weighted scores of each feasible alternative are as follows:

WANT Objective	Alternative Score				
	A	B	C	D	E
1. Delay costs		90	100	60	
2. Vehicle operating costs		80	64	56	
3. Number of days for project completion		70	70	100	
4. Traffic control & associated construction costs ($)		64	64	80	
5. Average time to clear a non-injury incidence		24	24	40	
6. Maintenance of emergency services		36	36	60	
7. Environmental impacts		9	9	30	
Total weighted score		373	367	426	

In this example, Alternative D is considered as the tentative choice.

Step 7.9 Evaluate Adverse Consequences

After the completion of alternative evaluation using MUST and WANT objectives, the feasible alternatives should be evaluated against potential risks identified in the work zone impact assessment. The objective of this step is to understand the consequences of selecting an alternative by evaluating them separately. No comparative assessment is made as to identify which alternative is more likely to produce adverse consequences than other alternatives.

The risk assessment begins with the tentative choice (i.e., the alternative with the highest total weighted score). For this alternative, the probability of the occurrence of an adverse consequence is rated on a scale from "Low" to "High," with a rating of "Low" indicating "an unlikely event" and "High" indicating "a most probable event." The severity of the impact (i.e., performance of an alternative under that event) is assessed and rated on a similar scale, with a value of "Low" indicating "inconsequential" and "High" indicating "very severe." This evaluation is repeated for each alternative that passes all the MUST objectives.

The likelihood of the adverse events occurring and the performance of an alternative under these situations were rated as probability and severity ratings, respectively. An alternative is considered a high-risk choice if it has at least one potential adverse consequence that is considered both highly probable and very severe, while those alternatives with low probability and low-severity consequences are considered low-risk choices.

For Example 3.2, three potential risks were considered:

- Event of flooding.
- High-severity crashes (involving multiple crashes and longer incidence time).
- Event of an emergency evacuation due to hurricanes.

The evaluation of adverse consequences for the MOT alternatives B, C, and D considered in the example are shown as follows:

Adverse Consequence	**Alternative**					
	B		**C**		**D**	
	Probability	**Severity**	**Probability**	**Severity**	**Probability**	**Severity**
Flood impact	LM	HM	LM	HM	LM	HM
High-severity crashes	HM	L	HM	L	HM	LM
Emergency evacuation	HM	L	HM	L	HM	H
H=High HM=High-medium M=Medium LM=Low-medium L=Low						

Based on this evaluation, the adverse consequences of implementing Alternative B or Alternative C are deemed less significant, and therefore, selected for further consideration. Implementing Alternative D is more likely to create problems and confusion during emergency evaluation for the following reasons:

- An emergency mass evacuation is more probable during late summer and early fall (the period when the construction is expected to be scheduled).
- Failure to remove full closure traffic controls within a shorter period of time could be problematic.
- Local users are more likely to avoid this route, assuming that the full closure would still be in place, thus resulting in network-level bottlenecks and confusion.

Alternative D is considered as a high-risk choice, while Alternatives B and C are deemed low-risk choices.

Step 7.10 Select the Preferred MOT Strategy

The total weighted score and the results of adverse consequence evaluation are summarized for each alternative from steps 7.8 and 7.9.

High-risk choices can be eliminated from further consideration. Other alternatives are then ranked based on their weighted scores. The alternative with the lowest rank is selected as the preferred MOT strategy.

Alternatively, high-risk choices may be enhanced with additional measures to mitigate the impacts of an adverse consequence. These enhancements may incur additional costs and may impact work zone performance. Therefore, these revised choices may need to be re-evaluated through the decision analysis process with other alternatives. Engineering judgment should be exercised in making any decisions relating to eliminating, reviewing, and/or re-evaluating high-risk choices.

In Example 3.2, Alternative D is identified as a high-risk choice despite its highest total weighted score. However, a decision was made to review Alternative D for possible enhancements rather than eliminating it. Since only nighttime full closures are made under Alternative D, there was scope for addressing the concerns related to emergency evacuation with no requirement for re-evaluation. Risks associated with emergency evacuation can be mitigated effectively through improvements in public awareness and motorist information strategies. The cost of implementing mitigation measures is marginal and can be justified with road user cost savings.

For Example 3.2, the recommended MOT strategy is Alternative D with additional public awareness and motorist information strategies.

Alternative	Description	Total Weighted Score	Adverse Consequence	Rank
A	Daytime partial lane closure -closed between 7 a.m. to 5 p.m.	Eliminated	-	-
B	Nighttime partial lane closure -closed between 8 p.m. to 6 a.m.	373	Low Risk	2
C	Nighttime partial lane closure -closed between 9 p.m. to 7 a.m.	367	Low Risk	3
D	Nighttime full lane closure -closed between 9 p.m. to 7 a.m.	426	High Risk Improvements identified	1
E	Truck traffic diverted through alternative detour routes during peak hours.	Eliminated	-	-

Appendix A provides a worksheet for performing K-T decision analysis for MOT strategy selection.

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CHAPTER 4. APPLICATION OF WZ RUC ANALYSIS IN CONTRACTING/PROJECT DELIVERY METHODS

4.1 OVERVIEW

Time delay has been a chronic problem in the delivery of highway construction projects. In 2002, the General Accounting Office (GAO) observed that it typically takes about 9 to 19 years to plan, gain approval for, and construct a new, major Federally funded highway project that has significant environmental impacts.[98] Construction delays not only result in cost overruns but also cause adverse economic impacts and disruption to traveling public and local neighborhood. These impacts are more significant in urban areas with high traffic volumes.

Highway agencies increasingly are interested in shortening project delivery to manage the overall impacts of construction delays and associated road user costs. The benefits of shorter construction time are obvious: minimizes inconvenience and disruption of the traveling public, improves the safety performance of both construction crew and traffic, minimizes the adverse economic impacts on local businesses, provides savings in direct agency costs, and minimizes the social costs of traffic delays and additional travel.

Highway agencies use schedule-focused contracting methods and accelerated construction techniques to shorten construction time and minimize WZ RUC. [99,100,101] The schedule-focused methods focus on reducing the number of calendar days of construction, completing the critical project milestones within the intended timeframe, stipulating the hours and days the contractor is allowed to close the roadway lanes for work, and incentivizing the contractor to complete the project ahead of schedule. These contracting methods can be pursued through any project delivery method: traditional, design-build, or construction manager/general contracting (CMGC). Accelerated construction uses various innovative planning, design, materials, and construction methods to reduce the installation time.

Both schedule-focused contracting methods and accelerated construction techniques focus on reducing the onsite construction time, which in turn, minimizes the work zone exposure time and associated costs. The deployment of non-traditional contracting methods or accelerated construction techniques to achieve shorter construction time often carries additional costs associated with innovations. This cost premium generally is offset partially or fully with WZ RUC savings gained from shorter work zone time. The computation of WZ RUC thus plays an

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[98] Siggerud, *Highway Infrastructure: Preliminary Information on the Timely Completion of Highway Construction Projects*, Report No. GAO-02-1067T, United States General Accounting Office, Washington, DC, 2002.

[99] Fick, G., E. T. Cackler, S. Trost, and L. Vanzler, *Time-Related Incentive and Disincentive Provisions in Highway Construction Contracts*, Final Report, NCHRP Report No. 652, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 2010.

[100] Ellis, R., J. Pyeon, Z. Herbsman, E. Minchin, and K. Molenaar, *Evaluation of Alternative Contracting Techniques on Florida DOT Construction Projects*, Final Report, Contract No. FDOT BDC51, Submitted to the Florida Department of Transportation, Gainesville, 2007.

[101] Anderson, S.D., and I. Damnjanovic, *Selection and Evaluation of Alternative Contracting Methods to Accelerate Project Completion*, NCHRP Synthesis 379, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 2008.

important role in evaluating the economic efficiency of deploying non-traditional contracting/ construction strategies.

Furthermore, the computation of WZ RUC forms the basis for calculating contractor incentives/disincentives (I/D) set by an agency for early and late project completion. In the Milton Construction Company vs. Alabama case, the Alabama Supreme Court ruled that State of Alabama failed to adequately demonstrate that the disincentive amount was set based on the work zone road user costs. Though the outcome of this case did not set legal precedence for I/D provisions, the ruling emphasizes the primary role of road user costs in establishing I/D provisions.

This chapter presents an overview of schedule-focused alternative contracting strategies, identifying the need for their application, selecting an appropriate strategy based on project needs, determining I/D amounts, and identifying a balance between construction costs and the level of schedule acceleration required for early completion.

4.2 SCHEDULE-FOCUSED ALTERNATIVE CONTRACTING STRATEGIES

4.2.1 Need for Schedule-focused Alternative Contracting Strategies

Traditionally, the owners of highway facilities have focused on acquiring construction services through low bid contracts—maximum value at minimum cost (Thomas et al., 2006).[102] To ensure construction completion on time, owners have used liquidated damages clauses in their contracts. Liquidated damages are imposed to recover the additional construction oversight costs incurred by the owners if the contractor fails to complete the construction on time. Though these penalty mechanisms were put in place to enforce mandatory completion, nearly half of projects were not completed on time. On-schedule performance was worse for larger projects over 5 million dollars, as nearly two-thirds of these projects were not completed on time (Crossett and Hines, 2007).[103] These findings suggest that the liquidated damages were only partially effective in enforcing project completion time.

With increasing pressures to complete construction on time, owner agencies have turned to non-traditional, schedule-focused contracting methods for use in conjunction with liquidated damages. These methods include:

- I/D for early/late completion.
- Lane rental.
- Cost (A) + time (B) bidding with I/D.
- Interim milestones.
- No-excuse bonus (otherwise called locked incentives).
- Liquidated savings.
- Accelerated construction techniques.[104]

[102] Thomas, H. R., R. D. Ellis, and S. K. Sinha, *Improving the Time Performance of Highway Construction Contracts*, Final Report, NCHRP Project No. 20-24(12)A, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 2006.
[103] Crossett, J., and Hines, *Comparing State Dots' Construction Project Cost & Schedule Performance – 28 Best Practices from 9 States*, Final Report, NCHRP Project 20-24, Task 37A, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 2007.
[104] Although an accelerated construction technique is not considered as a contracting strategy, it is often used to shorten project completion time and minimize road user impacts.

Except for accelerated construction techniques, all these contracting methods have been evaluated on select Federal-aid projects since the 1990s under the FHWA's SEP-14 program. Of these strategies, A+B bidding and lane rental were declared operational (no longer considered experimental) after a period of evaluation, while the others are under evaluation. These strategies, including accelerated construction techniques, were put in practice in several highway projects under the FHWA's HfL program.

Schedule-focused methods augment the traditional design-bid-build delivery method by focusing on improving its schedule performance. In addition, design-build and CMGC have been found effective in shortening the construction completion time. The use of CMGC in Federal-aid projects is under SEP-14 evaluation, while the design-build method is no longer considered experimental. Though CMGC and design-build primarily focus on improving the overall project delivery time (i.e., preliminary engineering through construction), the early involvement of the contractor in the pre-construction phases has helped the owner agencies manage work zone impacts and achieve early completion through increased coordination and better planning.

NOTE

In this guide, the term "contracting strategy" refers to both the contracting method and the project delivery method.

4.2.2 Overview of Schedule-focused Contracting Methods and Alternative Delivery Methods

This section presents an overview of the schedule-focused contracting methods and alternative delivery methods.

4.2.2.1 Incentive/Disincentive for Early Completion

FHWA's Contract Administration Core Curriculum (CACC) Manual defines I/D for early completion as "a contract provision which compensates the contractor for each day that identified critical work is completed ahead of schedule and assesses a deduction for each day that completion of the critical work is delayed."[105] In this approach, the contractor is required to complete the project by the engineer's estimate of the contract time specified in the bid documents. Upon completion, the contractor is rewarded with bonus payments for completing the project ahead of schedule and penalized with disincentive charges for late completion. The owner agency determines both the maximum allowable time and the I/D structure.

The I/D structure and the engineer's estimate of the contract time should be well justified and determined on a project-by-project basis. The incentive payments should be adequate enough to motivate the contractor to complete the work on or ahead of schedule; in other words, the incentives paid to the contractor should be higher than the additional costs incurred by the contractor for accelerating the work. On the other hand, the disincentive charges for delivery delay should compensate the additional costs incurred by the owner agency and road users.

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[105] FHWA, *Contract Administration Core Curriculum Participant's Manual and Reference Guide*, Office of Program Administration, Federal Highway Administration, Washington, D.C., 2006.

NOTE

When both liquidated damages and disincentives are applied in a project, care should be taken not to double count the cost items.

The I/D structure should be established using the road user costs, traffic control and maintenance costs, and construction engineering inspection costs. FHWA recommends a cap of 5 percent of the total contract amount for the maximum incentive payment, while no such cap is recommended on the maximum disincentive amount.

Similarly, the maximum time for completion allowed in the contract (engineer's estimate) should be well balanced and effective. An unreasonable completion date may attract unbalanced bids, while an incentive payment to contractors is unjustified for little or no effort. Project scheduling using the critical path method (CPM) can help determine an optimal completion time.

The use of I/D provisions is suitable for virtually all types of projects, but especially those with high-traffic volumes in urban areas. Typical projects include new/reconstruction, rehabilitation projects, detour projects, intersection upgrades, and bridge rehabilitation projects. However, I/D generally is not used on non-critical, low WZ RUC projects that create little disruption to traffic, such as signal systems, landscaping, and signing projects.

The advantages and disadvantages of using I/D provisions are summarized in Table 44.

Table 44. Advantages and disadvantages of incentives/disincentives.

Advantages	Disadvantages
• Reduces WZ RUC • Shortens project completion time • Enhances work zone safety • Encourages contractor efficiency and productivity • Accommodates local traffic flow • Opens critical phases of a project earlier • Reduces construction engineering inspection, traffic control costs	• Would not necessarily result in time savings • Additional agency resources • Increased construction costs • Negotiations difficult with contract changes • May lead to adversarial relationship • Additional documentation and coordination • Risks of unbalanced bids with both cost and time component if planned not properly. • Needs additional planning

NOTE

Incentive/disincentive provisions are effective when the agency goal is to minimize work zone impacts and associated road user costs through early completion.

4.2.2.2 A+B Bidding (with I/D)

A+B bidding allows an owner agency to solicit bids for the cost of work items and the time to complete the work and procure them in a single contract. This method involves two components:

- Cost (A): The dollar amount of contract items (equipment, materials, and manpower) for all work to be performed under the traditional low-bid contract.

- Time (B): The dollar amount for the time component of a contract, estimated by multiplying the number of calendar days to complete the work by the daily road user cost.

The cost and time components are combined to arrive at a bid value:

Bid value = (A) + (B x Daily Road User Cost)

The contract is then award to the lowest bid value for contract award. This formula is not used in determining the payment to the contractor. The contractor receives incentives for early completion and is required to pay disincentives (and liquidated damages) for delaying beyond the completion date agreed in the contract.

A+B bidding generally is suitable for time-critical projects such as high-traffic volume roadways, business, tourist, and environmentally sensitive areas. Typical projects include new/reconstruction, rehabilitation projects, simple bridge replacement projects, detour projects, intersection upgrades, and bridge rehabilitation projects. A+B bidding is not required for non-critical, low impact projects such as signal systems, landscaping, and signing projects.

Example 4.1: Illustration of A+B bidding

RUC specified by the agency = $2,000/day

Bidder	Cost	Number of Calendar Days	Total Bid Amount
A	$ 195,000	23	=$ 195,000 + 23 * $ 2,000 =$ 241,000
B	$ 198,000	22	=$ 198,000 + 22 * $ 2,000 =$ 242,000
C	$ 210,000	17	=$ 210,000 + 17 * $ 2,000 =$ 244,000
D	$ 200,000	20	=$ 200,000 + 20 * $ 2,000 =$ 240,000
E	$ 205,000	19	=$ 205,000 + 19 * $ 2,000 =$ 243,000

Winning Bidder: D

The advantages and disadvantages of this method are summarized in Table 45.

Table 45. Advantages and disadvantages of A+B bidding.

Advantages	Disadvantages
• Reduces WZ RUC • Shortens project completion time • Enhances work zone safety • Encourages contractor efficiency and productivity • Accommodates local traffic flow • Opens critical phases of a project earlier • Reduces construction engineering inspection, traffic control costs	• Would not necessarily result in time savings • Additional agency resources • Increased construction costs • Negotiations difficult with contract changes • May lead to adversarial relationship • Additional documentation and coordination • Bidding risks with insufficient competition • Risks of unbalanced bids with both cost and time component if planned not properly. • Needs additional planning

> **NOTE**
> A+B bidding allows the market to determine the required contract time to complete the project. It is effective when the owner agency is not certain of its completion time estimates. It is not recommended when few bids are expected. Suitable for time-sensitive projects when combined with I/D.

4.2.2.3 Lane Rental

In lane rental, the contractor pays a rental fee for the time period a lane is closed to through traffic for construction activities. This provision is intended to minimize the disruption of the work zone traffic and to encourage minimal use of lanes for construction activities.

In this approach, the owner agency determines the number and duration of lane closures. The lane rental fee is estimated using the WZ RUC of the closure period. Closures may be continuous or intermittent, restricted to off-peak hours, night work, weekend, or during the execution of specific tasks, such as blasting.[106] The owner must estimate the closure time accurately, and the methodology for determining closure time should be defined clearly in the specifications. In some cases, the contractor may be allowed to propose the required amount of closure time and number of closures in their bid submissions.[99] Lane rental fee can be combined with an I/D provision or may apply only for the period of schedule overrun. Lane rental also can be combined with the A+B bidding method.

Lane rental generally is suitable when detours are long, unavailable, or impractical, or when peak hour traffic is impacted adversely. It is well suited for multiple lane roads with high traffic volumes where there is flexibility for intermittent or temporary lane closures to keep at least one lane open to traffic through the work zone. Typical projects include mill and overlay, temporary widening, patching, diamond grinding, dowel retrofitting, reclamation and recycling, guardrails, striping, signing, bridge painting, crack sealing, signal systems, and traffic management projects. Lane rental is not suitable for projects where long-term permanent lane closures are required, such as bridge re-deck or concrete rehabilitation projects.
The advantages and disadvantages of this method are summarized in Table 46.

> **NOTE**
> Lane rental is effective for projects where the owner wants to encourage the work to done during non-peak hour periods. It is not suitable when full closure is inevitable. For long-term projects, combine lane rental with A+B bidding.

Table 46. Advantages and disadvantages of lane rental.

Advantages	Disadvantages
• Reduces WZ RUC • Shortens project completion time • Enhances work zone safety • Encourages contractor efficiency and productivity • Accommodates local traffic flow	• Work at night and worker safety • Would not necessarily result in time savings • Additional agency resources • Negotiations difficult with contract changes • May lead to adversarial relationship • Additional documentation and coordination

[106] Caputo, F., and S. Scott, *Criteria and Guidelines for Innovative Contracting*, Final Report, Study No. SD95-07, Submitted to the South Dakota Department of Transportation, Pierre, SD, 1996.

4.2.2.4 No-Excuse Incentives

In this method, the contractor is given a "firm completion date" with no excuses for delay. The contractor receives incentives for completing by or before the specified date but there are no disincentives applied for failure to meet the target date (liquidated damages may apply). This method is also referred to as locked incentive dates.

No-excuse incentive clauses have been successful in encouraging early completion for projects that must be open by an event date, such as a sporting event. However, if construction is not completed by that date, appropriate disincentive or liquidated damage provisions may be used to recover public and agency costs.

No-excuse incentives are suitable for time-critical and full closure projects such as in urban, business, tourist, or environmentally sensitive areas. They are well suited for larger projects with multiple phases where the pace of work progress needs to be controlled.

NOTE

No-excuse incentives are effective when the owner agency is confident of the contract time estimates. They are suitable for time-critical projects and when few bids are anticipated.

The advantages and disadvantages of this method are summarized in Table 47.

Table 47. Advantages and disadvantages of no-excuse incentives.

Advantages	Disadvantages
• Reduces WZ RUC • Shortens project completion time • Enhances work zone safety • Encourages contractor efficiency and productivity • Opens critical phases of a project earlier • Better control of project acceleration compared to A+B • Reduces construction engineering inspection, traffic control costs	• Additional agency resources • Increased construction costs • Negotiations difficult with contract changes • May lead to adversarial relationship • Needs additional planning • Legal constraints may not permit

4.2.2.5 Interim Completion Dates (with or without I/D)

In this method, the contractor is required to complete one or more specific portions of a project within a set duration or by a firm completion date. Schedule-related incentives and disincentives may apply.

NOTE

Interim completion date is effective when the completion of one or more intermediate phases of a project is critical.

4.2.2.6 Liquidated Savings

Under this provision, the contractor receives an incentive amount equal to the savings in the owner agency's construction oversight costs for completing the project ahead of schedule. The same approach is used for calculating both liquidated savings and liquidated damages.

4.2.2.7 Accelerated Construction Techniques

Accelerated construction uses various techniques and technologies to help reduce construction time while enhancing/maintaining safety and quality. Accelerated construction techniques offer significant advantages over the traditional construction techniques:

- Reduces the on-site construction time.
- Minimizes inconvenience to traveling public.
- Makes the construction process efficient.
- Improves the work zone safety (with reduced exposure time).
- Reduces environmental impacts by minimizing the site access footprint.
- Reduces the associated road user costs.

Acceleration construction techniques include:

- Prefabricated Bridge Elements and Systems (PBES): These prefabricated elements are manufactured at an off-site location under controlled conditions, assembled as structural systems, transported to the construction site, and installed on a prepared foundation. Prefabricated elements include individual structural elements such as partial-depth or full-depth deck panels, pre-cast beams, pier cap, abutment wall, wingwall, and/or footing column, and/or footing. Prefabricated elements include superstructure, substructure, or the entire bridge system itself.
- Heavy Cranes/Transporters for Bridges: Self Propelled Modular Transporters (SPMT) facilitate quick removal of demolished bridge structures and rapid installation of a new superstructure. The SPMT technology reduces the sequential processes of conventional on-site bridge superstructure construction into one step: move prefabricated bridge superstructure to its final position. SPMTs can move the new bridge superstructure or the entire bridge into place in minutes, with construction inspection completed and traffic flow restored within several hours (FHWA, 2007).[107]
- Pre-cast Concrete Pavement Construction: Prefabricated concrete panels facilitate rapid repair, rehabilitation, and construction of pavements in high-volume-traffic roadways. These panels can be used for single lane replacements, full-depth repairs or full-width construction. These panels can be made thinner than cast-in-place panels, making them ideal for installation under overpasses with limited height clearances.[108]
- Material Innovations: Use of non-conventional materials, such as rapid strength concrete and polymer modified concrete, minimizes the lane closure time required for constructability reasons and facilitates the early opening of lanes to traffic.
- Non-destructive Testing: Use of non-destructive test devices, such as the light weight falling weight deflectometer and intelligent compaction, provides real-time monitoring of construction quality and saves construction time.

NOTE

Accelerated construction techniques are effective in high traffic volume areas. They also are effective in areas where detours are long and full closure is inevitable. They are suitable for both emergency and as-planned projects.

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[107] FHWA Manual on Use of Self-Propelled Modular Transporters to Move Bridges, Publication No. FHWA-HIF-07-022, Federal Highway Administration, 2007. http://www.fhwa.dot.gov/bridge/pubs/07022/hif07022.pdf

[108] FHWA, Modular systems reduce traffic congestion and speed project completion, http://www.fhwa.dot.gov/hfl/innovations/pdfs/precast.pdf

Accelerated construction techniques are appropriate for projects that require the least possible lane closure times. Installation of prefabricated bridge elements, systems, or concrete panels requires fewer hours of lane closure, thus limiting traffic disruption to shorter periods during non-peak hours, nights, or weekends. These techniques are suitable for high volume roadways, emergency bridge replacement, evacuation routes, over a railroad or navigable waterway, and locations where detours are long or impractical. These techniques also are suitable for bridges or concrete pavements that impact the critical path duration of the project.[109]

4.2.2.8 Design-Build Projects

Design-build is a project delivery method in which an owner combines procurement for both design and construction services into a single contract from a single private sector entity. In design-build contracting, the owner is responsible for defining the scope and requirements of the project, performing initial design and design oversight, soliciting proposals from bidders to procure services for both final design and construction, and evaluating those proposals for selection, while the responsibilities for final design is shifted to the design-builder.

In the design-build approach, the performance criteria for the project include schedule, project management, and technical and cost factors. Schedule is particularly important because owners typically select design-build as a means to compress the project delivery method.[110] The owner agency may require potential contractors to propose a time schedule for project completion in their bid submittal that may include interim milestones to control the pace of the project and a final completion date. The owner agency also may specify criteria for schedule restrictions in the proposal solicitation that include lane closure hours, forbidding certain types of work during specified periods of time, mandating holidays, and implementing security precautions. The contractor-proposed time schedule will then be evaluated (along with other criteria) for award. For low-bid awards, the owner agency can propose the schedule for project completion.

From the WZ RUC perspective, the direct involvement of the design-builder in the pre-construction phases helps to identify appropriate strategies for reducing work zone impacts and overall project delivery time; however, it is imperative that the responsibilities of the design-builder are defined clearly in the proposal solicitation.

NOTE

Design-build is effective when the owner agency is certain of the design scope. It is suitable for large, innovative, and more complex projects.

The advantages and disadvantages of the design-build contracting are summarized in Table 48.

[109] FHWA, Decision-Making Framework for Prefabricated Bridge Elements and Systems (PBES), Publication Number FHWA-HIF-06-030, Federal Highway Administration, May 2006.
[110] Molenaar, K. R., and A. D. Songer, "Model for Public Sector Design-Build Project Selection," Journal of Construction Engineering and Management, American Society of Civil Engineering, Vol. 24, Issue 6, 1998.

Table 48. Advantages and disadvantages of design-build project delivery.

Advantages	Disadvantages
• Shortened construction completion time • Less time impact on design errors and omissions as the design-build is in control on both design and construction details • More flexibility for contractor innovation in selecting design, materials and construction methods • Reduced change orders and claims • Inclusion of innovations and new technologies.	• Risks over the owner's inability to precisely define the project scope • Loss of owner's control over design details • Change orders are expensive • Uncertainty over life cycle performance and potential conflicts with the contractor's design.

4.2.2.9 Construction Manager/General Contractor

CMGC is a two-phase project delivery method where a construction manager, selected by an owner based on qualifications for both preconstruction and construction services of a project, will be at risk for the final cost and time of construction. As W. Strang puts it, "the construction manager is an agent of the Owner in managing the design process, but takes the role of a vendor when a total cost guarantee is given."[111]

In the first phase, the selected contractor collaborates with the owner and designer in the pre-construction phases to provide inputs particularly on constructability, budgeting, schedule, and materials ; assist in developing a complete contract package; and establish a guaranteed maximum price (GMP), delivery schedule, and construction quality when the design is nearly complete.

In the second phase, the contractor builds the project for a GMP acceptable to the owner. Upon failure to reach an acceptable price, the construction manager is entitled to payment for the pre-construction services, while the owner may put out the project as a low bid design-bid-build project in the market. Upon acceptance, the construction manager is at risk for any expenditure exceeding the GMP. Any cost savings realized in the project may be shared between the owner and the construction manager.

In the pre-construction phase, the construction manager's services may be utilized in all phases of the project, including but not limited to not limited to planning, design, third-party coordination, constructability reviews, budgeting, cost estimating, scheduling, value engineering, material selection, construction logistics plan, market surveys of construction materials and equipment, contract package development, and other services required in the contract.

The advantages and disadvantages of the CMGC are summarized in Table 49. Note that the advantages listed in this table of are basically linked to the cost, schedule, quality performance of the project, while the disadvantages are mostly related to the contract administration.

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[111] Strang, W., "The Risk in CM at-Risk," CM eJournal, Construction Management Association of America, McLean, Va., 2004.

Table 49. Advantages and disadvantages of CMGC.

Advantages	Disadvantages
• Contractor's inputs in the design decisions • Relatively higher precision cost estimates at early stages of the project • More realistic and faster delivery schedule • Early bid packages • Teaming atmosphere • Owner control over the details of the design • Identifies risks early and allocate to parties that better manage them.	• Conflict of interest between the construction manager and the designer (i.e., cost control versus conservative design to reduce design liability). • Additional owner responsibility to coordinate both design and construction phases of the contract. • Final cost unknown until the GMP is established • Inadequate training and experience.

In the context of WZ RUC, CMGC allows for the collaboration between the owner and the construction manager in developing a construction phasing and delivery schedule for the project. This approach may be advantageous in expediting project completion time and minimizing the work zone impacts on traffic and the local community, thus reducing road user costs.

In this method, at the time GMP is established, the construction manager establishes construction completion dates for final or substantial completion and any intermediate phases and milestones. The completion dates typically are established in terms of calendar days following the commencement date of the construction phase. In the event the construction manager fails to complete the project or any intermediate phases by the completion dates agreed upon, the construction manager may attract disincentives for late completion. Similarly, depending on the contract agreements, the construction manager may attract incentive bonus for early completion.

Another advantage of CMGC is the ability to incorporate the construction manager's perspective and inputs in developing MOT strategies. The construction manager either collaborates with the designer in preparing better MOT plans or improves on a prepared plan.

NOTE

CMGC allows for early participation of the contractor in the planning and design process. It is effective when the owner agency is uncertain of the design scope and is suitable for large, innovative, and more complex projects.

Though suitable for projects of all sizes and complexity, CMGC typically is used for larger, more complex projects with high road user costs. CMGC is appropriate when the owner has difficulties in identifying reasonable schedules and cost estimates for a project and when there is a need for optimizing design and improve constructability.

4.3 Selecting a Contracting Strategy to Expedite Project Completion

An owner agency decides on the contracting strategy to be used in the initiation and preliminary phase of a project. The process involves the selection of an appropriate project delivery method followed by a schedule-focused contracting strategy for early completion. The decision making process is influenced by the agency goals, project objectives, and the need to accelerate the project in particular.

In the earlier phases of the project, the owner agency typically establishes the preliminary cost estimates, a tentative time schedule, and milestones, and conducts public meetings and work zone traffic analyses to assess the impact the project will have on the public. Based on the preliminary estimates and impact assessment, the owner agency then establishes the need to accelerate the project, evaluates the project criteria for effective use of schedule-focused contracting methods, and selects an appropriate strategy for early completion. Estimates of key contract parameters, such as daily WZ RUC, I/D structure, accelerated schedule, and associated costs are refined as the design phase progresses. The process typically extends until all the pertinent design details are finalized.

Figure 14 presents a sample process proposed by Sillars (2007) for implementing schedule-focused contracting methods.[112]

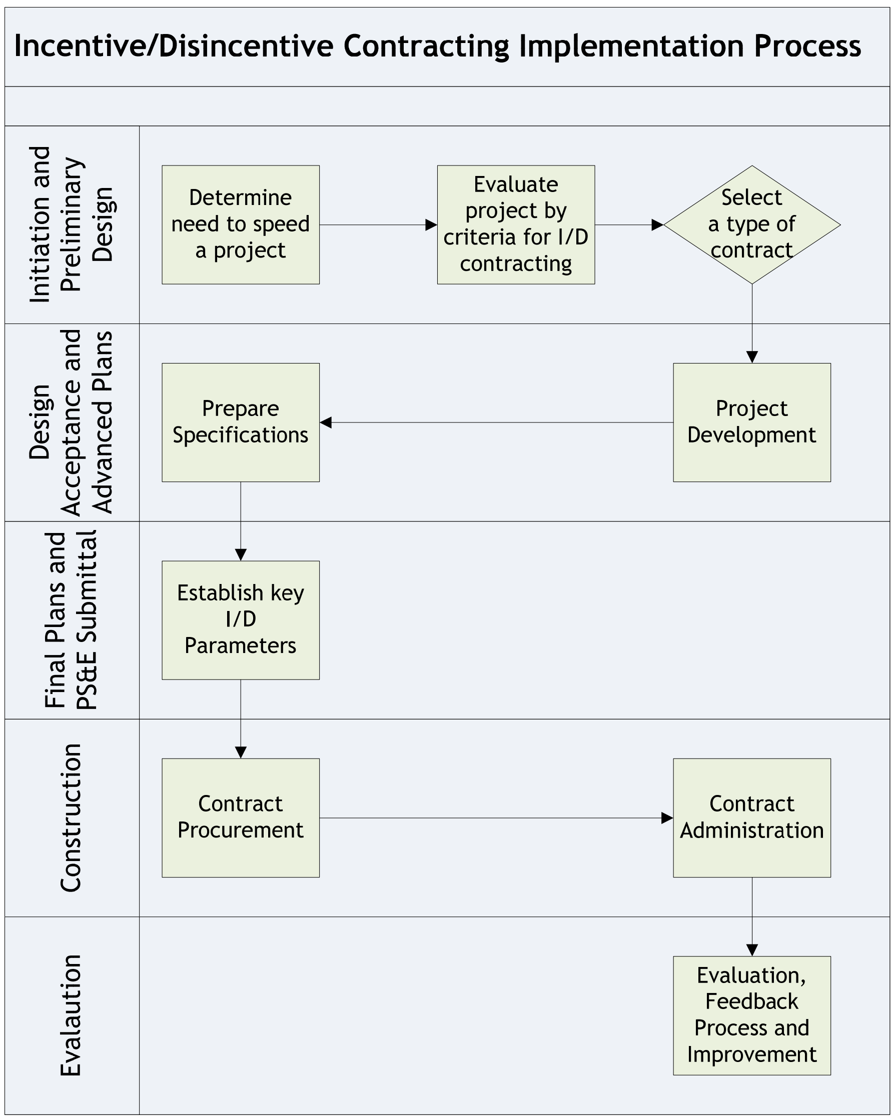


Figure 14. Sample flow chart of the I/D contracting implementation process (Sillars, 2007).

[112] Sillars, S. N. *Establishing Guidelines for Incentive/Disincentive Contracting at Oregon DOT*, Report No. FHWA-OR-RD-07-07, Oregon Department of Transportation, Salem OR, 2007.

For practitioners, the following references provide a more in-depth review of schedule-focused contracting methods:

- NCHRP Synthesis No. 379: Selection and Evaluation of Alternative Contracting Methods to Accelerate Project Completion — This report summarizes the state of practice of selecting schedule-focused contracting methods to accelerate project completion and to identify driving factors for selecting one method over another.[101]
- NCHRP Report No. 652: Time-Related Incentive and Disincentive Provisions in Highway Construction Contracts — This report provides recommendations for the effective use of time-related I/D provisions in highway construction contracts.[99]

The key steps involved in selecting a contracting strategy to expedite project completion are listed as follows:

1. Identifying the need for project acceleration
2. Selecting a project delivery method
3. Selecting a schedule-focused contracting strategy

4.3.1 Need for Project Acceleration

The first step of the process is to establish the need for using a schedule-focused contracting strategy and shortening the duration of the project. The owner agency may choose to accelerate the project completion to reduce work zone impacts and associated road user costs, in the larger interests of local community and political interests, to complete the project on or before an intended date or to close a gap in the local highway network. The impact assessment also helps in identifying the work zone needs by characterizing the travel and safety impacts on commuter and freight traffic, the economic effects on local business and inconvenience on neighborhood, and associated road user costs.

The agency can develop minimum guidelines to identify the need for project acceleration in the earlier phases of project development based on project characteristics, duration, and threshold levels of traffic delay time and road user costs. If a project meets such minimum guidelines for using schedule-focused contracting methods, the project team can further establish the potential benefits for its use.

FHWA's Technical Advisory T 5080.10 states that time-related I/D provisions are appropriate for projects identified with selective characteristics and not for routine use.[113] The advisory identifies projects with the following characteristics appropriate for its application:

- High-traffic volumes generally found in urban areas.
- Work that will complete a gap in the highway system.
- Major reconstruction or rehabilitation on an existing facility that will severely disrupt traffic.
- Major bridges out of service.

[113] Willett, T. O., Incentive/Disincentive (I/D) for Early Completion, Technical Advisory T 5080.10, Federal Highway Administration, dated February 8, 1989. http://www.fhwa.dot.gov/construction/contracts/t508010.cfm

- Significant impacts to local business and adjacent neighborhood.
- Lengthy detours.
- Significant increase in road user costs.

In addition, an agency may consider the following factors:

- Significant safety issues of workers and traffic are anticipated during construction.
- Where political and local community interests are needed to be accommodated.
- Time-sensitive projects.
- To encourage innovative construction processes.

Table 50 presents a list of questions that can help to identify the need for accelerating project completion. If the answer to several of these questions is YES, choosing a schedule-focused contracting strategy may help achieve the project goals. Guidance on selecting an appropriate contracting strategy is presented in section 4.3.2.

Table 50. Questions on identifying the need for accelerating a project schedule.

Question	Yes	Maybe	No
Is the project goal to shorten the duration of construction phase?			
Is the estimated WZ RUC high for the baseline duration?			
Is the traffic volume high enough to cause significant disruptions? Does the work zone affect the intersecting traffic?			
Is this roadway located in an urban area? Does the local traffic depend on this highway for commute?			
Does this area lack any viable detour alternative that does not adversely impact the local network?			
Are there local community and political interests to be considered?			
Does the work zone adversely impact the local business and neighborhood?			
Are the safety issues of construction workers and traffic a concern?			
Is the project time-sensitive?			
Does this project close a gap in the local highway network?			
Is the project located in tourist or environmentally sensitive areas?			

However, the effectiveness of schedule-focused strategy would be lost if the project development process fails to provide complete and well-defined set of plans, specifications, and estimate (PS&E). Schedule-focused methods can be very costly in time as well as money with change orders, design omissions and errors and conflicts, and finally, may lose its effectiveness. These strategies are not recommended for use until the following complications are resolved:

- Right-of-way not secured before the letting date or such issues hinders the sequencing and overall progress of work.
- Third-party conflicts such as permits, municipal agreements, utilities, railroad agreements, hazardous materials environmental/archaeological issues.
- Design is either incomplete; change orders or plan additions are anticipated.
- Field review does not guarantee against restrictions any unfavorable site conditions such as geotechnical and environmental issues.
- Design uncertainties or incomplete design.

- Agency-wide activities that may restrict available resources (staffing, labor, equipment, and material shortages) typically demanded by an accelerated schedule.

Therefore, the owner agency should make sure to resolve these issues before the commencement of construction schedule. The P&SE submittal should be complete before the letting date.

4.3.2 Selecting an Appropriate Schedule-Focused Alternative Strategy

This section provides guidance on selecting a particular contracting strategy for a project to achieve schedule-related objectives. This guidance is intended to support the decision making process of an owner agency and should be used in conjunction with agency goals and any applicable State laws.

4.3.2.1 Selecting a Project Delivery Method

Project Size, Scope, and Complexity

- For small, medium sized, and routine projects, the design-bid-build method will be more appropriate for project delivery. The owner agency will have knowledge, experience, and control over planning, design details, and cost of the project.
- For medium to large, innovative, and more complex projects, alternative project delivery methods (design-build and CMGC) are recommended. Early involvement of the contractor in the design or pre-construction phases will help in better coordination, planning, and sequencing.

Design Scope

- When the owner agency is less certain over the design scope of the project, CMGC will be a more pragmatic choice over design-build. Bringing the contractor into the pre-construction process helps refining the design scope through direct contractor inputs and feedback over design and costs, thereby reducing related risks. Design-build is more appropriate when the owner agency has a clearer vision of the design scope.

Innovations

- CMGC is a good choice for introducing innovations and new technologies, as the process allows collaboration and control with the contractor. CMGC encourages out-of box innovations that the contractors would not have chosen independently. With the agency's willingness to share risks and costs, CMGC makes this choice possible by involving the contractor early in the process and thereby providing more time and options to identify the appropriate strategies for risk reduction (Alder, 2007).[114] CMGC is preferable to design-build for introducing innovations, as owners sometimes have questions concerning life cycle decisions made by design-builders. Design-build is more appropriate when the owner has knowledge and confidence over the innovations.

Table 51 presents a simple matrix to select an appropriate project delivery method based on road user costs and project completion factors only.

[114] Alder, R. "UDOT Construction Manager General Contract (CMGC) Annual Report," Utah Department of Transportation Project Development Group, Engineering Services and Bridge Design Section, Salt Lake City Utah, 2007, 39pp.

Table 51. Project delivery method selection matrix.

Project size	Is project routine or innovative?	Certain over design scope?	In-house design ?	Early cost certainty?	Certain over constructability?	Suggested strategy	
Small-medium	Routine	Yes	Yes	Yes	Yes	DBB	Follow Table 52 for schedule related strategies.
Small-medium	Innovative	Yes	Yes	Yes/No	Yes/No	DBB[++]	
Medium-large	Routine	Yes	Yes	Yes	Yes	DBB/DB/CMGC	
Medium-large	Innovative	Yes	Yes	Yes	No	DBB[++]	
Medium-large	Innovative	Yes	Yes	No	Yes/No	CMGC/DB	
Medium-large	Innovative	Yes	No	Yes	Yes/No	DB	
Medium-large	Innovative	Yes	No	No	Yes/No	DB	
Medium-large	Innovative	No	Yes	Yes	Yes/No	CMGC	
Medium-large	Innovative	No	Yes	No	Yes/No	CMGC	
Medium-large	Innovative	No	No	Yes	Yes/No	CMGC	
Medium-large	Innovative	No	No	No	Yes/No	CMGC	

[++]May hire consultants or seek constructability advice from local contractors or trade associations.

NOTE

The actual selection of an appropriate project delivery method requires a comprehensive evaluation of a broader range of factors not mentioned herein. For selection of an appropriate project delivery method, practitioners are referred to the following publications:

- State DOT design-build guidelines.
- FHWA's Design-Build Web Page[115]
- AASHTO Joint Task Force on Design-Build Web Page[116]
- Construction Manager-at-Risk Contracting for Highway Projects[117]

4.3.2.2 Selecting a Schedule-Focused Contracting Strategy

Early Completion Required

- I/D will be more appropriate if the project goal is early completion. Incentives provide motivation to the contractor to complete the project early, whereas disincentives discourage schedule delays.
- Liquidated damages will be more appropriate to ensure completion on time if early completion is not a priority.

Time-Sensitive Projects

- For time-sensitive projects, A+B bidding, no-excuse incentives, and interim milestones are more appropriate. These methods can be used when the project is required to be completed by a specific date. These methods also are appropriate where early completion is preferred, such as in urban, tourist, and environmentally sensitive areas.
- When the project is not time-sensitive, lane rental can help achieve the desired level of work zone performance.

[115] http://www.fhwa.dot.gov/construction/cqit/desbuild.cfm

[116] http://designbuild.transportation.org/?siteid=63&pageid=1223

[117] Gransberg, D. and J. S. Shane, *Construction Manager-at-Risk Project Delivery for Highway Programs*, NCHRP Synthesis 402, National Cooperative Highway Research Program, Transportation Research Board, Washington DC, 2010. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_402.pdf

Project Duration

- Generally, for short-term projects, lane rental and no-excuse incentives are suggested.
- For long-term projects, A+B bidding and no-excuse incentives are preferable.

Intermediate or Multiple Phases

- If the completion of one or more intermediate phases of a project is critical, A+B bidding, no-excuse incentives, and interim milestones are recommended. For non-critical phases, lane rental can help achieve the desired level of work zone performance.
- If the goal is to control the pace of a large, multi-phase project, A+B bidding, no-excuse incentives, and interim milestones will be more appropriate.

Detours are Long, Impractical, or Unavailable

- Use of lane rental is recommended when detour alternatives are not feasible and full closure is not required. To be effective, lane rental requires at least one lane should be available for through traffic at all times. Accelerated techniques can be considered for use on case-by-case basis when cost-effective.
- When detour alternatives are not feasible and full closure is inevitable, accelerated construction techniques will be effective. Installation of prefabricated elements and systems requires fewer hours of lane closure and can be scheduled during non-peak hours, nighttime, or weekends, in one or more stages.

Urban Commuter Traffic

- Use of lane rental during non-peak hours is recommended for urban commuter traffic when full closure is not required. Accelerated techniques can be considered for use on case-by-case basis when cost-effective.
- When full closure is inevitable, accelerated construction techniques will be effective. Use of accelerated techniques is recommended in emergency projects.

Owner's Confidence on Estimated Duration

- When the owner agency is not confident about the estimated project duration, A+B bidding allows the market to determine the number of days of completion. It also provides flexibility to reject bids with unreasonably high or unjustified completion time.
- When the owner agency is confident about the estimated project duration, both A+B bidding and no-excuse incentives can be used.

Table 52 provides a matrix for selecting an appropriate contracting strategy based on the decision rules discussed above.

NOTE

Schedule-focused contracting strategies typically are used in traditional design-bid-build projects. When design-build and CMGC delivery methods are used, the time-related provisions of schedule-focused contracting methods, such as the number of calendar days for completion of A+B bidding, lane closure restrictions of lane rental method, or interim milestones can be incorporated in the contract provisions of a project utilizing design-build or CMGC methods.

Table 52. Schedule-focused contracting strategy selection matrix.

Baseline Project duration		Time sensitivity		Complete Early		Intermediate Phases		Detours impractical/long, Urban commuter traffic			Owner's confidence on estimated duration		Suggested Strategy
Short	Long	Yes	No	Yes	No	Critical	Not critical	Yes - Full closure required	Yes-full closure not required	No	High	Low	
✓		✓		✓			✓	✓			✓		(A+B)/NEB/(I/D) + ACT
✓		✓		✓			✓	✓				✓	(A+B) / (I/D) +ACT
✓		✓		✓			✓		✓		✓		(A+B)/NEB/(I/D) + LR/ACT
✓		✓		✓			✓		✓			✓	(A+B) / (I/D) +LR/ACT
✓		✓		✓			✓			✓	✓		(A+B)/NEB/(I/D) + LR
✓		✓		✓			✓			✓		✓	(A+B) / (I/D) +LR
✓			✓	✓			✓	✓			✓		(A+B)/NEB + (I/D)
✓			✓	✓			✓	✓				✓	(A+B) + (I/D)
✓			✓	✓			✓		✓		✓		(A+B)/NEB/(I/D) + LR
✓			✓	✓			✓		✓			✓	(A+B) / (I/D) +LR
✓			✓	✓			✓			✓	✓		(A+B)/NEB/(I/D) + LR
✓			✓	✓			✓			✓		✓	(A+B) / (I/D) +LR
✓			✓		✓		✓	✓			✓		(L/D)
✓			✓		✓		✓	✓				✓	(L/D)
✓			✓		✓		✓		✓		✓		LR + (L/D)
✓			✓		✓		✓		✓			✓	LR + (L/D)
✓			✓		✓		✓			✓	✓		(L/D)
✓			✓		✓		✓			✓		✓	(L/D)
	✓	✓		✓		✓		✓			✓		(A+B)/NEB/IMS/(I/D) + ACT
	✓	✓		✓		✓		✓				✓	(A+B)/IMS/(I/D) + ACT
	✓	✓		✓		✓			✓		✓		(A+B)/NEB/IMS /(I/D) + LR
	✓	✓		✓		✓			✓			✓	(A+B)/IMS/(I/D) + LR
	✓	✓		✓		✓				✓	✓		(A+B)/NEB/IMS /(I/D)
	✓	✓		✓		✓				✓		✓	(A+B)/IMS/(I/D)

Notes:
LR = lane rental; L/D = liquidated damages; A+B = cost plus time bidding with incentives and disincentives;
NEB = no-excuse bonus (or no-excuse incentives); I/D = incentives and disincentives for early completion;
ACT = accelerated construction techniques; IMS = interim milestones (or interim completion dates).

Table 52. Schedule-focused contracting strategy selection matrix.

Baseline Project duration		Time sensitivity		Complete Early		Intermediate Phases		Detours impractical/long, Urban commuter traffic			Owner's confidence on estimated duration		Suggested Strategy
Short	Long	Yes	No	Yes	No	Critical	Not critical	Yes - Full closure required	Yes-full closure not required	No	High	Low	
	✓	✓		✓			✓	✓			✓		(A+B)/NEB/(I/D) + ACT
	✓	✓		✓			✓	✓				✓	(A+B)/(I/D) + ACT
	✓	✓		✓			✓		✓		✓		(A+B)/NEB/(I/D) + LR/ACT
	✓	✓		✓			✓		✓			✓	(A+B)/(I/D) + LR/ACT
	✓	✓		✓			✓			✓	✓		(A+B)/NEB/(I/D)
	✓	✓		✓			✓			✓		✓	(A+B)/(I/D)
	✓		✓	✓		✓		✓			✓		(A+B)/NEB /IMS/(I/D) + ACT
	✓		✓	✓		✓		✓				✓	(A+B) /IMS/(I/D) + ACT
	✓		✓	✓		✓			✓		✓		(A+B)/NEB /IMS/(I/D) + LR
	✓		✓	✓		✓			✓			✓	(A+B) /IMS/(I/D) + LR
	✓		✓	✓		✓				✓	✓		(A+B)/NEB /IMS/(I/D)
	✓		✓	✓		✓				✓		✓	(A+B) /IMS/(I/D)
	✓		✓	✓			✓	✓			✓		(A+B)/NEB /(I/D) + ACT
	✓		✓	✓			✓	✓				✓	(A+B)/(I/D) + ACT
	✓		✓	✓			✓		✓		✓		(A+B)/NEB/(I/D) + LR/ACT
	✓		✓	✓			✓		✓			✓	(A+B)/(I/D) + LR/ACT
	✓		✓	✓			✓			✓	✓		(A+B)/NEB/(I/D)
	✓		✓	✓			✓			✓		✓	(A+B)/(I/D)
	✓		✓		✓		✓	✓			✓		(A+B)/NEB + (L/D) + ACT
	✓		✓		✓		✓	✓				✓	(A+B) + (L/D) + ACT
	✓		✓		✓		✓		✓		✓		(A+B)/NEB + (L/D) + LR
	✓		✓		✓		✓		✓			✓	(A+B) + (L/D) + LR
	✓		✓		✓		✓			✓	✓		(A+B)/NEB + (L/D)
	✓		✓		✓		✓			✓		✓	(A+B) + (L/D)

Example 4.2: HfL demonstration project, "Improvements to the 24th Street-I-29/80 Interchange in Council Bluffs"

This example illustrates the selection for appropriate schedule-focused strategy for the 24PthP Street Intersection project in Iowa, an HfL demonstration project, using Tables 52 and 53.

Project Overview:
The Iowa DOT, Nebraska Department of Roads, and FHWA, in coordination with the City of Council Bluffs and the Metropolitan Area Planning Agency, proposed improvements to the Council Bluffs Interstate System (CBIS) around Council Bluffs, IA, with improvements extending across the Missouri River on I-80 into Omaha, NE. The proposed improvements were intended to upgrade mobility through the I-80, I-29, and I-480 corridors. The 24th Street interchange reconstruction was selected as a part of the proposed improvements to the CBIS. The primary component of this project was to replace the existing four-span concrete bridge with a wider and longer two-span steel girder bridge. The owner, Iowa DOT, has used partial-depth panels for low-volume bridges, but full-depth panels are still a new concept for high-volume corridors.

24th Street carried AADT of 12,400 vehicles per day (vpd) in 2004 with 14 percent truck volume, while I-29/80 carried an AADT was 81,900 vpd in 2004 with 11 percent truck volume. The 24th Street interchange provides vital access to major businesses and regional attractions in the area that includes a large outdoor retailer, a convention and event center, and several casinos, hotels, and semitruck service centers. Access to these businesses and attractions was a major concern when access from the interstate to 24th Street was restricted. Both the City and the State made a commitment to provide access to these businesses during construction.

Using a conventional cast-in-place construction for bridge replacement would have extended the construction duration over 2 seasons (16 months), and thus resulting in negative mobility and safety impacts on the 24th Street and I-29/80 traffic, and economic implications on local businesses. Therefore, the owner examined the possibility of using accelerated construction methods to reduce construction duration and minimize work zone impacts. The owner convened a constructability review meeting with local contractors to discuss the feasibility of accelerated methods for the project. The contractors were found to favor of a staged construction for one full construction season. Completely closing the bridge to 24th Street traffic and reconstructing the entire bridge would have been the least expensive option in terms of construction costs, but it would have been unacceptable to the surrounding businesses that rely heavily on the interchange. The MOT alternative analysis indicated that it was possible to maintain at least one lane of traffic in each direction and left-turn lanes at all times on 24th Street with the use of phased construction.

Strategy Selection:
Using the information presented above, the 24th Street Intersection project was evaluated to identify appropriate contracting strategies for schedule acceleration and project delivery. The selection factors and evaluation results are presented below:

<u>Project Delivery Method</u>:

- Project size = Medium to large.
- Is project routine or innovative? = Innovative.
- Certain over design scope? = Yes.
- In-house design? = Information unavailable. Assumed to be Yes.
- Early cost certainty? = Information unavailable. Assumed to be Yes.
- Certain over constructability? = Partially No. Partial-depth panels for low-volume bridges were used in the past, but full-depth panels in high-volume corridors were for Iowa DOT.

Suggested project delivery strategy (from Table 51) = Design-bid-build. May hire consultants or seek constructability advice from local contractors and trade associations.

Schedule-Focused Contracting Strategy:

- Baseline project duration = Long.
- Time sensitivity? = No.
- Complete early? = Yes.
- Intermediate phases? = No.
- Detours impractical? = No.
- Urban commuter traffic = Yes
- Full closure required? = No.
- Owners confidence on estimated duration? = Low.

Suggested schedule-focused contracting strategy (from Table 52) = A+B bidding with incentive and disincentive, lane rental and/or accelerated construction techniques.

Actual contracting strategies used in the 24th Street Intersection project were:

- Design-bid-build.
- Convened constructability review from local contractors.
- A+B bidding with I/D.
- Accelerated construction techniques.

4.4 Establish Key I/D Parameters

Upon the selection of an appropriate contracting strategy for the project, key cost and schedule parameters must be determined in the design stage. These parameters are paramount for the successful execution of the selected strategy and include:

- Daily WZ RUC.
- I/D amount.
- Baseline and accelerated schedule.
- Costs of acceleration.

Figure 17 presents a theoretical construct to illustrate the relationships among these key parameters. Combining the concepts of "time-cost tradeoff" and "time is money," this model is based on the following rationale:

- Project acceleration requires additional labor, materials, and equipment and therefore costs more money.
- Delaying the project beyond the normal completion time results in increased costs due to inefficient allocation and utilization of resources.
- The longer construction takes, the greater the road user costs and agency overhead costs will be.

Proposed by McFarland et al. (1994), this model can be used to determine the optimum construction completion time at which the direct agency costs and road user costs are balanced.[118] This model presents at least three cost curves: construction costs, road user

[118] McFarland, W. F., R.J. Kabat, and R. A. Krammes, *Comparison of Contracting Strategies for Reducing Project Completion Time*, Report No. FHWA/TX-94/1310-F, Texas Department of Transportation, Austin, TX, 1994.

costs and construction engineering costs (combined for the presentation purposes), and total project costs.

The construction cost curve represents the contractor's cost for completing the project (assumed to include a normal profit). For every construction project, the construction cost is the lowest at the baseline duration (point C_L). Any deviation from this baseline schedule will result in increased construction costs. Expediting completion requires additional contractor effort through tighter schedules and overtime, additional resource mobilization and deployment and/or innovation, and incurs additional costs to the contractor. Extending the completion beyond the baseline duration results in penalty and misallocation and underutilization of resources, and hence incurs additional costs to the contractor. In other words, the construction costs increase with each additional day saved or delayed from the standard schedule.

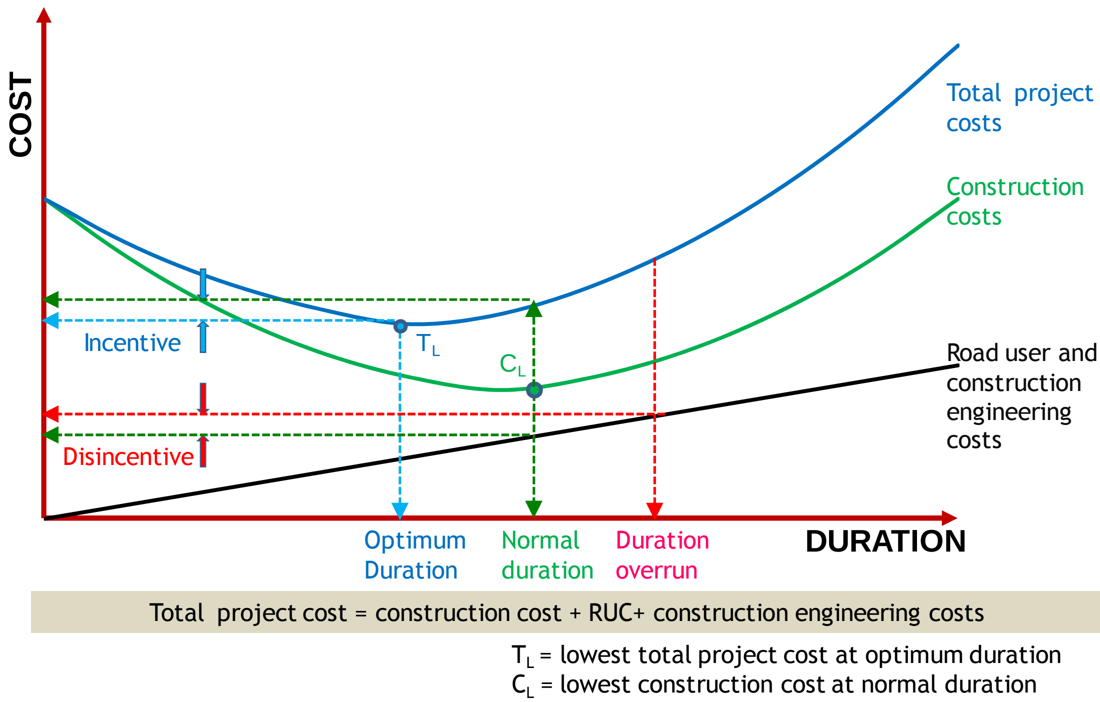


Figure 15. Relationship between project cost and duration.

On the other hand, the agency's construction oversight cost and WZ RUC increase linearly with project duration. When these indirect costs are combined with the construction costs, the resulting cost curve shifts to the left. In other words, the combined costs are lowest at an optimal duration (point T_L) shorter than the normal expected duration. Any further acceleration will no longer be justifiable, as the difference between benefits and costs would be negative.

Any difference between the total costs and the construction costs will be used in calculating incentives and disincentives. While the disincentives will be based on the differential road user and construction engineering costs, the incentives should be lower than the disincentives, as the incentive calculation will take the additional amount paid by the agency toward the contractor's costs of acceleration. However, for practical purposes, both incentives and disincentives are generally kept the same.

These curves can be used as a basis for establishing the key parameters of schedule-focused contracting strategies. However, it should be noted that the cost curves are merely the theoretical constructs of “real world” scenarios. There are several key assumptions behind the development of these curves:

- The owner agency has adequate projects (for sample size) and detailed cost data for developing statistically valid models.
- The agency costs, road user costs, and duration data are estimated accurately.
- There is effective competition among contractors with no collusion.
- The cost curves are deterministic, as opposed to a stochastic model.

Practitioners can use one of the following methods in developing construction cost curves:

- Generic cost vs. duration models can be developed using regression analysis of multiple project data utilizing alternative contracting projects. Such models generally are less sensitive to project specifics and may provide less accurate cost estimates. Therefore, these models should be limited to cursory estimations in the early stages for project delivery. To cite an example, Shr et al. (2000) [119] developed polynomial cost models for Florida DOT to estimate project acceleration costs. Cost and duration data from 15 construction projects were used in developing this model. Schedule-focused (alternative) contracting projects were used on all of these projects that included I/D, no-excuse bonus, and A+B bidding.

  The polynomial cost model developed to estimate the construction costs is presented as follows:

  $$CC = 1.0059 * C_O - 0.1048C_O\left(\frac{D-0.8875*D_O}{D_O}\right) + 0.4657C_O\left(\frac{D-0.8875*D_O}{D_O}\right)^2 \text{(Eq. 1)}$$

  where,
  CC= actual project cost
  C_o = contractor bid price
  D = actual days used by the contractor
  D_o = contract time specified in the bid

- More accurate, project-specific cost vs. duration models can be developed using detailed time-cost tradeoff analysis. These models can be developed for project-level applications by computing cost and duration estimates for activities (interchangeably used with work items) on the critical path schedule at various levels of acceleration (by applying different production rates). Developing these models can be cumbersome and computation-intensive, as real-world projects involve hundreds of activities. Furthermore, detailed cost and productivity data are required for each activity.

[119] Shr, J. F., B. P.Thompson, J. S. Russell, B. Ran, and H. P. Tserng, “Determining Minimum Contract Time for Highway Projects,” Transportation Research Record No. 1742, Journal of the Transportation Research Board, Transportation Research Board, Washington, D.C., 2000.

Example 4.3: Illustration of cost vs. duration relationship

The following example illustrates the relationship between construction costs, road user costs, and duration for a hypothetical highway construction project. Assume that the contract time specified in the bid is same as the normal construction time at which the contractor's construction costs would be lowest. For sake of illustration, the construction cost model developed by Shr et al. (2000) was used in this example.

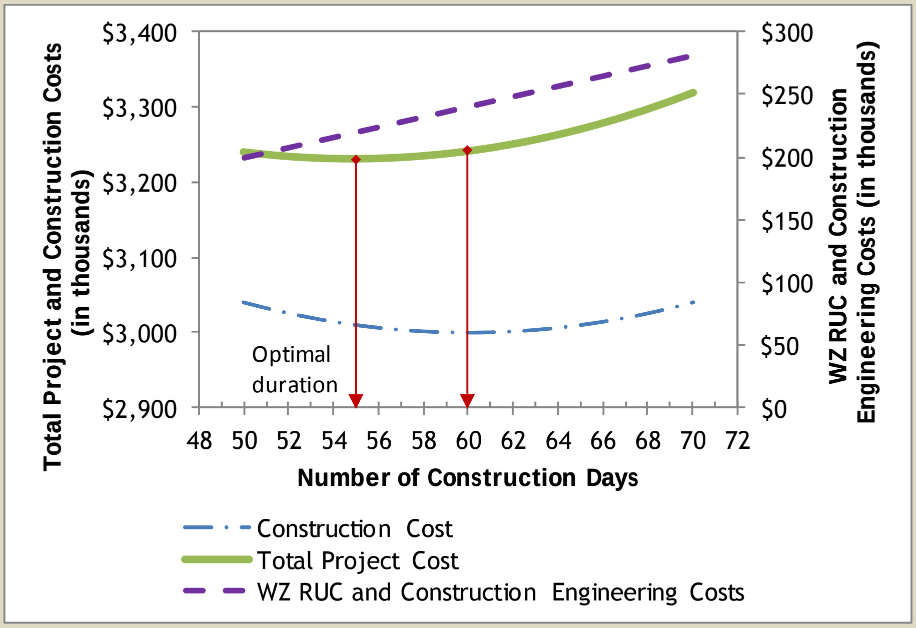
1. Using the construction cost model presented in Eq. 1, develop cost vs. duration curve similar to the one shown in Figure 15. Assume that the actual duration used by contractor would vary from the bid duration by +/- 10 days. Identify the optimum duration for project acceleration at which the total project cost will be minimum. The inputs are as follows:

- Road user costs (RUC) = $3,500/day
- Agency's construction engineering costs (AGCEC) = $500/day
- Contract time specified in the bid (D_o) = 60 days
- Contractor's bid price (C_o) = $3,000,000

The following table presents the information required for constructing the curve:
- Actual duration (D) = D_o +/- 10 days
- Construction cost CC = use Eq. 1 (proposed by Shr et al., 2000)
- RUC+CC =(Daily WZ RUC + AGCEC) * D
- Total project costs (TCP) = CC + (Daily WZ RUC + AGCEC) * D (i.e. Columns 2+3)

Actual Duration D (days)	Construction Cost CC ($, 000)	RUC+AGCEC ($,000)	Total Project Cost ($,000)	
50	3038.8	200.0	3238.8	
51	3031.5	204.0	3235.5	
52	3024.9	208.0	3232.9	
53	3019.0	212.0	3231.0	
54	3014.0	216.0	3230.0	
55	3009.7	220.0	3229.7	←Optimum duration
56	3006.2	224.0	3230.2	
57	3003.5	228.0	3231.5	
58	3001.6	232.0	3233.6	
59	3000.4	236.0	3236.4	
60	3000.0	240.0	3240.0	←Normal duration
61	3000.4	244.0	3244.4	
62	3001.6	248.0	3249.6	
63	3003.5	252.0	3255.5	
64	3006.2	256.0	3262.2	
65	3009.7	260.0	3269.7	
66	3014.0	264.0	3278.0	
67	3019.0	268.0	3287.0	
68	3024.8	272.0	3296.8	
69	3031.4	276.0	3307.4	
70	3038.8	280.0	3318.8	

The cost vs. duration curve developed using the information presented in the above table is shown below:



The optimum number of days for project acceleration is 55 days.

4.4.1 Establishing I/D Amount

Each schedule-focused contracting strategy discussed herein is based on the concept that the owner agency would reimburse a portion of the delay costs to the contractor for shortening the construction delivery time, while the contractor is penalized for delaying the project delivery beyond the allowable time.[120] To accomplish the objectives of shorter delivery time, the incentive amount must be sufficient to motivate the contractor to accelerate the project.

If the acceleration costs are equal to or greater than the incentive amount, then there is no real incentive to accelerate production, and the use of I/D provisions will not produce the intended results. If the incentive amount exceeds the costs of delay, the agency cannot justify the use of incentives based on road user cost savings.

The contractor's costs of acceleration (CA) and road user costs form the lower and upper limits for the incentive/disincentive amount. Therefore, a balance must be struck between the two bounds in determining an appropriate incentive/disincentive amount for the project.[121,122] The following equation illustrates the relationship among the I/D amount, WZ RUC, and CA:

$$CA \leq I/D \leq WZ\ RUC$$

[120] Herbsman, Z. J., W. T. Chen, and W. C. Epstein, "Time is Money: Innovative Contracting Methods in Highway Construction," *Journal of Construction Engineering and Management*, American Society of Civil Engineering, Vol. 121, No. 3, 1995.
[121] Jaraiedi,M., R. W. Plummer, and M. S. Aber, "Incentive/Disincentive Guidelines for Highway Construction Contracts", Journal of Construction Engineering and Management, American Society of Civil Engineering, Vol.121, No. 1, 1995.
[122] Sillars, D. N., and J. Riedl, "Framework Model for Determining Incentive and Disincentive Amounts," Transportation Research Record No. 2040, Journal of the Transportation Research Board, Transportation Research Board, Washington, D.C., 2007.

While most owner agencies can estimate daily road user costs, there is no standardized approach for determining CA. Furthermore, this information generally is not available to agencies. However, individual highway contractors regularly determine this value for their firms[112]. In such cases, the owner agencies may use a discount factor (DF) to convert WZ RUC to I/D values as illustrated as follows: [123,124]

I/D = DF * WZ RUC

In either case, the maximum incentive and disincentive amounts should follow the guidelines of the FHWA's Technical Advisory T 5080.10.[113] The advisory stipulates the maximum incentive payment at 5 percent of the total contract amount, while no cap should be placed on the maximum disincentive amount. Generally, the incentive daily rate should equal the disincentive daily rate. If different rates are selected, the incentive daily rate should not exceed the disincentive daily rate.

4.4.2 Establishing Daily WZ RUC

At the end of the design stage (i.e., 90 percent design), the daily WZ RUC estimates should be finalized for use in the bidding documents. At this stage, the agency should have finalized the MOT strategy that will be implemented in the construction phase.

Example 4.4: Computing incentives

As a continuation of Example 4.3, assume that the contractor took 58 days to complete the work (2 days earlier than the contract time specified in the bid). Calculate the incentive amount paid the contractor. Assume that the agency paid 40 percent of the total savings to the contractor.

Contractor's bid price (C) = $3,000,000 (from Example 4.3)
Contract time specified in the bid (D) = 60 days
Actual days used = 58 days

Step 1. Determine the contractor's CA.
Actual construction cost (for 58 days) = $3,001,600 (from Example 4.3)
Contractor's CA = $1,600

Step 2. Calculate the agency savings through WZ RUC and AGCEC.
Bid WZ RUC+AGCEC (for 60 days) = $240,000 (from Example 4.3)
Actual WZ RUC+AGCEC (for 58 days) = $232,000 (from Example 4.3)
Savings through WZ RUC and AGCEC = $8,000

Step 3.Compute the I/D paid by the agency to the contractor.
Total savings = $8,000
Discount factor = 40 %
Incentives paid to the contractor = 40% of $8,000 = $3,200

[123] Pyeon, J. H., and E. B. Lee, CA4PRS Application for Determination of Incentive/Disincentive Dollar Amount, Presented at the CA4PRS Peer Exchange Workshop, St. Louis, MO, 2010.
[124] NJDOT, Road User Cost Manual, New Jersey Department of Transportation, Trenton, NJ, 2001. http://www.state.nj.us/transportation/eng/documents/RUCM/pdf/RUCManual.pdf

4.4.3 Establishing Baseline and Accelerated Schedule

The owner agency should establish a final baseline and accelerated schedule at the end of the design stage. FHWA Technical Advisory TA 5080.15[125] provides procedures for determining contract time, baseline or accelerated, for construction projects. The use of calendar days or completion date is recommended, as it has proven to be most effective in controlling contract times.

The baseline schedule typically is developed using standard production rates, which in turn are based on the agency's historical productivity rates of an average contractor working 5 days a week, 8 hours a day. The accelerated schedule can be developed by compressing the baseline schedule using the performance of a good typical contractor working extended shifts with extra workers for 6 or 7 days a week. However, such extended periods of work will result in declining productivity (Mubarak, 2010).[126]

Several highway agencies use the CPM[127] to determine and control project scheduling. The prerequisite for using CPM or other techniques to analyze project schedules is to create a work breakdown structure (WBS).[128] The WBS activities are then mapped to determine the duration of the critical path, which is same as the minimum time required to complete the entire project.

The accelerated project schedule can be established first by identifying the WBS activities on the critical path and then exploring the feasibility of shortening the duration of those activities. As a rule of thumb, the work item with the least acceleration cost is selected first. For example, the baseline schedule may assume that an activity C cannot start until activity B is complete. Reviewing these finish-to-start relationships can help to identify if activity C can be started before activity B is complete.

Another common approach is to shorten the activity duration by achieving higher production rates through efforts such as extended work hours, multiple crews, additional equipment accelerated construction techniques etc. The production rate required to achieve the desired level of acceleration is ascertained. For example, if the baseline duration of an activity is 3 calendar weeks (15 working days), it takes 120 hours to complete that activity. With the same crew size and assuming no productivity loss, extending the work shifts to 10-hr, 6-day weeks means the same activity can be completed in 2 calendar weeks (10 working days).

The level of acceleration that can be achieved depends on the number of critical work items selected for acceleration and the production rates.[129] This iterative process is continued until a satisfactory level is achieved. Some examples of different productivity rates include:

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[125] FHWA Guide for Construction Contract Time Determination Procedures, Technical Advisory TA 5080.15, Office of Program Administration, Federal Highway Administration, Washington, DC, 2002. http://www.fhwa.dot.gov/construction/contracts/t508015.cfm

[126] Mubarak, S. Construction Project Scheduling and Control, Second Edition, John Wiley & Sons, Inc., 2010.

[127] More detailed information of CPM scheduling can be found in text books on construction project scheduling and control.

[128] The work breakdown structure is defined as the decomposition of the total project work into discrete work items or activities in a way that helps to accomplish the work in an organized and detailed manner.

[129] To compute the accelerated duration of critical work items, refer to standard text books on construction project scheduling and control.

- 8-hr day, 5-day week with standard crew size.
- 10-hr day, 5-day week with standard crew size.
- 8-hr day, 5-day week with increased crew size.
- 10-hr day, 5-day week with standard crew size.
- 10-hr day, 7-day week with increased crew size.

For more guidance on establishing accelerated project schedules, refer to FHWA Technical Advisory TA 5080.15, agency-specific documents, and other sources such as textbooks and training materials on project scheduling.

4.4.4 Establishing Contractor's Costs of Acceleration

Achieving higher production rate often carries a cost premium; higher the production rate, shorter the activity duration, greater are the costs incurred for additional resources or innovative processes. Typically the production rate required for the desired level of acceleration is not finalized unless it is cost-feasible. Often trade-offs are to be made by the owner agency to balance between the level of acceleration and the corresponding costs. Furthermore, if the incentive plans are not adequate enough to cover the additional costs, the contractor will have no real incentive to accelerate the project. Hence there is a need to establish the costs of acceleration for determine the required level of acceleration as well as the lower bound of the incentives. This section provides some insights in computing the additional costs associated with the schedule acceleration.

NOTE

Direct costs typically increase non-linearly with the level and duration of project acceleration due to use of expensive materials and process methods, extended work hours, and related productivity effects, while indirect costs increase linearly with the same. The net increase in acceleration costs is non-linear.

Owner agencies are well equipped to estimate the construction costs for a normal schedule within an acceptable level of tolerance. Most highway agencies develop cost estimates for a project using unit cost data extracted from historical bids with appropriate adjustments for project characteristics, market conditions, and prevailing prices. Though less frequent, some agencies use production rates and cost associated with equipment, labor, materials, and overhead (i.e., cost-based estimation[130]) in developing cost estimates for a project.

While historical cost data may be adequate for developing project cost estimates at standard production rates, these data may not represent the conditions typically encountered in schedule acceleration, such as the change in construction techniques, crew size and productivity, daily and weekly working patterns, and overtime policy. If an agency has historical cost data for projects constructed under schedule acceleration, the agency can develop parametric models using statistical regression to develop preliminary cost estimates for use in early stages of project delivery only.

On the other hand, the owner agencies can use the cost-based estimation method to estimate the contractor's costs of schedule acceleration. This method allows the agencies to develop

[130] Cost-Based Estimates contain six basic elements: Material, Equipment, Labor, Time, Overhead and Profit. Each item of work on a project can be broken up into tasks that it takes to complete the item of work. Each of these tasks contains the six basic elements that result in the cost for the project.

more detailed and accurate cost estimates using the accelerated production rates and individual cost components. It also allows the agencies to take into consideration the project-specific characteristics such as type and complexity, geographical location, market factors, and volatility of material prices.[131]

> **NOTE**
>
> Anderson et al. (2008)[131] conducted an online survey to identify how State highway agencies develop unit prices for construction and maintenance projects. Out of the 38 respondent DOTs, 32 states use historical bid-based estimation and 10 states use cost-based estimation as their primary estimation technique.

Under this method, the costs of activities defined in the project's WBS are broken down into the following elements:

- Direct costs—these costs are attributed directly to the production activities of a project. The computation of direct costs takes into account the quantity of a WBS activity, its production rates and unit costs for the following sub-elements:
    - Labor – includes mobilization, hourly wages for additional resources and overtime wages for extended shifts.
    - Equipment – includes mobilization and rental costs of equipment.
    - Materials – includes additional costs associated with early delivery of materials.
    - Subcontractors – Includes the subcontractor's costs for materials, labor, equipment, profit and overhead.

  Some of the common sources of direct unit cost data are presented in Table 53.
- Indirect costs— these are overhead expenses related to a specific project but not directly linked to any specific work item. They include:
    - Mobilization and demobilization.
    - Staffing for project management and supervision.
    - Office trailers and vehicles assigned to project team.
    - Lighting during night work and other indirect expenses.
    - Insurance and taxes.

  Typically the percentage of overhead can range from 7 to 10 percent of volume of work for larger contractors to over 15 percent for smaller contractors (AASHTO, 2009).[132]
- General overhead[133]— these are company level general and administrative overhead expenses incurred by the contractor in support of the overall construction program. These costs are usually shared by all projects in proportion to their cost and duration. Examples include:
    - Office maintenance (e.g., rent, utilities).
    - Office personnel.

[131] Anderson, S., I. Damnjanovic, A. Nejat, and S. Ramesh, *Synthesis on Construction Unit Cost Development: Technical Report*, Report No. FHWA/TX-09/0-6023-1, Texas Department of Transportation, Austin, Texas, 2008.

[132] AASHTO, *A Practical Guide to Estimating,* Prepared by AASHTO Technical Committee on Cost Estimating, American Association of State Highway and Transportation Officials, Washington, DC, 2009.

[133] For the purpose of taxonomy, the general overhead costs are sometimes listed either under the indirect costs category or the markup costs category. Therefore, to avoid any confusion, the general overhead costs are defined herein as a separate category. Nevertheless, the general overhead costs should be included in the cost estimations.

- Office equipment and vehicles.
- Office services (e.g., lawyers and accountants).

Table 53. Common sources of unit cost data.

Direct Cost Components	Common Data Sources
Material costs	Quotes from supplies, cost information for in-stock materials
Labor rates	State Department of Labor
Equipment costs	Bluebook equipment rental
Production rates	Agency experience, RS Means,[134] Site Manager (Trns*port)[135]

- Markup costs— these include the project contingency costs as well as the contractor profit. Adjusting the cost estimates for market condition and contractor's markup costs is highly subjective and requires engineering judgment.
  - Contingency costs— these are an additional sum of money allocated for the unknown and uncertain events that are most likely occur during the life of the project such as scope changes, scope increase, high-risk elements, and unforeseen site conditions; they are directly proportional to the risk taken in the project. The contingency costs typically are 5 to 10 percent of the total project costs at the PS&E stage of the project.
  - Profit margin—The contractor's profit margin typically includes 3 to 10 percent of the total project costs though it is likely to be outside this range (AASHTO, 2009). The profit margins on construction projects are highly variable and are often unknown to an agency. However, the profit margins marked by the contractor are likely to vary based on the project size and complexity, size of the contracting company, market condition and the total project costs. In proposing a I/D framework for Oregon DOT, Sillars (2007) has proposed a generic formula[136] to estimate the contractor's profit margin and is presented as follows:

$$P = \frac{f}{\log C^m}$$

Where,
P = forecasted profit at the time of bid
C = estimated total project cost
f = project type (see Table 54)
m = market condition (see Table 54)

Table 54. Empirical factors for estimating profit margin.

Project Type	f	Market Condition	m
Roadway	1.0	Busy	1.40
Interchange	1.1	Normal	1.50
Bridge	1.25	Slow	1.60
Complex	1.35		

[134] Reed Construction Data, http://rsmeans.reedconstructiondata.com/.
[135] AASHTOWare®, http://www.aashtoware.org/Pages/Trnsport.aspx
[136] Sillars (2007) has adopted the general form of the formula proposed by Carr and Beyor (2004) to estimate the professional compensation fees for consultants on construction projects. Refer to: Carr, P. G., and P. S. Beyor, "Design Fees, the State of the Profession, and a Time for Corrective Action," Journal of Management in Engineering, American Society of Civil Engineering, Vol. 21, No. 3, July 1, 2005.

Detailed information typically is required for cost-based estimation. Such level of detail may not be available to some owner agencies, and not likely in the preliminary stages of the design process. In such situations, owner agencies can apply project knowledge and engineering judgment, through common tools such as parametric estimating, to estimate the percentage increase in each of the cost elements aggregated at a project level (Sillars, 2007), until detailed analysis can be done.

NOTE

Minnesota DOT uses the 80/20 rule (or the Pareto principle). According to this rule, 20 percent of project work items contribute to 80 percent of the total estimated cost. DOT estimators use cost-based estimating for major items (i.e., 80 percent cost items), while the minor items are estimated using arithmetic averages of historical bid data.

The generalized proportions of direct, indirect, and markup costs, as a percentage of total project costs, are likely to vary from project to project and from one geographic location to another; however, their statistical averages based on the project type generally are robust enough for preliminary estimations. Sillars (2007) presented the generalized percentages of cost elements developed by Oregon DOT using historical costs and breakdown presented in trade guides such as RS Means and Trns*port (see Table 55).

Table 55. Typical cost breakdown by project type (Sillars, 2007).

Cost Category	Project Type			
	Roadway	Interchange	Bridge	Complex
Direct cost	81%	78%	79%	77%
Labor	25%	30%	30%	33%
Materials	45%	35%	30%	37%
Equipment	30%	35%	40%	30%
Subcontract	0%	0%	0%	0%
Indirect cost	6%	9%	8%	9%
Supervision	2%	3%	2%	4%
Time-related facilities	1%	1%	1%	1%
Non-time-related	1%	1%	1%	1%
Mobilization/demobilization facilities	3%	5%	5%	5%
Insurance and taxes	1%	1%	1%	1%
Markup	12%	13%	14%	14%
Risk	3%	5%	5%	6%
Home Office G&A	8%	8%	8%	8%
Profit (Calculated separately)				

The acceleration costs at a given production rate can be calculated by determining the direct costs for equipment, labor, and materials required for maintaining that production rate, and then adjusting the direct costs for overhead and markup costs. The acceleration costs are calculated typically for the activities on the critical duration path.

4.4.5 Establishing Time-Cost Tradeoff Point

The level of schedule acceleration depends on the level to which the contractor deploys additional resources, multiple crew shifts, overtime work, and supervision. The higher the level of acceleration, the shorter the project duration and the higher the acceleration costs.

Figure 16 presents the relationship among the acceleration costs, time savings, and the level of acceleration.[99]

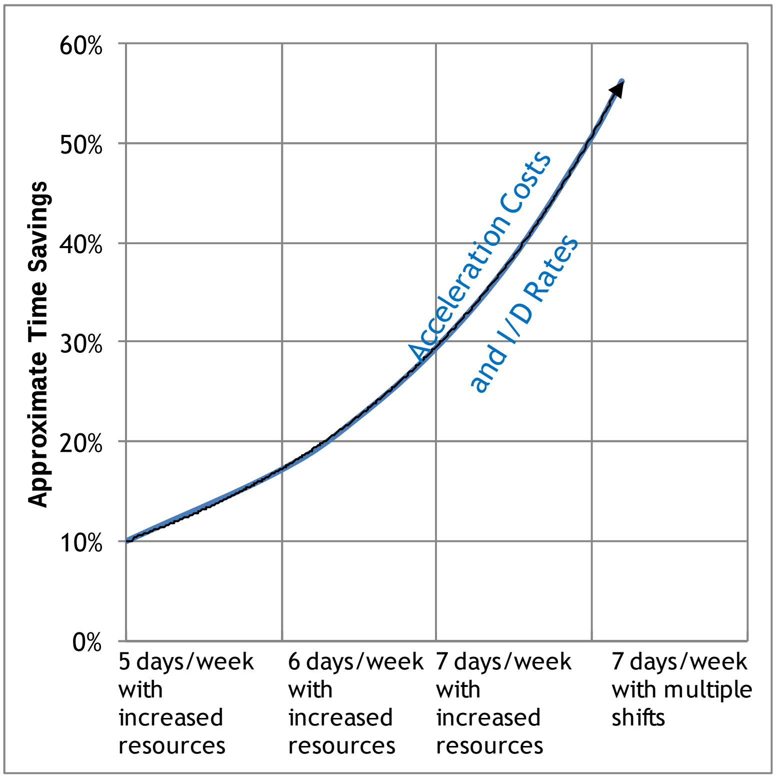

Figure 16. Relationship among the level of acceleration, acceleration costs, and time savings (adopted from Fick et al., 2010).

At some point, the acceleration costs may exceed the perceived benefits of time savings (i.e., CA > WZ RUC), and the goal of expediting construction time may not prove beneficial. In other words, there is an optimum level of acceleration beyond which there are no benefits of time savings. Hence, a tradeoff is needed between the level of acceleration (or CA) and the benefits of time savings (RUC).[137] This can be accomplished by evaluating the cost and time impacts of various productivity rates on work items on the project's critical duration path.

4.4.6 Calculating Incentives/Disincentives – Discount Factor Approach

The steps involved in calculating I/D using discount factors are as follows:

1. Establish baseline schedule for the project using standard production rates. See section 0 for further discussion.
2. Establish road user cost estimates for project using baseline schedule and a preferred MOT strategy. See section 0 for more discussion.
3. Determine the discount factor. The value typically ranges from 0.2 to 1.0.
4. Calculate daily I/D value by multiplying daily WZ RUC by the discount factor.

Daily I/D = Discount factor * daily WZ RUC

[137] For more information on time-cost trade off analysis, refer to standard textbooks on construction project scheduling and control.

Example 4.5: Calculation of I/D

An 8.6-mile section of Interstate 80 in the City of Sacramento will be closed for concrete pavement rehabilitation. The MOT selected for this project is 55-hour weekend closure. Work zone impact analysis using CA4PRS produced an estimate of approximately $300,000 for each 55-hour weekend closure. Determine the I/D rates for each closure using a discount factor of 0.25 and 0.20.

I/D at a discount rate of 0.25 = $300,000*0.25 =$75,000 for each closure
I/D at a discount rate of 0.20 = $300,000*0.20 =$60,000 for each closure

The discount factor is the portion of road user cost savings that an owner is willing to share with the contractor. The selection of this factor typically is an owner agency's management decision by taking factors into account such as market conditions, confidence on the accuracy of WZ RUC estimates, work zone factors, and time sensitivity of project completion. The discount factor is selected in such a way that the value of the WZ RUC matches the agency cost (Pyeon and Lee, 2010) particularly when the total WZ RUC of the project exceeds the agency costs. As several agencies have limited the total incentive amount at 5 percent of the total contract amount, this requirement is also taken into consideration in selecting a discount factor.

While selecting a discount factor for I/D, the agency should check if the liquidated damages clause still applies in the event of a schedule overrun. In the absence of a liquidated damages clause, the discount factor may not adequately cover the agency's construction engineering charges and a justifiable proportion of road user costs. Note that the lower discount factor has a diminishing effect on the contractor's I/D—in other words, the contractor is paid a lower incentive amount for early completion and pays a lower disincentive amount for schedule overrun. However, the trend reverses for the owner agency (combined societal and agency costs) when the liquidated damage clause does not apply—at a lower discount factor, the agency's savings are higher for early completion while the unrecovered losses are also higher when there is a schedule overrun.

Example 4.6: Computing disincentives

As a continuation of Example 4.3, assume that the contractor took 63 days (3 days more than the contract time specified in the bid) to complete the work. Calculate the disincentive amount to be paid. Use the same discount factor for disincentive calculation. Estimate the direct loss to the agency as well as the unrecovered road user costs, if any, assuming that the only the disincentive clause apply but not the liquidated damages. Assume a discount factor of 25%.

Contractor's bid price (C) = $3,000,000 (from Example 4.3)
Contract time specified in the bid (D) = 60 days (from Example 4.3)
Actual days used = 63 days
Bid WZ RUC+AGCEC (for 60 days) = $240,000 (from Example 4.3)
Actual WZ RUC+AGCEC (for 63 days) = $252,000 (from Example 4.3)
Additional costs incurred through WZ RUC and AGCEC = $12,000
Discount factor = 25 %
Disincentives paid by the contractor = $3,000
Uncovered agency and user costs = $12,000-3,000 = $9,000

The agency has incurred a total loss of $12,000 through additional costs in WZ RUC and AGCEC; however, it has recovered only $3,000 through disincentives. Since the liquidated damage clause does not apply to recover the remaining amount, the combined loss incurred by the agency and road users is $9,000.

Out of the recovered disincentives of $3,000, the direct cost incurred by the agency is only the construction engineering costs (i.e. $500/day).

AGCEC = $500/day
Additional AGCEC due to project delay = 3 days * 500 = $1,500
Road user costs recovered from disincentives = $3,000 - $1,500 = $1,500
Unrecovered road user costs = $9,000 - $1,500 = $7,500

In this example, the agency was able to cover the construction engineering costs, while nearly 71 percent of the road user costs were uncovered. Note that agencies typically do not consider the dollar value of WZ RUC at par with the dollar value of I/D.

4.4.7 Calculating Incentives/Disincentives – Cost of Acceleration Approach

1. Establish baseline schedule for the project using standard production rates. See section 0 for further discussion.
2. Establish road user cost estimates for project using baseline schedule and a preferred MOT strategy. See section 0 for more discussion.
3. Analyze the CPM schedule of baseline duration by using increased production rates for activities on the critical path. See section 0 for further discussion.
4. Estimate the contractor's CA for increased production rates. See section 4.4.4 for further discussion.
5. Select an I/D amount that is less than or equal to unit WZ RUC costs but greater than the acceleration costs for the desired optimal duration. A discount factor can also be introduced to discount the road user costs.

$$\text{Cost of Project Acceleration} < I/D \leq \text{WZ RUC}$$
$$\text{Cost of Project Acceleration} < I/D = DF^* \text{ WZ RUC}$$

The practitioners can make use of tools such as sensitivity analysis to identify an appropriate discount factor and evaluate its effectiveness. As illustrated in Example 4.7, the contractor and agency profits and losses can be estimated for various combinations of discount factors and project completion scenarios. In Example 4.7, a hypothetical project scenario was assumed and the cost model presented in Eq. 1 was utilized.

At higher discount factors, the agency pays a larger portion of WZ RUC savings to the contractor as incentives for early completion and recovers an equal portion of WZ RUC losses from the contractor as disincentives for late completion. Put briefly, the agency transfers a large portion of schedule related risks, including benefits and costs, to the contractor at higher discount factors.

At lower discount factors, the agency pays only a smaller portion of WZ RUC savings to the contractor for early completion and recovers an equal portion of the losses from the contractor for late completion. To be effective, the incentives paid to the contractor must to be adequate enough to compensate the contractor costs of acceleration, while the disincentives recovered from the contractor should commensurate with the WZ RUC losses. With increasing discount factor, the contractor receives more incentives to complete earlier as long as the costs of acceleration do not exceed the incentive amount. To summarize, the discount factor selected by the agency should be adequate enough to ensure that the agency's early completion goals are met.

Example 4.7: Sensitivity of the I/D discount factor

As a continuation of Example 4.3, perform a sensitivity analysis to demonstrate the effect of discount factor on:

- Agency's savings and losses (road user costs + construction engineering cost)
- Contractor's profits and losses

The calculation steps presented in the previous example 4.2.3 was repeated over a range of discount factors and actual days of construction. Here are the results:

<u>Case 1. Agency's savings and losses (RUC + construction engineering cost only):</u>

		Discount Factors									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Actual days to complete the project (normal = 60 days)	70	-36	-32	-28	-24	-20	-16	-12	-8	-4	0
	69	-32	-29	-25	-22	-18	-14	-11	-7	-4	0
	68	-29	-26	-22	-19	-16	-13	-10	-6	-3	0
	67	-25	-22	-20	-17	-14	-11	-8	-6	-3	0
	66	-22	-19	-17	-14	-12	-10	-7	-5	-2	0
	65	-18	-16	-14	-12	-10	-8	-6	-4	-2	0
	64	-14	-13	-11	-10	-8	-6	-5	-3	-2	0
	63	-11	-10	-8	-7	-6	-5	-4	-2	-1	0
	62	-7	-6	-6	-5	-4	-3	-2	-2	-1	0
	61	-4	-3	-3	-2	-2	-2	-1	-1	0	0
	60	0	0	0	0	0	0	0	0	0	0
	59	4	3	3	2	2	2	1	1	0	0
	58	7	6	6	5	4	3	2	2	1	0
	57	11	10	8	7	6	5	4	2	1	0
	56	14	13	11	10	8	6	5	3	2	0
	55	18	16	14	12	10	8	6	4	2	0
	54	22	19	17	14	12	10	7	5	2	0
	53	25	22	20	17	14	11	8	6	3	0
	52	29	26	22	19	16	13	10	6	3	0
	51	32	29	25	22	18	14	11	7	4	0
	50	36	32	28	24	20	16	12	8	4	0

- Red (negative) and Green (positive) indicate the magnitude of agency's losses and savings, respectively. The profit and loss magnitude increases with hue density.
- Loss to the agency is the difference between additional construction engineering and road user costs due to completion delays and the amount recovered from the contractor as disincentives.
- Savings to the agency is the difference between savings in construction engineering and road user costs due to early completion and the incentives paid to the contractor.
- At a discount factor of 1, the agency has no savings or losses since the cost differentials are either paid to or recovered from the contractor through incentives and disincentives.
- When the project is delayed, the agency recovers only a smaller portion of additional construction engineering and road user costs at lower discount factors; and hence, the agency's losses increase with the increasing delay period.
- When the project is completed earlier than the schedule, the agency shares only a smaller portion of savings to the contractor; and hence, the agency's savings increase with the increased number of days saved.

Case 2. Contractor’s profits and losses:

Actual days to complete the project (normal = 60 days)	Discount Factors									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
70	-43	-47	-51	-55	-59	-63	-67	-71	-75	-79
69	-35	-39	-42	-46	-49	-53	-57	-60	-64	-67
68	-28	-31	-34	-38	-41	-44	-47	-50	-54	-57
67	-22	-25	-27	-30	-33	-36	-39	-41	-44	-47
66	-16	-19	-21	-24	-26	-28	-31	-33	-36	-38
65	-12	-14	-16	-18	-20	-22	-24	-26	-28	-30
64	-8	-9	-11	-13	-14	-16	-17	-19	-21	-22
63	-5	-6	-7	-8	-9	-11	-12	-13	-14	-15
62	-2	-3	-4	-5	-6	-6	-7	-8	-9	-10
61	-1	-1	-2	-2	-2	-3	-3	-4	-4	-4
60	0	0	0	0	0	0	0	0	0	0
59	0	0	1	1	2	2	2	3	3	4
58	-1	0	1	2	2	3	4	5	6	6
57	-2	-1	0	1	3	4	5	6	7	9
56	-5	-3	-1	0	2	3	5	7	8	10
55	-8	-6	-4	-2	0	2	4	6	8	10
54	-12	-9	-7	-4	-2	0	3	5	8	10
53	-16	-13	-11	-8	-5	-2	1	3	6	9
52	-22	-18	-15	-12	-9	-6	-2	1	4	7
51	-28	-24	-21	-17	-13	-10	-6	-3	1	5
50	-35	-31	-27	-23	-19	-15	-11	-7	-3	1

- Red (negative) and Green (positive) indicate the magnitude of losses and profits, respectively.
- Loss to the contractor is the sum of disincentive amount paid to the agency and contractor cost of delay for late completion or the negative cost differential between the incentives received from the agency and the contractor cost of acceleration for early completion.
- Profit to the contractor is the positive cost differential between the incentives received from the agency and the contractor cost of acceleration.
- As expected, the contractor’s total loss increases as the number of days exceeding the normal duration increases. This amount also increases as the discount factor increases.
- The contractor’s net profit increases with the number of days saved; however, depending on the discount factor used in incentive calculation, the amount of net profit peaks at a certain number of saved days beyond which the incentives are not adequate enough to compensate the contractor cost of acceleration.
- At lower discount factors, for instance at 0.3, the contractor realizes no savings, and hence has no incentive to complete the project in less than 58 days. At even lower discount factors, the contractor sees no incentive at all to accelerate project completion.
- At higher discount factors, for instance at 0.8, the contractor maximizes the savings through incentives when the project the complete in 56 days. Contractor incentives are not adequate enough to complete the project in less than 56 days. In other words, the contractor is encouraged to accelerate completion schedule further with increasing discount factor.

CHAPTER 5. CASE STUDIES

5.1 CONCRETE PAVEMENT REHABILITATION ON INTERSTATE-66, FAIRFAX COUNTY, VIRGINIA

A concrete pavement rehabilitation project on Interstate 66 in Fairfax County was selected to illustrate the application of WZ RUC in the selection of a schedule-focused contracting method for a given project. This case study illustrates the computation of various monetary components of WZ RUC; the selection of an appropriate project delivery/contracting strategy; and the computation of lane rental charges. The actual information obtained for this project was modified with a number of assumptions for illustration purposes.

5.1.1 Project Description

Location

I-66 in Fairfax County is an urban interstate highway that primarily serves as a commuter route in the Washington metropolitan area. It is the main non-toll connector between Fairfax County and Washington, DC. Virginia Department of Transportation (VDOT) was owner of this project.

The project limits included the westbound traffic lanes on the mainline I-66 located between US 50 (Milepost 58) and SR 123 Chain Bridge Road (Milepost 60) interchanges and the ramp from I-66 leading to US 50W towards Chantilly. The general location of the project is shown in Figure 17.

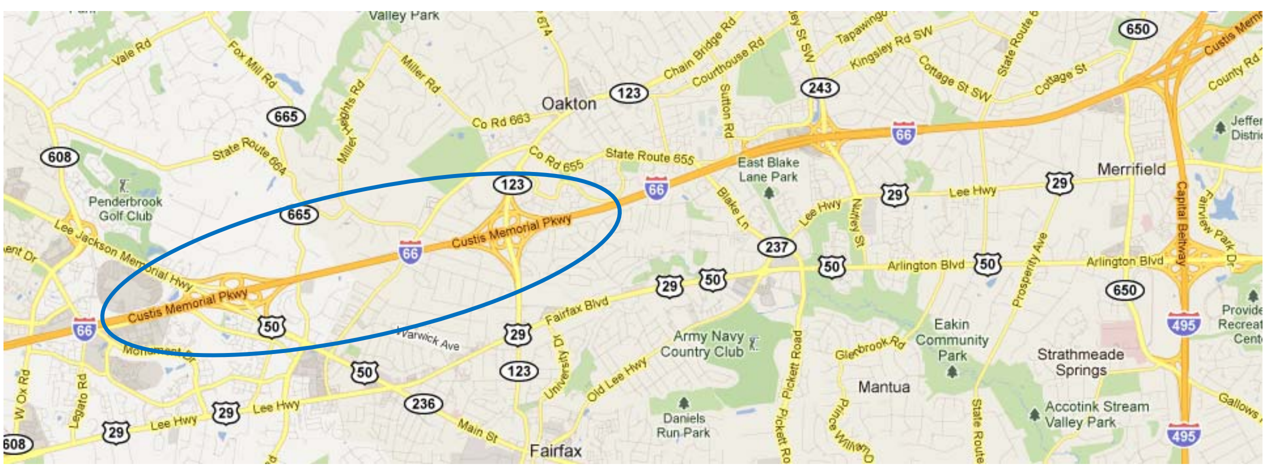

Figure 17. Project location on I-66 in Fairfax County, Virginia. (Map Source: Google)

Traffic Data and Operations

The westbound direction of I-66 mainline has four lanes: high occupancy vehicle (HOV) lane (inside), passing lane (middle), travel lane (outside), and auxiliary shoulder. The auxiliary shoulders are used only during peak hours from 5:30 am to 11:00 am in the eastbound direction and from 2:00 pm to 8:00 pm in the westbound direction, while only three lanes are open during non-peak hours (see Figure 18). The estimated ADT in westbound direction was 90,000 vehicles (with 5 percent trucks) in 2009.

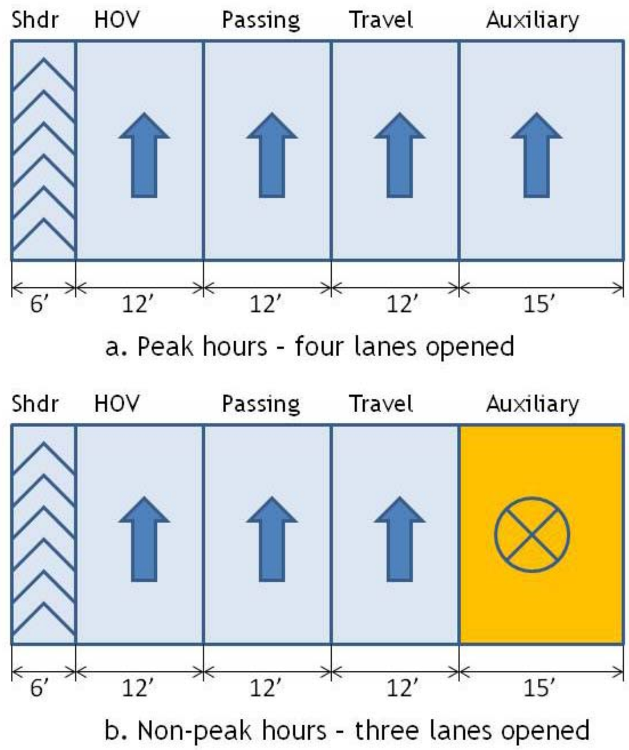

Figure 18. Number of lanes open during peak and non-peak hours on I-66 mainline.

The ramp leading from I-66 mainline to the US 50 W ramp has two lanes and a shoulder. The 3-mile-long ramp carried an estimated traffic volume of 28,000 vehicles per day. The speed limit on both mainline and the ramp under normal conditions is 55 mph.

The hourly traffic distributions for weekday and weekend traffic are shown in Table 56, Table 57, and Figure 19. The figure suggests that weekday traffic peaks at about 7:30 am and again between 3:00 and 7:00 pm. The traffic peaks between 11:00 am and 6:00 pm on weekends.

Table 56. Weekday hourly traffic distribution over a 24-hour period for I-66 westbound lanes.

Hour	% of daily traffic	Hour	% of daily traffic	Hour	% of daily traffic
Midnight	1.46%	8:00 AM	5.22%	4:00 PM	6.66%
1:00 AM	0.95%	9:00 AM	4.85%	5:00 PM	6.56%
2:00 AM	0.72%	10:00 AM	4.45%	6:00 PM	6.30%
3:00 AM	0.63%	11:00 AM	4.63%	7:00 PM	6.10%
4:00 AM	0.86%	Noon	5.21%	8:00 PM	4.91%
5:00 AM	2.52%	1:00 PM	5.48%	9:00 PM	4.17%
6:00 AM	4.36%	2:00 PM	6.15%	10:00 PM	3.38%
7:00 AM	5.23%	3:00 PM	6.85%	11:00 PM	2.36%

Table 57. Weekend hourly traffic distribution over a 24-hour period for I-66 westbound lanes.

Hour	% of daily traffic		Hour	% of daily traffic		Hour	% of daily traffic
Midnight	2.77%		8:00 AM	3.82%		4:00 PM	6.40%
1:00 AM	1.97%		9:00 AM	4.81%		5:00 PM	6.38%
2:00 AM	1.58%		10:00 AM	5.53%		6:00 PM	6.01%
3:00 AM	1.25%		11:00 AM	6.08%		7:00 PM	5.13%
4:00 AM	0.90%		Noon	6.36%		8:00 PM	4.41%
5:00 AM	1.17%		1:00 PM	6.51%		9:00 PM	4.03%
6:00 AM	1.87%		2:00 PM	6.47%		10:00 PM	4.02%
7:00 AM	2.89%		3:00 PM	6.27%		11:00 PM	3.36%

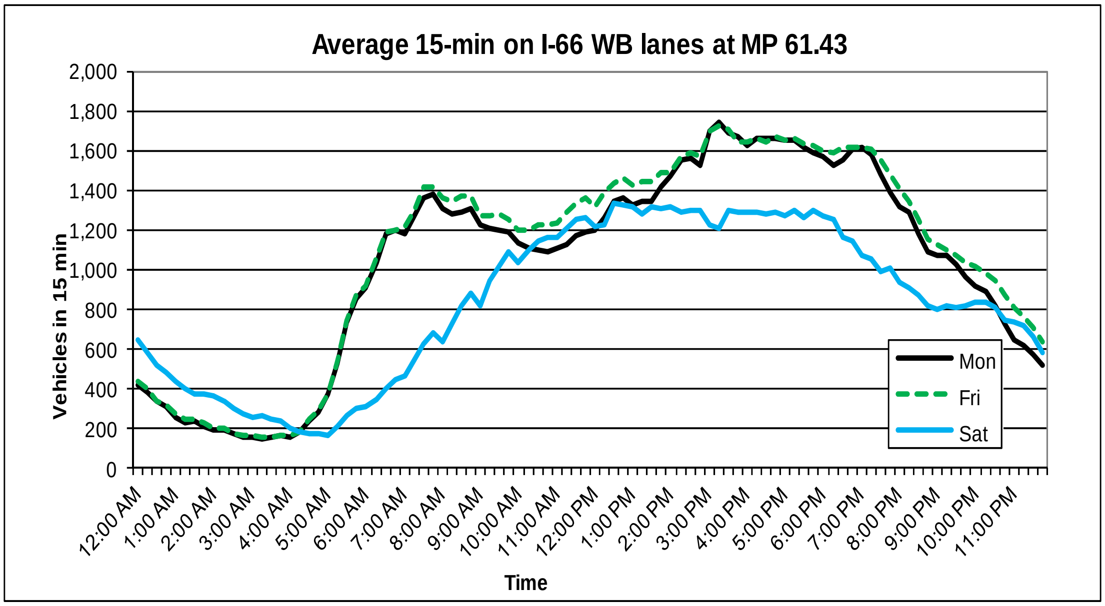

Figure 19. Hourly traffic distribution on I-66 westbound lanes.

Pre-construction Crash Data

The 3-year averages of pre-construction crash data for both mainline and ramp segments are shown in Table 58. No fatalities were reported. Three of the five events involved injuries. The severity of these injuries was not reported. The total value of property damage resulting from the accidents was $39,620.

Existing Project Condition

The PCC pavement in this roadway segment was built in the 1960s. The pavement was in a highly deteriorated condition and exhibited extensive cracking and deteriorated joints. Although the pavement in this segment had undergone maintenance repairs over the last several years, the condition was deteriorated enough to warrant an overall replacement.

Table 58. VDOT's accident records along I-66 project site.

Incident	1	2	3	4	5
Location	mainline	ramp	ramp	ramp	ramp
Type	Rear end	Fixed object off road from outside of ditch	Deer	Deer	Rear end
Weather	Clear	Snowing	Mist	Clear	Clear
Surface	Dry	Snowy	Dry	Dry	Dry
Vehicle count	2	1	2	1	2
Fatality	0	0	0	0	0
Injury	1	0	1		2
Property Damage	$1,000	$20,620	$6,000	$5,000	$7,000

Construction Technique

Pre-cast concrete technology was adopted as the preferred construction technique for this project. The feasibility of using two other alternatives, cast-in-place rigid pavement reconstruction options with a regular concrete mix and cast-in-place with a high early strength mix, were considered.

Contracting Strategy

For this project, VDOT adopted the "fixed price best value" contracting method. The bidders were allowed to compete on the extent of pavement replacement for a fixed bid price of $5 million. A repair plan outlining the required repairs as well as optional repair areas was provided. The bid advertisement specified the use of pre-cast pavement technology for repair, while the responsibility for the design of pre-cast systems was left to the contractor. The bid that proposed the greater square yards of pavement repair in optional areas, including all necessary work such as the required repairs, traffic control, pavement making, and mobilization, was awarded the contract.

Maintenance of Traffic Strategy

For the I-66 mainline, the construction was scheduled during nighttimes: two lanes were closed at 9:00 pm, a third lane was closed at 10:00 pm, and all lanes were opened to traffic by 5:00 am. At least one lane was kept open for traffic at all times. The slab installation was carried in two construction stages. In Stage 1, the two inner lanes (HOV and passing lanes) and the inside shoulder were closed for slab removal and installation. In Stage 2, the outside travel lane and the auxiliary shoulder were closed for slab removal and installation (see Figure 20). The posted speed limit in the work zone was 45 mph. For the I-66 ramp leading to US 50W, VDOT selected nighttime full closure for traffic maintenance. The traffic entering the US 50W ramp was diverted through designated detour routes. Figure 21 shows VDOT posted detours for motorists as marked on the plans and the agency website.

Travel Time Studies

The per-vehicle delays and queue lengths were measured during construction through the travel time studies. The floating car methodology was used in collecting travel time statistics. The maximum queue length, delay time, and associated timing are summarized in Table 59.

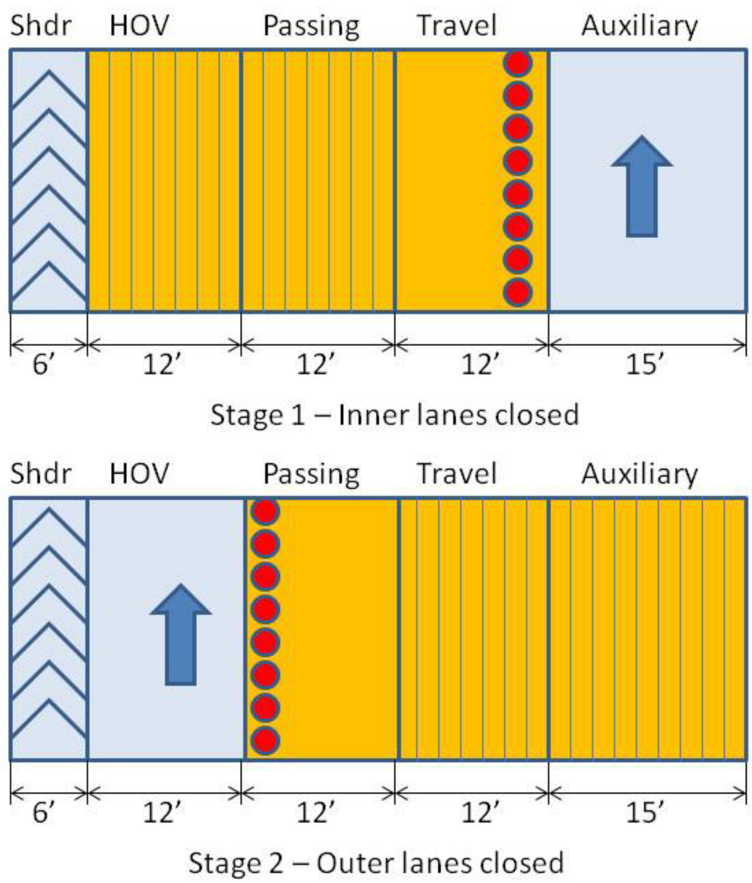

Figure 20. Construction staging on I-66 mainline.

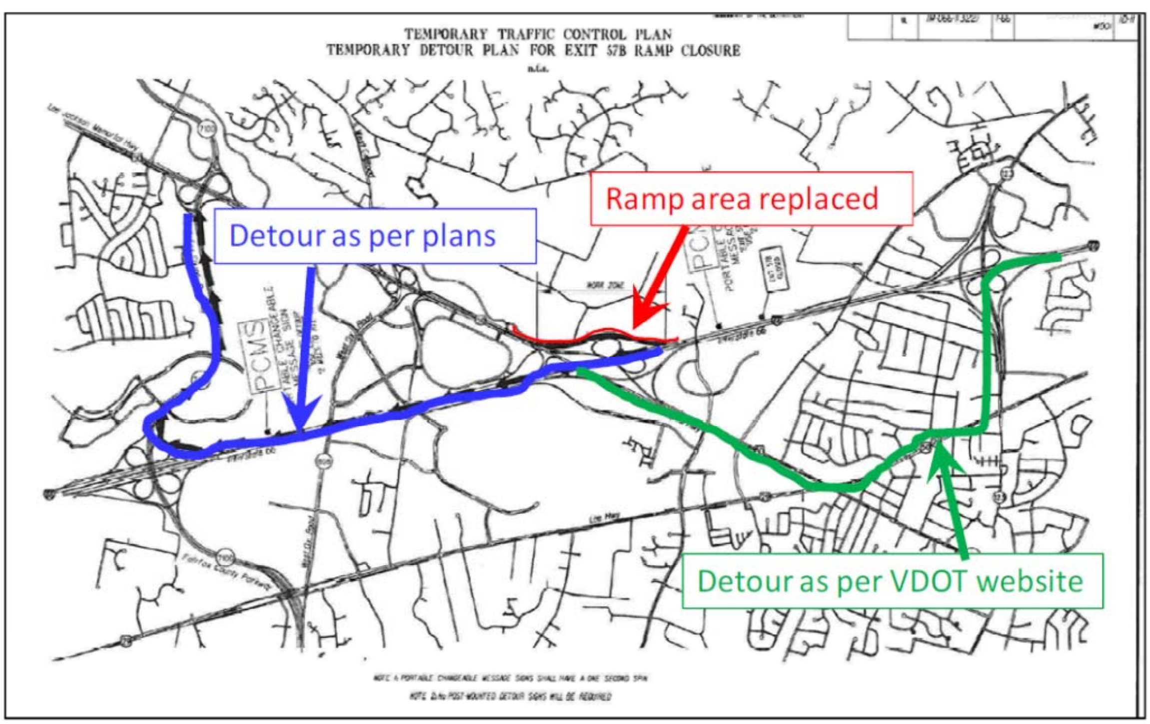

Figure 21. VDOT designated detour for I-66 ramp closure. (Source: VDOT)

Table 59. I-66 project: travel time statistics.

Day	Time	Maximum Queue, miles	Maximum delay, minutes
1	11:00 pm	1.5	14.3
2	11:00 pm	2.0	22.9
3	11:00 pm	2.1	25.9

Construction Duration

The as-built construction duration for the I-66 mainline involved 44 nighttime closures with 3 lanes closed and 27 nighttime closures with 2 lanes closed. The ramp was fully closed at night for 30 days.

Work Hour/Lane Closure Restrictions

VDOT issued special provisions placing restrictions on lane closures and work hours. The key features of the limitations are as follows:

- The lane closure schedule shall follow the restrictions specified in Tables 60 and 61 for mainline and ramp.
- No lane closures between Friday at 5:00 am and Sunday at 9:00 pm.
- Complete I-66 mainline closures performed at night will be permitted from 12:00 am to 5:00 am only, for a maximum of 15 minutes.
- The ramp from I-66 westbound to US 50 westbound was allowed to be closed to through traffic for a maximum of 24 closures without substantiation of need by the contractor and written authorization by the Area Construction Engineer.
- The charges for failure to restore all lanes to traffic by the previously designated times would be assessed user fee charges at the rates reflected in Table 62 for every 15 minutes interval starting from the approved time.

Table 60. Lane closure restrictions for mainline I-66.

Day	Open all lanes to traffic no later than	Reduce to 2 lanes of traffic no earlier than	Reduce to 1 lane of traffic no earlier than
Monday	5 AM	9 PM	10 PM
Tuesday	5 AM	9 PM	10 PM
Wednesday	5 AM	9 PM	10 PM
Thursday	5 AM	9 PM	10 PM
Friday	5 AM	NO LANE CLOSURES	NO LANE CLOSURES
Saturday	NO LANE CLOSURES	NO LANE CLOSURES	NO LANE CLOSURES
Sunday	NO LANE CLOSURES	9 PM	10 PM

Table 61. Lane closure restrictions for ramp from I-66 westbound to US 50 westbound.

Day	Open all lanes to traffic no later than	Reduce to 1 lanes of traffic no earlier than	Close to thru traffic with detour no earlier than
Monday	5 AM	9 PM	10 PM
Tuesday	5 AM	9 PM	10 PM
Wednesday	5 AM	9 PM	10 PM
Thursday	5 AM	9 PM	10 PM
Friday	5 AM	NO LANE CLOSURES	NO LANE CLOSURES
Saturday	NO LANE CLOSURES	NO LANE CLOSURES	NO LANE CLOSURES
Sunday	NO LANE CLOSURES	9 PM	10 PM

Table 62. I-66 project user fees for lane closures.

Monday-Friday	Failure to Remove Double Lane Closure By:	Failure to Remove Single Lane Closure By:
6:01 AM—6:15 AM	$1,000	
6:16 AM—6:30 AM	$2,000	
6:31 AM—6:45 AM	$3,000	$100
6:46 AM—7:00 AM	$3,000	$100
7:01 AM—7:15 AM	$4,000	$100
7:16 AM—7:30 AM	$5,000	$100
7:31 AM—7:45 AM	$5,000	$100
7:46 AM—8:00 AM	$5,000	$100
8:01 AM—8:15 AM	$5,000	$100
8:16 AM—8:30 AM	$5,000	$100
8:31 AM—8:45 AM	$5,000	$100
8:46 AM—9:00 AM	$5,000	$100
9:01 AM—9:15 AM	$5,000	$100
9:16 AM—9:30 AM	$5,000	$100
9:31 AM—9:45 AM	$5,000	$100
9:46 AM—10:00 AM	$5,000	$100
10:01 AM—10:15 AM	$10,000	$1,000
And continues until all lanes are restored to traffic	at the rate of $10,000 per 15 minute period	at the rate of $1,000 per 15 minute period

5.1.2 Case Study Objectives

The objectives of this case study are:

- To demonstrate the calculation of WZ RUC.
- To demonstrate the derivation of unit cost data for use in WZ RUC calculation.
- To demonstrate the application of WZ RUC and work zone impacts in selecting an appropriate construction strategy.
- To demonstrate the application of WZ RUC and work zone impacts in selecting appropriate project delivery and schedule-focused contracting strategies.
- To demonstrate the application of WZ RUC in determining lane closure timings and lane closure user fees (otherwise called lane rental charges).

5.1.3 RUC Computation

The computation of WZ RUC involved a two step process: (1) the estimation of work zone impacts for a given MOT strategy and (2) the computation of unit cost data. The estimated impacts were then multiplied by the unit cost data to compute daily WZ RUCs.

RealCost was used to compute delay and vehicle operating costs for mainline lane closures. For ramps, the additional time and distance resulting from traffic detours were calculated using simple mathematical formulae. The as-built lane closure strategies and timings were used for both mainline and ramp closures. The following components were considered:

- Mainline I-66
    - Work zone travel delay costs
    - Work zone VOC
    - Crash costs

- Ramps
    - Detour travel delay costs
    - Detour VOC
    - Crash costs

VDOT used Highway User Benefit-Cost Analysis Program (HUB-CAP) to quantify WZ RUC and benefits for this project and evaluate the cost-effectiveness of alternatives including detours, night work, and various project delivery methods.

5.1.3.1 Computation of Unit Costs

This case study demonstrates the derivation of unit cost data using regional data in the computation of travel delay costs in lieu of unit cost data provided in HUB-CAP lookup tables. The wage statistics in the Washington metropolitan area, designated by the Office of Management and Budget (OMB) as the Washington-Baltimore-Northern Virginia, DC-MD-VA-WV Combined Statistical Area (CSA), were used. For VOC and crash-related injury costs, the national averages presented in Chapter 2 were used due to the absence of region-specific data.

The unit cost data requirements for the computation of WZ RUC components mentioned above are shown in Table 63.

Table 63. I-66 project: unit cost data requirements for WZ RUC computation.

Unit Cost	Mainline		Ramp		Crash
	WZ Travel Delay	WZ VOC	Detour Travel Delay	Detour VOC	
Value of personal travel time ($/hr)	✓		✓		
Value of business travel time ($/hr)	✓		✓		
Value of truck travel time ($/hr)	✓		✓		
Time-related vehicle depreciation ($/hr)	✓		✓		
Cost of Freight Inventory ($/hr)	✓		✓		
Composite VOC($/mile)				✓	
Idling cost VOC ($/hour)		✓			
Speed Change VOC($/1000 stops)		✓			
Queue stopping VOC ($/1000 stops)		✓			
Fatalities					✓
Injury					✓
Property Damage					✓

Value of Travel Time for Passenger Cars

The monetary value of time for passenger cars is the weighted average of two components: travel time value of passenger cars on personal travel and travel time value of passenger cars on business travel. Per 2009 NHTS statistics, the passenger cars on personal and business travel were estimated to be 93.7 and 6.3 percent, respectively.

The computations of travel time values for passenger cars on both personal and business travel are presented as follows:

Hourly $ Value of Personal Travel Time

Median annual household income in 2010 inflation-adjusted dollars for the Washington-Arlington-Alexandria, DC-VA-MD-WV Metro Area was $84,523.[138] The steps presented in section 2.2.2.1 were followed.

Median annual household income of the area = $84,523
Hourly time value of a person on personal travel (assuming local travel)
= 50% of $84,523÷2080 hrs
Hourly time value of a person on personal travel = $20.32/person-hr
Average vehicle occupancy for personal travel = 1.24 persons per vehicle[139]
Hourly travel time value of a passenger car on personal travel = 1.24 * 20.32
= $25.19/vehicle-hr

Hourly $ Value of Business Travel Time

The sum of hourly wages and benefits for the Washington Metropolitan area were estimated using the CSA-specific ECEC statistics available on the BLS website. The steps presented in section 2.2.2.2 were followed.

Hourly employment cost for the quarter March 2010= $33.79[140]
Hourly time value of a person on business travel = $33.79/person-hr
Average vehicle occupancy = 1.24 persons per vehicle
Hourly travel time value of a passenger car on business travel = $33.79 * 1.24
= $41.90/vehicle-hr

Weighted Average of Travel Time Value

The weighted average of travel delay time values for passenger cars on both personal and business travel were computed using the ratios presented in 2009 NHTS statistics.

Travel delay value of a passenger car on personal travel = $25.19/vehicle-hr
Travel delay value of a passenger car on business travel = $41.90/vehicle-hr
Weighted average of hourly time value of passenger cars = 93.7% of $25.19 + 6.3% of $41.90
= $26.25/ hr

Travel delay value of a passenger car = $26.25/hr

Value of Truck Travel Time

Following the steps presented in section 2.2.2.3, the hourly compensation of truck drivers was used in computing the value of truck travel time.

Average compensation of single-unit truck drivers = $28.50/person-hr
Average vehicle occupancy of single-unit trucks = 1.025

[138] Source: American Fact Finder, U.S. Census Bureau, 2010 American Community Survey (Item Code B19013) http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml
[139] Assumed based on the value reported in “A Look Back at Rezoning Cases to Compare Projected and Actual Transportation Impacts” Fairfax County Technical Assistance Project, 2008. http://www.mwcog.org/transportation/activities/tlc/pdf/Ffx_FinalReport.pdf
[140] http://www.bls.gov/news.release/archives/ecec_06092010.pdf

Hourly time value of single-unit trucks = 1.025 * $28.50 = $29.21/hr
Average compensation of combination truck drivers = $27.95/person-hr
Average vehicle occupancy of combination trucks = 1.12
Hourly time value of combination trucks = 1.12 * $27.95 = $31.30/hr

Due to lack of data, the proportion of single-unit and combination trucks on I-66 was assumed to be typical of urban interstate highways.

Percent single unit trucks = 12.9% of total trucks[141]
Percent combination trucks = 87.1% of total trucks

Hourly $ value of truck travel time = 12.9% of $29.21 + 87.1% of $31.30 = $31.03/hr

Hourly $ Value of Vehicle Depreciation Cost

The values presented in the Step 1 of Example 2.5 (section 2.2.2.4) were used.

Hourly depreciation cost for passenger cars = $1.23/hr
Hourly depreciation cost for single-unit trucks = $3.09/hr
Hourly depreciation cost for combination trucks = $9.29/hr

Hourly $ Value of Freight Inventory Cost

The values presented in Step 7 of section 2.2.2.5 were used.

Hourly vehicle inventory cost for single-unit trucks = $0.18/hr
Hourly vehicle inventory cost for combination trucks = $0.31/hr

Total Delay Costs

Hourly costs for passenger cars	= time value + depreciation cost
	= $26.25 + 1.23 =$27.48/hr
Hourly costs for single-unit trucks	= time value + depreciation + freight inventory
	= $29.21 + 3.09 + 0.18 = $32.48/hr
Hourly costs for combination trucks	= time value + depreciation + freight inventory
	= $31.30 + 9.29 + 0.31 = $40.90/hr
Hourly costs for all trucks	= 12.9% of $32.48 + 87.1% of $40.90 = $39.81/hr

Composite Vehicle Operating Costs

Composite VOC (per mile cost) was used for diverted vehicles on detour routes only. For passenger cars, the AAA estimates presented in Table 16 were used. A median sedan car was assumed to represent all passenger cars on I-66. For trucks, the ATRI estimates presented in Table 17 were used.

VOC for passenger cars = $0.403/mile
VOC for trucks = $0.818/mile

[141] Based on the Long-term Pavement Performance (LTPP_ Truck Traffic Classification (TTC) national averages for urban interstate highways.

Individual Vehicle Operating Costs

Individual VOC components for idling, speed change, and queue stopping were obtained from the RealCost cost tables presented in Table 12.

Crash Costs

Based on the accident information presented in Table 58, the crash costs are presented as follows:

Since the VDOT accident data contain the dollar value of property damage, no unit costs were computed. The sum of property damage values presented in Table 58 was used.

Total monetary value of property damage = $39,620
Number of injuries = 4 (all incidents involving two vehicles with crash geometry resembling rear end collisions).

Using the data provided in Appendix A, Table 2 of the FHWA report "Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries," [49] the mean human capital and comprehensive costs (in 2001 dollars) were obtained. For the given set of factors—crash geometry code No. 15, injured but severity unknown, speed limit > 50 mph—the mean human capital and comprehensive costs in 2001 dollars are $34,399 and $68,218, respectively. The crash costs were then adjusted to 2010 dollars using the approach illustrated in the Step 7 of Example 2.10 in section 2.4.3.

Adjustment factor for human capital costs = 1.2313
Adjustment factor for comprehensive costs = 1.3095

Adjusted comprehensive cost = ($34,399*1.2313) + ($68,218 -$34,399)*1.3095
=$86,641.47/injury

Cost per injury = $86,641.47

There were no fatalities reported, and therefore, the crash cost for a fatal event was not computed.

5.1.3.2 RUC for Mainline I-66 through Traffic (Delay and VOC only)

RealCost was used to estimate work zone traffic impacts and compute the delay and VOC components of WZ RUC for the mainline I-66 through traffic. The following inputs were used:

- One-way AADT = 90,000
- Percent single-unit trucks = 0.6%
- Percent combination trucks = 4.4%
- Diverted traffic = 0% (assumed)
- Normal speed limit= 55 mph
- Work zone speed limit = 45 mph
- Normal lane capacity = 2250 passenger cars/hr/lane
- Work zone lane capacity = 2100 passenger cars/hr/lane (obtained from VDOT's HUB-CAP estimate)

Two different lane closure conditions were used:

- Two of four lanes closed from 9:00 pm to 5:00 am
- Three of four lanes closed from 10:00 pm to 5:00 am

Tables 64 and 65 present the estimated queue length, delay time, and associated delay and VOC components of WZ RUC for two- and three-lane closures, respectively. The estimated daily costs of the delay and VOC components for these conditions are $2,247 and $72,291, respectively.

The estimations presented in these tables indicate that the traffic impacts were severe when three lanes were closed, particularly between 11:00 pm and 12:00 am. The estimated maximum queue length and delay time with the three-lane closure was 2.2 miles and approximately 34 minutes during this time period. These values were similar to the travel time statistics presented in Table 59, thus validating the RealCost estimations.

Table 64. I-66 mainline traffic impacts (two of four lanes closed).

Time	WZ Conditions	RUC per Hour	Queue Length (miles)	Delay (min)		
				Car	Single Unit Trucks	Combination Trucks
0 - 1	WZ & No Queue	$230	0.0	0.4	0.4	1.1
1 - 2	WZ & No Queue	$139	0.0	0.4	0.4	1.1
2 - 3	WZ & No Queue	$112	0.0	0.4	0.4	1.1
3 - 4	WZ & No Queue	$88	0.0	0.4	0.4	1.1
4 - 5	WZ & No Queue	$88	0.0	0.4	0.4	1.1
5 - 6	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
6 - 7	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
7 - 8	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
8 - 9	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
9 - 10	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
10 - 11	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
11 - 12	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
12 - 13	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
13 - 14	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
14 - 15	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
15 - 16	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
16 - 17	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
17 - 18	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
18 - 19	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
19 - 20	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
20 - 21	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
21 - 22	WZ & No Queue	$647	0.0	0.4	0.4	1.1
22 - 23	WZ & No Queue	$562	0.0	0.4	0.4	1.1
23 - 24	WZ & No Queue	$380	0.0	0.4	0.4	1.1
Total		$2,247				
Maximum			0.0	0.4	0.4	1.1

Table 65. I-66 mainline traffic impacts (three of four lanes closed).

Time	WZ Conditions	RUC per Hour	Queue Length (miles)	Delay (min)		
				Car	Single Unit Trucks	Combination Trucks
0 - 1	WZ & Queue	$21,362	1.5	22.9	23.1	24.7
1 - 2	WZ & Queue	$1,795	0.4	6.5	6.8	9.0
2 - 3	WZ & No Queue	$112	0.0	0.4	0.4	1.1
3 - 4	WZ & No Queue	$88	0.0	0.4	0.4	1.1
4 - 5	WZ & No Queue	$88	0.0	0.4	0.4	1.1
5 - 6	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
6 - 7	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
7 - 8	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
8 - 9	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
9 - 10	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
10 - 11	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
11 - 12	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
12 - 13	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
13 - 14	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
14 - 15	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
15 - 16	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
16 - 17	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
17 - 18	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
18 - 19	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
19 - 20	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
20 - 21	No WZ & No Queue	$0	0.0	0.0	0.0	0.0
21 - 22	WZ & No Queue	$0	0.0	0.0	0.0	0.0
22 - 23	WZ & Queue	$16,890	1.1	17.5	17.8	19.3
23 - 24	WZ & Queue	$31,956	2.2	33.8	34.1	35.6
Total		$72,291				
Maximum			2.2	33.8	34.1	35.6

Two of four lanes closed:

Number of work days = 27
Daily WZ RUC (delay and VOC only) = $2,247
Total WZ RUC (delay and VOC only) = 27 * $2,247 = $60,669

Three of four lanes closed:

Number of work days = 44
Daily WZ RUC (delay and VOC only) = $72,291
Total WZ RUC (delay and VOC only) = 44 * $72,291 = $3,180,804

Total WZ RUC (delay and VOC only) = $60,669 + $3,180,804 = $3,241,473

5.1.3.3 RUC for I-66 Ramp Closure and Detours (Delay and VOC only)

The I-66 ramp leading to US 50 was fully closed for traffic between 9:00 pm and 5:00 am for 30 days. The following inputs were used:

Number of work days = 30
Lane closure timing = 9:00 pm to 5:00 am
Number of vehicles diverted during closure = 5,460

Normal travel distance = 3.1 miles (with no work zone in place and no detours)
Normal speed = 55 mph

Detour travel distance = 5.3 miles (as a result of ramp closure)
Detour speed = 40 mph

Additional travel time per vehicle = (5.3/40) – (3.1/55) = 0.076 hour = 4.57 minutes

Total travel delay time for all diverted vehicles = 5,460 * 0.076 = 415.7 hours
Delay costs per day = 95%*415.7*$27.48 + 5%*415.7*$39.81
= $10,852.26+827.45 = $11,679.72

Additional distance traveled per vehicle = 5.3 – 3.1= 2.2 miles
VOC for passenger cars = $0.403/mile
VOC for trucks = $0.818/mile
VOC per day = 95%*5460*$0.403 + 5%*5460*$0.818 =$2,313.68

Total delay and VOC for all working days = ($11,679.72 + $2,313.68) * 30 days
= $13,993.4 * 30 days = $419,802

On this project (as would be standard procedure in most real-world scenarios), the pavement repairs on the ramp were undertaken concurrently with repairs on the mainline. The ramps were fully closed for traffic when the lane closures on the mainline were in effect. Therefore, while analyzing the traffic impacts of mainline lane closures, the demand-capacity analysis should duly account for the diverted vehicles in computing the mainline hourly traffic volume. However, as no information on the exact dates of ramp closures was available, the number of diverted vehicles was not deducted from the mainline hourly traffic volume. Therefore, it was assumed for the sake of simplicity that the mainline closures and ramp closures were not in effect concurrently, and they were considered separately.

5.1.3.4 Crash Costs

Crash costs were determined based on the crash rates reported in Table 58 for the ramp and the mainline. The key steps involved in computing the crash costs are as follows:

1. Compute the pre-construction crash rate
2. Compute the work zone crash rate using work zone crash modification factor
3. Estimate the measure of work zone exposure
4. Compute unit cost for crashes
5. Compute work zone crash costs for the project

The detailed discussion of these steps is presented in section 2.4.

Pre-construction Crash Rate

The pre-construction crash statistics reported in Table 58 were converted to crash rates using the following equation:

$$CR = \frac{A * 10^6}{T * L * AADT * 365}$$

Length of roadway section (L) = 4 mile
Exposure period (T) = 3 years
Average AADT per year = 90,000 vehicles/day

Number of fatalities = 0
Pre-construction crash rate for fatalities = 0

Number of injuries = 4
Pre-construction crash rate for injuries = (4*10^6)/(3*4*90,000*365) = 0.01015/MVMT

Since the property damage values were available for each incident, those values were directly used in computing the pre-construction crash rates.

Value of Property Damage (A_{PDO}) = $39,620
Pre-construction crash rate for PDO (Pre-CR_{PDO})= (39,620*10^6)/(3*4*90,000*365)
= $100.50/MVMT

Work Zone Crash Rate

No agency-specific work zone crash rates or CMFs were available for this project. To account for crash-related risk escalation in work zones, a CMF value of 1.61 was assumed for night-time temporary lane closures in this project based on the work done by Ullman et al. [42] See section 2.4.1 for more discussion on selecting a work zone crash rate.

Crash modification factor for work zone = 1.61
Work zone crash rate for fatalities = 0
Work zone crash rate for injuries (WZ-CR_{INJ})= 0.01015 * 1.61 = 0.01634/MVMT
Work zone crash rate for PDO (WZ-CR_{PDO})= $100.50 * 1.61 = $161.81/MVMT

Work Zone Exposure

The VMT during the work zone period is computed for both ramp and mainline traffic. Note that the exposure periods and work zone length were different for both ramp and mainline traffic. The mainline traffic is exposed to I-66 work zone related crash risks for the entire construction duration of 71 days, while the ramp traffic is exposed to the I-66 work zone related crash risks only for the time period when the ramps are opened for traffic during construction (i.e., 71-30 = 41 days). When the full ramp closure was in effect, the ramp traffic was exposed to the crash risks of detour routes. Since no crash data are available for detour routes, it was not considered in this case study.

Mainline Traffic:
Exposure period (T*365) = 71 days
AADT (mainline) = 90,000
Work zone length (mainline) = 1 mile
Ramp Traffic:
Exposure period = 41 days
ADT(ramp) = 28, 000 vehicles/day
Work zone length (ramp) = 4 miles

Million vehicle miles traveled = (71*90,000*1/10^6)+ (41*28,000*4/10^6) = 10.982 MVMT

Unit Cost of Crashes

Refer to section 5.1.3.1 for computation of unit costs of crashes.

Cost per injury = $86,641.47
Note that the monetary values of property damage were directly used in computing the pre-construction crash rate for PDO, and hence, unit costs were not required.

Crash Costs

The crash costs were computed by multiplying work zone crash rate with the measure of exposure (MVMT) and the corresponding mean comprehensive costs.

Work zone crash rate for fatalities = 0
WZ costs for fatalities = 0

Work zone crash rate for injuries=0.01634/MVMT
WZ exposure = 10.982 MVMT
Cost per injury = $86,641.47
WZ costs for injuries = 0.01634*10.982*$86,641.47 = $15,547.46

Work zone crash rate for PDO = $161.83/MVMT
WZ exposure = 10.982 MVMT
WZ costs for PDO= $161.81*10.982= $1,777.00
Total crash costs = $15,547.46 + $1,777.00 = $17,324.46
Daily crash costs = $17,324.46/71 = $244.00

5.1.3.5 Total WZ RUC

Total WZ RUC for the entire project is the sum of delay costs and VOC for mainline and ramp traffic and crash costs.

Total WZ RUC = total delay costs and VOC for mainline +
total delay costs and VOC for ramp + crash costs

= $3,241,473 + 419,802 + 17,324.46 = $3,678,599.46

Daily WZ RUC for two lanes closed (mainline) = $2,247 + 244.00 = $2,491.00
Daily WZ RUC for three lanes closed (mainline) = $72,291 + 244.00 = $72,535.00

Daily WZ RUC for detour traffic = $13,993.40 + 244.00 = $14,237.40

5.1.4 Selection of Construction Technique

VDOT's selection of pre-cast pavement technology as the preferred technique over other feasible alternatives appeared to have taken the following factors into account:

- Anticipated work zone impacts on mobility and safety: This segment of I-66 primarily serves as a commuter route carrying high volumes of traffic in both directions on both weekdays and weekends. Any daytime or continuous lane closures would have resulted in severe disruption of work zone traffic.

  In such situations, the use of pre-cast pavement technology typically allows all construction activities to be accomplished during nighttime hours, including traffic control set-up and removal, with no significant disruption to traffic. This was evident as the production rates achieved during construction ranged between 8 to 12 panels for the single lane width installation in a 6-hour work window.

  The use of cast-in-place concrete with high early strength concrete mix may result in similar productivity rates and lane closure requirements; however, the placement of conventional concrete mix requires several days of continuous lane closure to allow concrete curing, resulting in severe disruptions to work zone traffic.

- Cost-effectiveness: The use of conventional concrete mix is cheaper and typically provides a 30-year service life with minimal intervention needed for pavement maintenance but would require longer construction time (or higher road user costs).

  On the other hand, the use of high early strength concrete typically carries a cost premium and can be cost-prohibitive for large-scale construction. Despite the advantage of shorter construction time, the cast-in-place pavement with high early strength mix may exhibit material durability problems leading to shorter service life and may warrant frequent intervention for pavement maintenance and rehabilitation (M&R). Over the pavement's life cycle, frequent M&R interventions typically offset the WZ RUC savings gained from shorter construction time.

  Thus, the use of pre-cast pavement technology seemed to provide a balance with lower life cycle costs (including road user costs), long-term pavement performance, and shorter construction time requirements.

5.1.5 Selection of Contracting Strategy

As mentioned earlier, VDOT adopted the "fixed price best value" contracting method for this project. The fixed price best value approach is being widely used under the SEP-14 program. The basic element of this method (i.e., bid that provides maximum value for a fixed price) is commonly used as a bid award basis in design-build contracting.

The bidders were allowed to compete on the extent, in terms of square yard size, of pavement repair for a fixed bid price of $5 million. This alternative contracting approach was used for this project to maximize the square yardage of pavement repair. VDOT adopted a lane rental strategy for this project, given the fact that the I-66 mainline is an urban interstate carrying a high volume of commuter traffic each day.

Step 1. Identifying the need for project acceleration.

This case study critically analyzes the need for a schedule-focused contracting strategy for this project and provides suggestions for selecting a particular contracting strategy to achieve schedule-related objectives. The approach presented in section 4.3 was used herein to evaluate the need for such strategies for this project. The questions presented in Table 66 were answered based on the available information. The evaluation results indicate that the answers to several of these questions were YES, thus indicating the need for a scheduled-focused contracting strategy for this project.

Table 66. I-66 project: evaluating the need for a schedule-focused contracting strategy.

Question	Yes	Maybe	No
Is the project goal to shorten the duration of construction phase?	✓		
Is the estimated WZ RUC high for the baseline duration?	✓		
Is the traffic volume high enough to cause significant disruptions? Does the work zone affect the intersecting traffic?	✓		
Is this roadway located in an urban area? Does the local traffic depend on this highway for commute?	✓		
Does this area lack any viable detour alternative that does not adversely impact the local network?	✓		
Are there local community and political interests to be considered?		✓	
Does the work zone adversely impact the local business and neighborhood?		✓	
Are the safety issues of construction workers and traffic a concern?	✓		
Is the project time-sensitive?			✓
Does this project close a gap in the local highway network?			✓
Is the project located in tourist or environmentally sensitive areas?			✓

Step 2. Selecting a project delivery method.

Upon establishing the need for schedule acceleration, an appropriate project delivery method was selected using the guidelines presented in Table 51 (see section 4.3.2). An evaluation was performed to identify the suggested project delivery method, and the discussion is presented as follows:

- *Project size, scope and complexity*: Small-Medium — The project size was $5 million. The scope primarily involved pavement repairs and some roadway realignment of ramps for pre-cast pavement slab installation.
- *Is project routine or innovative?*: Innovative — The use of pre-cast pavement technology was an innovative venture for VDOT.
- *Certainty over design scope*: Yes — VDOT was certain over the design scope. The agency specified the use of pre-cast pavement technology in the bid advertisement. It also outlined the repair areas that were required under the contract and the optional areas.
- *In-house design*: Yes — VDOT specified the design for pre-cast slabs on the plans. VDOT also hired a design consultant for this project.
- *Early cost certainty*: Yes — The project cost was fixed at $5 million. The bid advertisement also specified the required repair areas.
- *Certainty over constructability*: Yes — VDOT specified the use of pre-cast pavement technology in the bid advertisement. It also hired a design consultant for this project.

The suggested strategy, in accordance with the recommendations presented in Table 51, was to adopt design-bid-build and, in addition, to hire consultants to seek design/constructability advice.

Step 3. Selecting a schedule-focused contracting method.

Following the project delivery method, another evaluation was performed to identify an appropriate schedule-focused contracting method based on the selection factors presented in Table 52. The discussion is presented as follows:

- *Is the project required to complete before the expected normal duration?*: YES – Since this roadway carries heavy commuter traffic, VDOT was interested in early completion.
- *Is the project time-sensitive?*: YES – This project was not time-sensitive.
- *Project duration*: Long— the expected project duration was 2-3 months.
- *Intermediate or Multiple Phases*: NO.
- *Detours are long, impractical, or unavailable*: YES for mainline, NO for ramp.
- *Urban commuter traffic*: YES
- *Owner's confidence on estimated duration*: Low - This project involved the adoption of a new, innovative technology. VDOT has no or little prior experience with the installation of the pre-cast pavement technology, and hence the owner's confidence was considered low.

Based on the discussion above, the suggested strategy, in accordance with the recommendations presented in Table 52 is A+B with I/D, lane rental, and accelerated construction. VDOT adopted only lane rental and accelerated construction techniques for this project; the A+B bidding was not used.

5.1.6 Computing Lane Rental Fee

This section illustrates the computation of lane rental fee for a given closure period using WZ RUC as the basis. RealCost was used in estimating the traffic impacts and mobility-related WZ RUC components for various lane closure scenarios. Tables 67 and 68 present the summary of the estimated WZ RUC and mobility impacts for both two-lane and three-lane closures at various lane closure timings. The daily WZ RUC values presented in these tables includes both mobility costs and crash costs. The net difference values indicate the difference in the daily WZ RUC estimates between the actual and the allowable closure period. In this project, the VDOT defined the allowable closure as the period between 9 pm and 5 am for two-lane closures, and between 10 pm and 5 am for three-lane closures.

As indicated in the Tables 67 and 68, closing a lane earlier than the scheduled time or failing to restore lanes per schedule results in increased WZ RUC. For the two-lane closure, the effect apparently is not significant if the lane closure is in effect as early as 8:00 pm or as late as 8:00 am the next day. Any closure outside this period is expected to cause longer delays and queue lengths with time, and accordingly, the estimated WZ RUC increases exponentially until the lanes are restored to traffic. For the three-lane closure, there is no buffer time for earlier closure, and the lane opening can only be delayed by an hour. As expected, the adverse impact of early closure or late restoration is more significant when three lanes are closed to traffic.

Table 67. I-66 mainline: RealCost WZ RUC estimates for different lane closure timings (two of four lanes closed).

Lane Closure Timings		Daily WZ RUC	Net Difference	Maximum Queue Length (miles)	Maximum Delay Time (minutes)
Closed	Opened				
6 pm	5 am	$457,844	$455,353	9.8	59.3
7 pm	5 am	$124,172	$121,681	3.9	25.4
8 pm	5 am	$3,219	$728	0	1.1
9 pm	5 am	$2,491	$0	0	1.1
Allowable closure period					
9 pm	6 am	$2,711	$220	0	1.1
9 pm	7 am	$3,253	$762	0	1.1
9 pm	8 am	$3,981	$1,490	0	1.1
9 pm	9 am	$12,635	$10,144	0.8	6.0

Table 68. I-66 mainline: RealCost WZ RUC estimates for different lane closure timings (three of four lanes closed).

Lane Closure Timings		Daily WZ RUC	Net Difference	Maximum Queue Length (miles)	Maximum Delay Time (minutes)
Closed	Opened				
7 pm	5 am	$1,590,723	$1,518,188	16.7	246.5
8 pm	5 am	$637,481	$564,946	9.4	140.3
9 pm	5 am	$264,440	$191,904	5.4	81.3
10 pm	5 am	$72,535	$0	2.2	35.6
Allowable closure period					
10 pm	6 am	$72,755	$220	2.2	35.6
10 pm	7 am	$90,072	$17,537	2.2	35.6
10 pm	8 am	$169,940	$97,405	5.7	65.2
10 pm	9 am	$351,057	$278,522	13.1	138.8

Table 69 presents a comparison of the VDOT and RealCost-based lane rental fees. The lane rental fee for a given closure period is calculated as the difference in the WZ RUC estimates between the actual and the allowable closure periods, and adjusted using a discount factor. Negative differences indicate that the adverse impacts for a given lane closure period are not worse than those allowed in the contract (i.e. impacts of the allowable closure period), and hence, no fees apply. The WZ RUC estimates presented in Tables 67 and 68 were used. A discount factor of 1.0 was used in developing RealCost-based lane rental fees.

Note that a one-to-one comparison between the VDOT and RealCost-based fees cannot be made for the comparison presented herein because of the differences in assumptions used in VDOT calculations such as the unit costs and the use of discount factors.

Table 69. I-66 project: comparison of VDOT and RealCost-based lane rental fees.

Two of Four Lanes Closed			**Three of Four Lanes Closed**		
Closure Period	**VDOT**	**RealCost**	**Closure Period**	**VDOT**	**RealCost**
9:00 PM to 5:00 AM	$0	$0	10:00 PM to 5:00 AM	$0	$0
9:00 PM to 6:00 AM	$200	$220	10:00 PM to 6:00 AM	$9,000	$220
9:00 PM to 7:00 AM	$600	$762	10:00 PM to 7:00 AM	$28,000	$17,537
9:00 PM to 8:00 AM	$1,000	$1,490	10:00 PM to 8:00 AM	$48,000	$97,405
9:00 PM to 9:00 AM	$1,400	$10,144	10:00 PM to 9:00 AM	$68,000	$278,522

Table 70 presents a comparison of lane rental fees at different discount factors for three lane closures only.

Table 70. I-66 project: comparison of lane rental fees at different discount factors (three of four lanes closed condition only).

Closure Period	VDOT Fee	RealCost-based Fees at a discount factor of :		
		DF =1.0	DF =0.5	DF =0.25
10:00 PM to 5:00 AM	$0	$0	$0	$0
10:00 PM to 6:00 AM	$9,000	$220	$110	$55
10:00 PM to 7:00 AM	$28,000	$17,537	$8,769	$4,384
10:00 PM to 8:00 AM	$48,000	$97,405	$48,703	$24,351
10:00 PM to 9:00 AM	$68,000	$278,522	$139,261	$69,631

5.2 IMPROVEMENTS TO THE 24TH STREET–I-29/80 INTERCHANGE IN COUNCIL BLUFFS, IOWA

This case study illustrates the application of WZ RUC in the benefit-cost analysis for a project to determine whether using an accelerated construction technique would be economically justifiable. A bridge replacement project at the interchange of 24th street and Interstate 29/80 in Council Bluffs, Iowa was selected for this case study.

The bridge replacement on the 24th Street and I-29/80 interchange was completed and opened to traffic in 2008. The post-construction information of this project was obtained for this case study; however, for the sake of illustration, it is assumed that the key pieces of during-construction information, such as the agency costs and work zone delay time, were available before construction for decision making. Note that the decision to use the accelerated construction technique is made in the pre-construction phase of a project.

5.2.1 Project Description

Background and Location

The Iowa DOT, Nebraska Department of Roads, and FHWA, in coordination with the city of Council Bluffs and the Metropolitan Area Planning Agency, proposed improvements to the Council Bluffs Interstate System around Council Bluffs, Iowa. The proposed improvements were intended to upgrade mobility through the interstate corridors and modernize them to accommodate future traffic needs.

As a part of the CBIS improvement plan, the Iowa DOT undertook a construction project to replace the existing four–span concrete bridge serving 24th Street over I-80 with a wider and longer two–span steel girder bridge. Figure 22 shows the general project location. The existing four–span pretensioned, prestressed concrete beam bridge was replaced with a two–span steel welded girder bridge. The roadway improvements were completed on 24th Street south of the bridge consisting of a five–lane roadway with a raised median.

Traffic Volume

24th street carried an estimated AADT of 12,400 vehicles in 2004 with 14 percent trucks and is expected to carry 27,700 vehicles in 2030. For I–29/80, the 2004 AADT was 81,900 vehicles per day and the estimated 2030 AADT is 124,400 vehicles per day with 11 percent trucks (see Figure 23). The interchange serves major businesses, such as a large outdoor retailer, a convention and event center, and several casinos, hotels, and semi truck service centers.

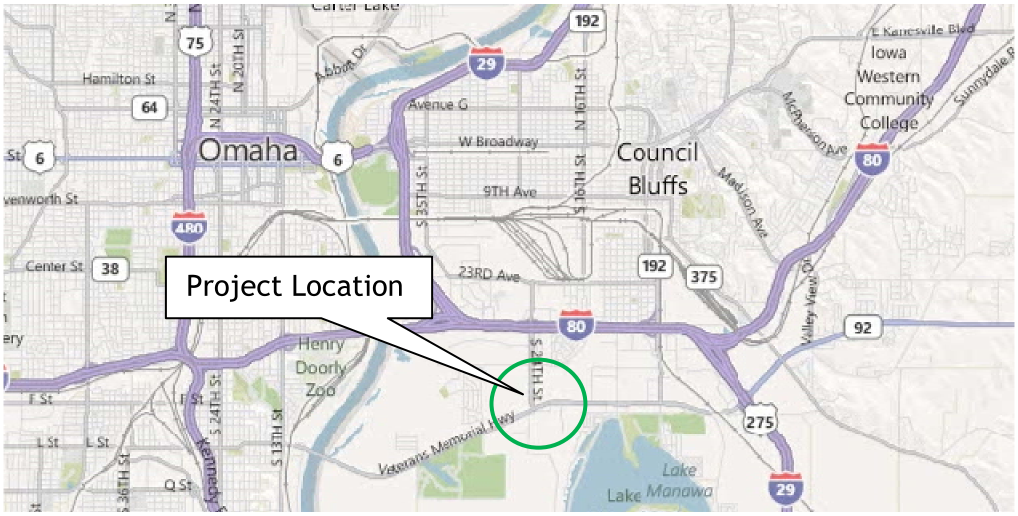

Figure 22. General project location of 24th Street Reconstruction Project. (Map Source: Bing)

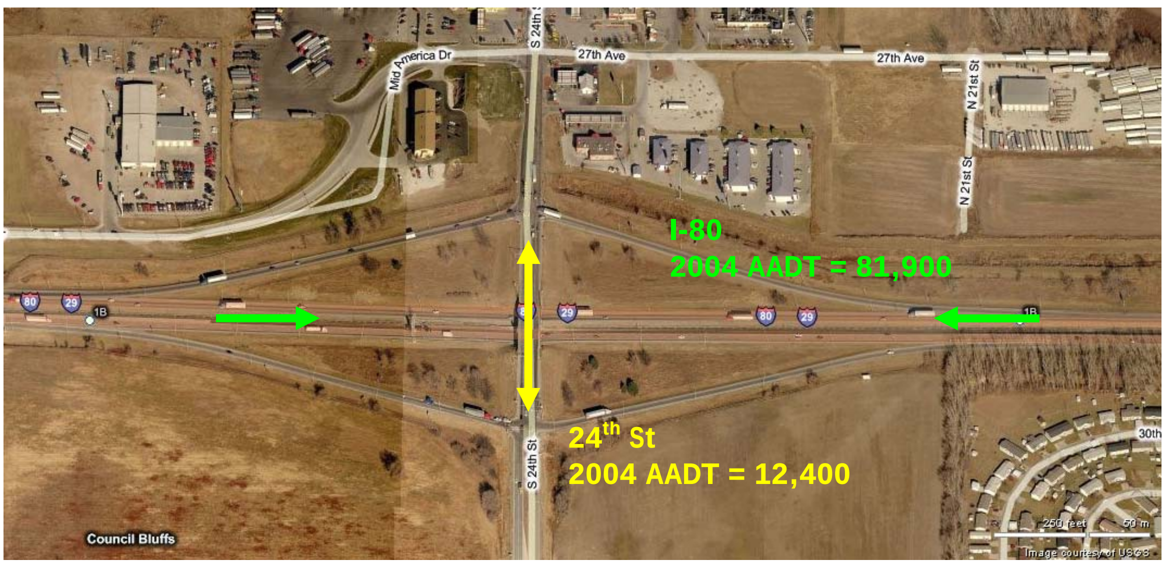

Figure 23. Traffic volume at the 24th Street Interchange.

Travel Time Estimates

During construction, none of the exit ramps of 24th Street was expected to create queue back onto the I-29/80 freeway mainline lanes. Travel speeds were estimated to be 60 mph on I-29/80. Travel times along the 1.5-mile length of 24th Street were estimated to be 5.8 and 6.5 minutes in the northbound and southbound directions, respectively. For eastbound I-29/80 traffic exiting at 24th Street and then turning left, travel times to the northern terminus of 24th Street were estimated to be 4.0 minutes over the 0.9-mile distance. For westbound I-29/80 traffic exiting and then turning left, the travel time for the 1.4-mile journey to the southern terminus of 24th Street were estimated to be 4.5 minutes. Table 71 presents per-vehicle travel time and delay estimates. For simplicity, a delay time value of 2.6 minutes per vehicle was deemed reasonable for use in delay cost calculations for all movement types within the interchange.

Table 71. 24th street reconstruction project: per vehicle travel time and delay estimates.

Movement	Normal travel time (min)	Travel time during construction (min)	Estimated Delay (min)
24th Street northbound	3.3	5.8	2.3
24th Street southbound	3.3	6.5	3.2
I-29/80 eastbound to 24th Street northbound	1.4	4.0	2.6
I-29/80 westbound to 24th Street southbound	1.9	4.5	2.6

Pre - Construction Crash Data

According to the Iowa DOT 2001-2005 crash statistics, the project area has experienced an average 0.215 crashes/MVMT. The crash rates for personal injury (injuries and fatalities) and property damage were 0.069 crashes/MVMT and 0.146 crashes/MVMT, respectively.

Construction Technique and Project Duration

The Iowa DOT considered the use of full-depth pre-cast concrete panels for bridge decks. The pre-cast panels would be cast offsite in a controlled environment, steam cured, and made with an innovative self-consolidating concrete to improve consolidation around the complicated arrangement of reinforcing and post-tension ducts. The panels would be prestressed transversely during casting and post-tensioned longitudinally after placement.

Pre-cast concrete technology was considered in place of conventional cast-in-place construction techniques primarily to reduce the project delivery time and open all lanes on the new bridge within one construction season (213 days). Standard phased construction with conventional cast-in-place construction techniques would have resulted in two or three open lanes, but would have taken more than two construction seasons for completion (426 calendar days). The use of pre-cast deck panels was expected to shorten the construction time to only 6 months (175 days).

Full closure of the bridge was expected to take less time but would have been unacceptable to the surrounding businesses that rely heavily on the interchange. The selection of pre-cast deck panels over cast-in-place construction was expected to save over 251 calendar days (i.e., 426-175 days) in construction time.

5.2.2 Case Study Objectives

The primary objective of this case study is to demonstrate the application of WZ RUC in benefit cost analysis to evaluate whether the use of pre-cast deck panels to minimize the work zone impacts would be an economically justifiable option for this project. The analysis entails an objective comparison of the cost premium associated with the use of pre-cast deck panels and the benefits through savings in WZ RUC and agency construction engineering costs. The conventional construction option is designated as the baseline option, while the pre-cast option is designated as the proposed option.

5.2.3 Construction Costs

The Iowa DOT provided the construction cost estimates for both baseline and pre-cast options. The construction costs included the design and engineering costs, bridge replacement costs, cost of roadway improvements, traffic control and miscellaneous costs.

Table 72 presents the differences in construction costs between the baseline and the pre-cast options. The following assumptions were used in determining the construction costs:

- The Iowa DOT used 6 and 8 percent of the total project costs for design and engineering for the baseline and pre-cast options, respectively.
- Since the agency was expected to use the same traffic management plan regardless of the use of pre-cast deck panels, the costs for traffic control and roadway improvements were assumed to be the same for both options.
- The agency assumed that the typical construction inspection costs would be about 1 percent of the bridge construction costs. The construction inspection costs for the pre-cast option were estimated to be 10 percent higher than the baseline option.

Table 72. 24th street reconstruction project: agency costs.

Cost Category	Baseline Option	Proposed Option
Design and Engineering	$ 304,380	$ 516,032
Bridge Construction	$ 5,073,000	$ 6,450,398
Roadway Improvements	$ 4,807,721	$ 4,807,721
Traffic Control	$ 272,521	$ 272,521
Construction Inspection	$ 50,730	$ 70,954
Other	$ 620,512	$ 388,636
Total Cost	**$ 11,128,864**	**$ 12,506,262**

Table 72 indicates that the use of pre-cast concrete panels would incur an additional cost of $1,377,398 or 12.4 percent for the agency when compared to the cast in-place option.

5.2.4 Work Zone Road User Costs

The WZ RUC considered in this case study included only travel delay and crash costs. The cost differentials between the proposed and baseline option were computed for each component.

5.2.4.1 Travel Delay Costs

Since the Iowa DOT would use the same traffic management plan for both proposed and baseline option, the delay time statistics reported in Table 71 were used in computing delay costs. The unit cost data were provided by the Iowa DOT. The Iowa DOT contracting office estimates the cost to the public at $8 an hour per private vehicle and $24 an hour per single and multiple-unit commercial truck in 2008.

The 2008 AADT of the 24th Street intersection was interpolated using the 2004 and 2030 AADT values.

AADT in 2004 = 12,400 vehicles/day
AADT in 2030 = 27,700 vehicles/day
AADT in 2008 = 14,000 vehicles/day (interpolated)
Percent trucks = 14 %

The delay cost computations are presented as follows:

Average delay time per vehicle = 2.6 minutes (from Table 71)
Delay time for passenger cars per day = number of passenger cars * delay time/vehicle
= 14,000 * 0.86 * 2.6 min/60 = 521.7 vehicle-hours/day

Delay costs per day for passenger cars = 521.7 * $ 8.00 = $4,173.87
Delay time for trucks per day = number of trucks * delay time/vehicle
= 14,000 * 0.14 * 2.6 min/60 = 84.9 vehicle-hours/day

Delay costs per day for trucks = 84.9 * $ 24.00 = $2038.40
Delay costs per day for all vehicles = $4,173.87 + 2038.40 = $6,212.27/day

The selection of accelerated construction techniques has saved 251 days of construction time.

Total days saved = 251
Total savings in delay costs = 251 * $6,212.27/day = $1,559,280

Therefore, it is estimated that an amount of $1,559,280 would be saved in delay costs as a direct result of accelerating the construction to only a single season.

5.2.4.2 Crash Costs

The approach presented in section 2.4 was used in computing the crash costs. The key steps included:

1. Compute the pre-construction crash rate.
2. Compute the work zone crash rate.
3. Estimate the measure of work zone exposure for both proposed and baseline options.
4. Compute unit cost for crashes.
5. Compute work zone crash costs for both options.

Pre-construction Crash Rate

The crash rates for personal injury (injuries and fatalities) and property damage were 0.069 and 0.146 crashes/MVMT, respectively.

Work Zone Crash Rate

No agency-specific work zone crash rates or CMFs were available for this project. To account for crash-related risk escalation in work zones, a CMF value of 1.63 was assumed for temporary lane closures in this project based on the work done by Ullman et al. [42] See section 2.4.1 for more discussion on selecting a work zone crash rate.

Crash modification factor for work zone = 1.63
Crash rate for personal injury =0.069 * 1.63 = 0.112 crashes /MVMT
Crash rate for crash = 0.146 * 1.63 = 0.238 crashes/MVMT

Work Zone Exposure

The VMT during work zone period is computed for both options. The affected area includes both 24th Street and I-29/80. Table 73 shows that the total volume of traffic exposed to crash risk was much lower for the pre-cast option than the baseline option.

Unit Cost of Crashes

The unit costs (in 2001 dollars) of personal injury and non-injury crashes were obtained from FHWA cost estimates.[49] The crash geometry of an accident is unknown, and therefore, Level 5 estimates were used. The mean comprehensive costs per crash for a rural highway with a posted traffic speed greater than or equal to 50 mph and an arterial highway with a posted traffic speed less than 45 mph were used for I-29/80 and 24th Street, respectively. Table 74 summarizes the mean comprehensive costs of personal injury and non-injury crashes in 2009 dollars for both I-29/80 (speed>50 mph) and 24th Street (speed <45 mph).

Table 73. 24th street reconstruction project: work zone exposure for baseline and pre-cast options.

Parameter	Baseline Case		Proposed Case	
	I-29/80	24th Street	I-29/80	24th Street
2008 AADT, vehicles/day	88,348	14,000	88,348	14,000
Construction period	426	426	175	175
Total Traffic Volume (millions)	37.64	5.96	15.46	2.45
	43.60		17.91	

Table 74. 24th street reconstruction project: unit cost data for crashes.

Parameter	I-29/80		24th Street	
	Injury-causing crash	Non-injury crash	Injury-causing crash	Non-injury crash
Human capital costs* (2001 dollars)	$49,624	$16,027	$38,344	$14,577
Mean comprehensive costs (2001 dollars)	$95,368	$25,735	$72,002	23,993
Mean comprehensive costs (2008 dollars)**	$117,391	$31,594	$88,601	$29,467

Note (*): Level 5 estimates from cost tables provided by Council et al.[49]
(**) : Follow the procedure presented in Section 2.4.3

Work Zone Crash Costs

The crash costs were computed by multiplying work zone crash rate with the measure of exposure (MVMT) and the corresponding mean comprehensive costs. Tables 75 and 76 present the crash cost computations for the baseline and pre-cast options, respectively. The selection of pre-cast option would result in $517,829 savings of crash costs.

Table 75. 24th street reconstruction project: crash costs for the baseline option.

Parameter	I-29/80	24th Street	Parameter	I-29/80
	Injury-causing crash	Non-injury crash	Injury-causing crash	Non-injury crash
Crash Rate	0.112	0.238	0.112	0.238
Exposure (MVMT)	37.64	37.64	5.96	5.96
Unit cost	$117,391	$31,594	$88,601	$29,467
Crash Cost	$494,883	$283,005	$59,143	$41,795
Total	$878,826			

Table 76. 24th street reconstruction project: crash costs for the pre-cast option.

Parameter	I-29/80	24th Street	Parameter	I-29/80
	Injury-causing crash	Non-injury crash	Injury-causing crash	Non-injury crash
Crash Rate	0.112	0.238	0.112	0.238
Exposure (MVMT)	15.46	15.46	2.45	2.45
Unit cost	$117,391	$31,594	$88,601	$29,467
Crash Cost	$203,265	$116,240	$24,312	$17,181
Total	$360,998			

5.2.4.3 Savings in WZ RUC

The total savings in WZ RUC is the sum of savings in delay and crash costs. The selection of pre-cast option would result in WZ RUC savings of $2,077,108.

Total savings in WZ RUC = savings in delay costs + savings in crash costs
= $1,559,280 + 517,828 = $2,077,108

5.2.5 Benefit-Cost Analysis

The expected savings in WZ RUC that will be realized through the use of pre-cast panels were compared with its additional construction costs.

Increase in construction costs (∆ cost) = $1,377,398 (from section 5.2.3)
Savings in WZRUC (∆ benefit) = $2,077,108 (from section 0)
Cost difference (∆ benefit -∆ cost) = $2,077,108 - 1,377,398 = $699,710

Incremental benefit-cost ratio is the ratio between the savings in WZ RUC (∆ benefit) and the increase in construction costs (∆ cost). An incremental benefit-cost ratio greater than 1.0 would indicate that the benefit of using pre-cast deck panels in this project would outweigh its costs.

Incremental benefit-cost ratio = ∆ benefit /∆ cost = $2,077,108/ 1,377,398 = 1.51 > 1.0

Percent benefit of total cost is the ratio of difference between the WZ RUC savings and the net cost increase (∆ benefit -∆ cost) relative to the total cost of the baseline option. Any positive difference between the WZ RUC savings and the construction cost premium would indicate that the benefit of using pre-cast deck panels in this project would outweigh its costs.

Percent benefit of total cost = (∆ benefit -∆ cost) / cost (baseline option)
=$699,710/11,128,864 = 6.3 percent

These computations clearly show that the benefit of using pre-cast concrete deck panels in this project outweighs its cost premium. Using pre-cast concrete deck panels would save an estimated $699,710 in this project. In other words, selecting the pre-cast panel option for this project would have a 6.3 percent cost benefit over traditional cast in-place methods.

5.3 RECONSTRUCTION OF EASTERN AVENUE BRIDGE OVER KENILWORTH AVENUE IN WASHINGTON, DC

The reconstruction of Eastern Avenue Bridge over Kenilworth Avenue was selected for this case study to demonstrate the application of the Kepner-Tregoe decision analysis method in MOT alternative analysis. The actual information obtained for this project was modified with a number of assumptions for illustration purposes.

5.3.1 Project Description

Project Location and Background

This project is located along Eastern Avenue in the northeastern corner of Washington, DC, at the border with Prince George's County, MD. The bridge crosses over Kenilworth Avenue, which is the continuation of the Baltimore Washington Parkway/I-295 through Washington, DC.

Kenilworth Avenue is a six-lane principal urban expressway that serves commuters between Washington, DC, and Prince George's County, Maryland. It also serves as a homeland security evacuation route for DC wards 7 and 8. US 50 (John Hanson Highway/New York Avenue) just north of the project site feeds a large portion of traffic to this segment of DC 295. Figure 24 shows the general location of the project.

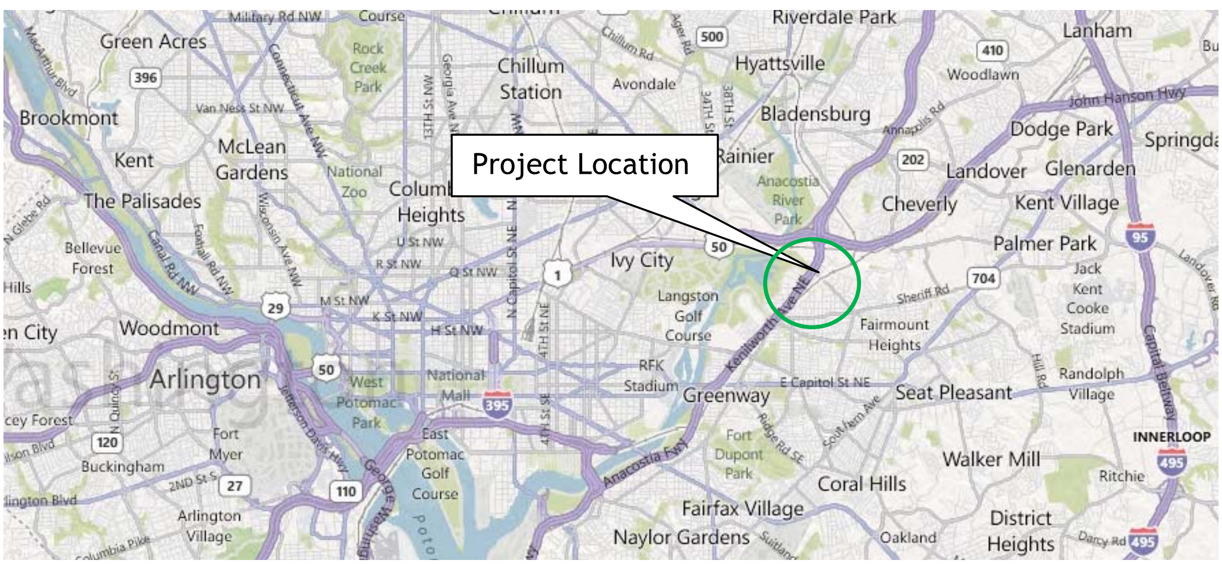

Figure 24. Location of Eastern Avenue project. (Map Source: Bing)

Figure 25 presents an aerial view of the project location and the conditions before reconstruction. The profile of Kenilworth Avenue is depressed to cross under Eastern Avenue at their intersection. Parallel to Kenilworth Avenue and on either side are two one-way service roads more than 24 ft wide that provide access to local homes and businesses.

The Eastern Avenue Bridge before reconstruction was a single-span bridge crossing all six lanes of Kenilworth Avenue. The intersection is signalized on top for turns between Eastern Avenue and Kenilworth Avenue service roads. Ramps between mainline Kenilworth Avenue and its parallel service roads provide access between Kenilworth Avenue and Eastern Avenue.

Kenilworth Aquatic Gardens, administered by the National Park Service, are located northwest of the intersection. The bridge serves as a pedestrian crossing, truck turnaround, and link between portions of northeast DC.

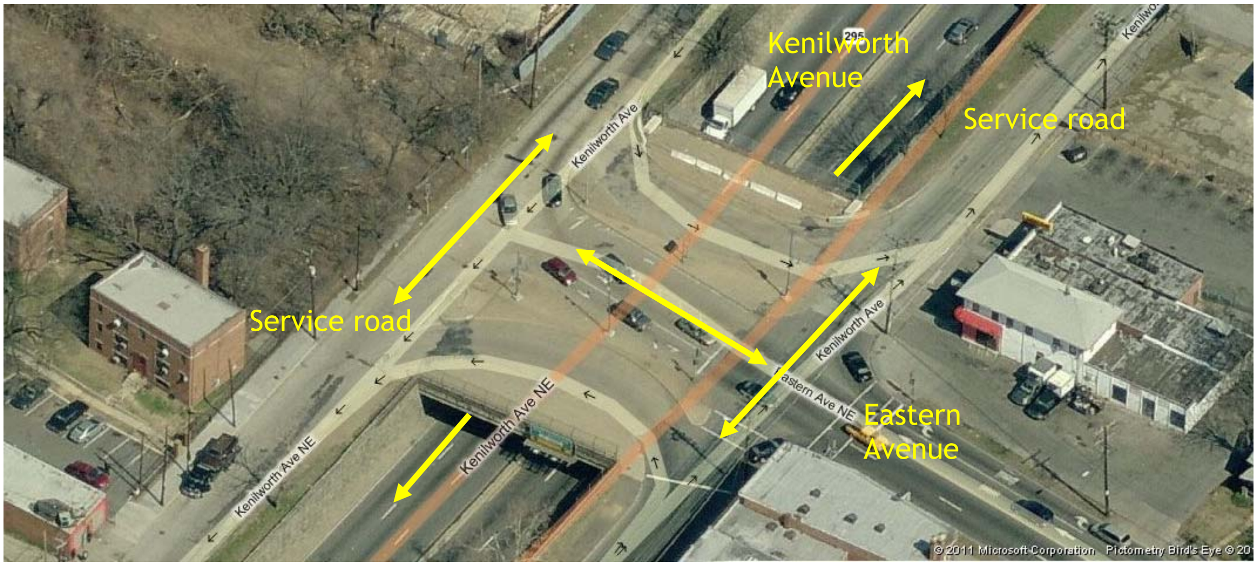

Figure 25. Preconstruction aerial photograph of Eastern Avenue bridge.

The existing bridge allows for a minimum vertical clearance of 14 ft along Kenilworth Avenue. Due to its low vertical clearance, it has been struck several times. As a result, the bridge structure was damaged and deteriorating. The Washington DC DOT reconstructed the bridge to increase the minimum vertical clearance to 16 ft, the maximum extent practicable, and to increase safety at the crossing for both pedestrians and vehicular traffic.

Pre-construction Crash Data

Statistics collected between 2001 and 2003 indicate a crash rate of 156 crashes/MVMT on the segment of Kenilworth Avenue south of Eastern Avenue. For the intersection of Eastern Avenue and the service roads, the crash data indicate there were a total of 70 accidents in the 3-year study period between 2003 and 2005. The majority of accidents at the intersection involved rear-end type hits, sideswipes, left turn accidents, broadsides, and fixed object accidents. Almost 50 percent of the accidents occurred between the hours of 6:30 pm and 7:30 am, indicating the possibility of lighting and visibility issues.

Traffic Volume

Kenilworth Avenue carries an ADT of approximately 150,000 vehicles with 4.9 percent trucks on the northbound lanes and 6.3 percent trucks on the southbound lanes. Figure 26 presents the typical hourly demand in both the northbound and southbound directions. The posted speed limits in the project area are 45 mph on mainline Kenilworth Avenue, 30 mph on the service roads, and 25 mph on Eastern Avenue.

Eastern Avenue is a minor arterial with 37,000 ADT and 7 percent commercial vehicles that runs in a northwest-to-southeast direction beginning at Kenilworth Avenue and continues southeast along the boundary between Washington, DC, and Prince George's County, MD.

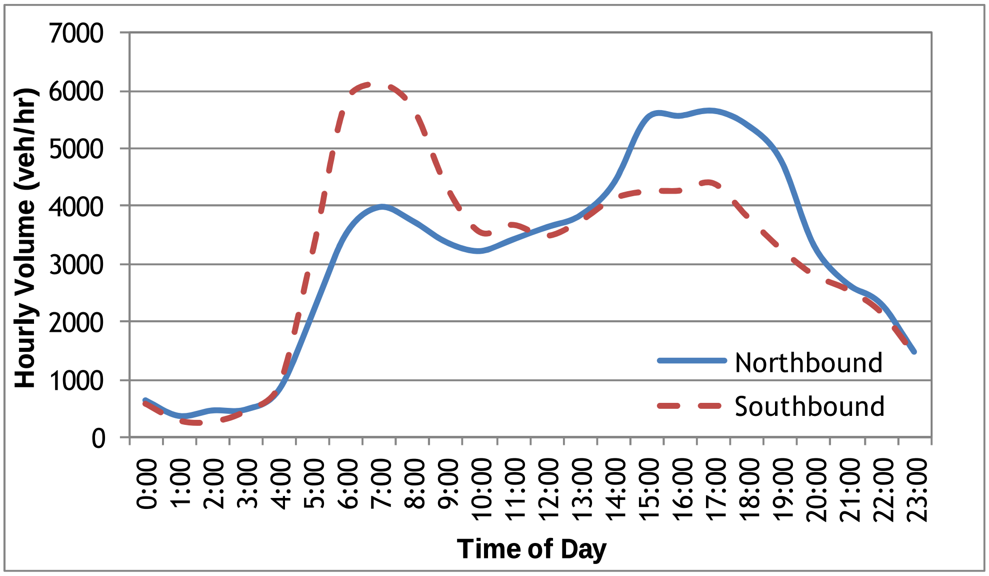

Figure 26. Hourly traffic volumes on Kenilworth Avenue.

Construction Strategies

Based on the feasibility analysis of several design and construction alternatives, the following strategies were selected:

1. Reconstruct the bridge pier using prefabricated pier units on a cast-in-place foundation.
2. Replace the existing single-span superstructure with a two-span bridge using prefabricated units.

Note: This case study focuses only on the MOT alternative analysis for the bridge pier construction.

Nearby Projects

Several nearby highway construction projects were undertaken during the same period:

- Reconstruction of MD 201 bridge over Amtrak railroad lines.
- Reconstruction of Kenilworth Avenue bridges over Nannie Helen Burroughs Avenue.
- Installation of utility lines along Nannie Helen Burroughs Avenue.
- Signalization improvements the intersection of Minnesota Avenue and Nannie Helen Burroughs Avenue.

Project Coordination

The DOT undertook project coordination efforts to manage the work zone impacts resulting from adjacent projects. Traffic control plans were refined to improve the traffic along Nannie Helen Burroughs Avenue, which serves as one of the detour routes for the Eastern Avenue project. In addition, the agency coordinated with Maryland SHA, Virginia DOT, and the National Park Service to manage any traffic spillback on adjacent routes and implement public information strategies such as overhead message signs.

MOT Strategies

A formal traffic impact assessment and MOT alternative analysis was conducted by project consultant Greenhorne & O'Mara, Inc.[142] Two MOT alternative schemes were considered for the mainline Kenilworth Avenue through traffic:

- MOT Option 1 – close one of three lanes in each direction on mainline Kenilworth Avenue.
- MOT Option 2 – close one of three lanes in each direction on mainline Kenilworth Avenue and supplement with two-lane service roads in each direction.

Detour routes were devised to facilitate all left turns at the Eastern Avenue/Kenilworth Avenue Intersection.

Note: This case study considers only the MOT strategies devised for the mainline Kenilworth Avenue through traffic. In addition to the two alternatives mentioned above, the following MOT strategies were considered for illustration purposes:

- MOT Option 3 - close two of three lanes in each direction on mainline Kenilworth Avenue and supplement with two-lane service roads in each direction.
- MOT Option 4 - full closure of this segment of Kenilworth Ave and divert traffic through detour.
- MOT Option 5 - close one of three lanes in each direction only during nighttime.

5.3.2 Objectives

The primary objective of this case study is to demonstrate the application of Kepner-Tregoe Decision Analysis framework in MOT alternative analysis.

5.3.3 Need for MOT Alternative Analysis

In accordance with the FHWA's Work Zone Rule, MOT alternative analysis is required for any project that is designated as significant. The DOT's Work Zone Safety and Mobility Policy defines a significant project as the one that, alone or in combination with other concurrent projects nearby, is anticipated to cause sustained work zone impacts that are greater than what is considered tolerable based on DOT policy and/or engineering judgment. The DOT considers the work zone impacts acceptable if the queue length is less than 1.0 mile. MOT alternative analysis is required for any project that is identified as a significant project.

The DOT identified this project as significant based on the following factors:

- Kenilworth Avenue is an urban interstate highway in a metropolitan area that carries heavy traffic volumes each day.
- Traffic disruption caused by work zone activities would directly affect a large number of travelers and result in unacceptable travel delay times and queues.

[142] Greenhorne & O'Mara, Inc. *Eastern Avenue Over Kenilworth Avenue, N.E. Work Zone Transportation Management Plan, Washington, D.C.* Prepared for District Department of Transportation Infrastructure Project Management Administration/Team 4. May 2009.

- This project was expected to occupy the Kenilworth Avenue and Eastern Avenue roadways for more than 2 months with intermittent or continuous lane closure.

Based on the above assessment, there is a need for conducting a comprehensive MOT alternative analysis for this project.

5.3.4 Kepner-Tregoe Decision Analysis

As detailed in section 3.2.7, the steps involved in the K-T decision analysis method are as follows:

1. Prepare decision statement.
2. Define MUST and WANT objectives.
3. Assign weights to WANT objectives.
4. Identify candidate MOT alternatives.
5. Summarize the findings of work zone impact assessment.
6. Evaluate alternatives against MUST objectives.
7. Evaluate alternatives against WANT objectives.
8. Calculate the weighted scores of alternatives.
9. Evaluate adverse consequences.
10. Select the preferred MOT strategy.

Step 1. Prepare a decision statement

The purpose of the decision analysis is to identify the most appropriate strategy for maintaining traffic on mainline Kenilworth Avenue during the reconstruction of bridge piers of the Eastern Avenue bridge.

Step 2. Define MUST and WANT objectives

The MUST objectives are mandatory attributes to be considered in the decision process. Any alternative that cannot comply with a MUST objective is eliminated from further consideration, while those comply with all the MUST objectives qualify as feasible alternatives. The MUST objectives identified for this project are as follows:

1. Does an MOT option satisfy constructability requirements? — Limited work zone space on mainline Kenilworth Avenue was identified as a key constraint of this project. Therefore, it is imperative to check whether the MOT alternative to be implemented in this project satisfies the constructability requirements.
2. Are there any alternate detour routes to accommodate full diversion of Kenilworth Avenue traffic? — The goal is to check whether there are any alternative detour routes that can accommodate full diversion of Kenilworth Avenue traffic to facilitate full closure for longer periods of time, such as a 55-hour weekend closure.

The WANT objectives are desired attributes based on which a preferred alternative is selected from those alternatives satisfying all of the MUST objectives. The WANT objectives identified for this project are as follows:

1. Travel delay time — Total delay in vehicle-hours was selected as the measure of effectiveness for this analysis.

2. Spillback on MD 201 southbound, US 50 westbound, and other routes— Queuing conditions on Kenilworth Avenue southbound lanes would cause spillback congestion on MD 201 and US 50. Traffic backup on northbound lanes would cause similar impacts on East Capitol Street, Benning Road, and Nannie Helen Burroughs Avenue interchanges. Queuing on Kenilworth Avenue mainlines is used as a surrogate measure for traffic spillback.
3. Crash-related risks — The work zone influence area of this project extends into a larger area and is more complex depending on the queuing conditions and detour arrangements. The crash costs were not computed in this case study for the purpose of simplicity, while a subjective assessment of crash-related risks will be taken into consideration.
4. Inconvenience to local residents — Large residential areas are located southwest and northeast of the site, especially along Eastern Avenue. The service roads parallel to Kenilworth Avenue serve as transit points (bus stop locations) for local residents using the Washington Metropolitan Area Transit Authority (WMATA) services. There may be a need to relocate WMATA bus stops and impose temporary parking restrictions on these service roads. The inconvenience caused by the work zone MOT implementation on local residents should be considered.
5. Emergency response and school transportation — There are several schools in the vicinity of the project area. Therefore, the effect of any traffic diversion, congestion and restriction imposed in the work zone vicinity on emergency response and school transportation should be taken into account.
6. Pedestrian access — The Eastern Avenue bridge and nearby service roads are used by many pedestrians, including school children and transit users. There are limited pedestrian bridges to cross Kenilworth Avenue. Therefore, the impact of the selected MOT option on pedestrians, such as the pedestrian restrictions or the distance to the proximate pedestrian bridge, should be considered.
7. Construction duration — The number of days for project completion associated with each MOT option should be considered.
8. Traffic control and improvement costs — The expenditure for traffic control devices, related roadway improvements (to maintain traffic), and public information strategies should be taken into account.

Step 3. Assign weights to WANT objectives

Each WANT objective is weighted on a scale of 1 to 10 based on their relative importance in the decision process, with 1 indicating “least preferable” and 10 indicating “most preferable” or “equally preferable” (see Table 77).

Table 77. Eastern Avenue project: weighting WANT objectives.

WANT Objective	Weights
Travel delay time	10
Spillback on nearby roadways	10
Crash-related risks	10
Inconvenience to local residents	5
Emergency response and school transportation	4
Pedestrian access	5
Construction duration	8
Traffic control and improvement costs	6

Step 4. Identify candidate MOT alternatives

The MOT alternatives identified for the decision analysis are listed as follows:

- MOT Option 1 – close one of three lanes in each direction on mainline Kenilworth Avenue.
- MOT Option 2 – close one of three lanes in each direction on mainline Kenilworth Avenue and supplement with two-lane service roads in each direction.
- MOT Option 3 - close two of three lanes in each direction on mainline Kenilworth Avenue and supplement with two-lane service roads in each direction.
- MOT Option 4 - full closure of this segment of Kenilworth Ave and divert traffic through detour.
- MOT Option 5 - close one of three lanes in each direction during nighttime only.

Step 5. Summarize the findings of work zone impact assessment

This step summarizes the findings of quantitative and qualitative assessment conducted to evaluate the impact of MOT alternative on work zone mobility, safety, constructability, and local community.

Constructability

A constructability review was conducted to evaluate the feasibility of the available MOT options. Options 1, 2, 3, and 4 appeared to be feasible from a constructability standpoint. These options allowed a continuous closure of one or more lanes until the bridge piers were installed.

Option 5, which allows only nighttime closure, appeared to be unfeasible, given the work zone space constraint on Kenilworth Avenue. A new foundation had to be cast-in-place before the installation of prefabricated components for the bridge pier, and hence, opening to traffic in the morning after a night closure was not feasible. Furthermore, since large residential areas are located in the work zone vicinity, the impact of construction noise had to be factored in. Though much of the construction work was accomplished at night, some types of activities were not permitted for night work. Therefore, Option 5 was removed from consideration.

Detour Alternatives

Given the volume of traffic, a feasibility analysis was conducted to identify any detour alternatives that would accommodate full diversion of Kenilworth Avenue traffic. The adjacent routes, including US 50 and Capital Beltway (i.e., I-95/I-495), carry similar volumes of traffic each day. As mentioned earlier, Kenilworth Avenue remains the only viable alternative available for commuters between downtown Washington, DC, and northern and eastern locations in Maryland. No alternative route appeared to have adequate capacity to accommodate the traffic that Kenilworth Avenue serves to facilitate a full closure of this segment for an extended period of time. Therefore, Option 4 was removed from consideration.

Service Roads

MOT Options 2 and 3 require using service roads to supplement the roadway capacity on Kenilworth Avenue. To open service roads for Kenilworth Avenue mainline traffic, the WMATA bus stops would have to be relocated. Temporary parking restrictions would have to be needed along the service lanes.

Pedestrian Access

Pedestrians typically use the Eastern Avenue bridge to cross Kenilworth Avenue. With the implementation of Options 2 and 3, pedestrians would have to detour approximately 0.5 mile round-trip to the nearest pedestrian bridge over Kenilworth Avenue. Pedestrian access improvements, such as temporary pedestrian bridge, were considered, but the high costs of these improvements would outweigh the likely minimal benefits to the low number of pedestrians using the intersection.

Emergency Response and School Transportation

With the selection of MOT Options 2 and 3, the DOT was required to provide advice on detours to emergency responder and school transportation officials. The adverse mobility impacts associated with an MOT alternative would have a proportional impact on emergency response time and incident management. The contractor was required to prepare incident/emergency response plan per the contract special provisions.

Construction Duration

The estimated construction duration with MOT Options 1, 2, and 3 was 2 months.

Traffic Control and Improvement Costs

No discernable difference in traffic control and related improvement cost was found among MOT Options 1, 2, and 3.

Mobility Impacts

Maryland SHA's Lane Closure Analysis Program (LCAP) was used to estimate delays along mainline Kenilworth Ave for Options 1, 2, and 3. Traffic demand volumes for a 48-hour period (Wednesday-Thursday) were entered into LCAP to determine the expected impacts of the lane closures. Traffic counts were taken along mainline Kenilworth Avenue for the same 48-hour period using automated machine count in October 2006. The work zone capacity values were obtained from Appendix B of the District of Columbia Work Zone Safety and Mobility Policy (dated 2007). The work zone capacity values assumed in the analysis were 1,490 and 1,170 vphpl for a single and two lane closures, respectively. The assumed work zone capacity was 1,000 vphpl for service roads.

Figures 27, 28, and 29 present the delay estimates varying along the time of day on northbound and southbound lanes of Kenilworth Avenue for MOT Options 1, 2, and 3, respectively. Table 78 presents the average and maximum delay time estimates for the three options. The statistics of delay time estimates indicate that the mobility impacts were much more severe with Options 1 and 3 than with Option 2. Figures 30, 31 and 32 present the delay estimates varying along the time of day on northbound and southbound lanes of Kenilworth Avenue for Options 1, 2, and 3, respectively. Table 78 presents the average and maximum queue estimates for these options. The average and maximum delay estimates with Option 2 appeared to be more tolerable than those with the other options.

Based on the LCAP estimates, Option 2 appeared to be the most advantageous from a mobility standpoint and was likely to result in much lower delay costs and VOC than other options.

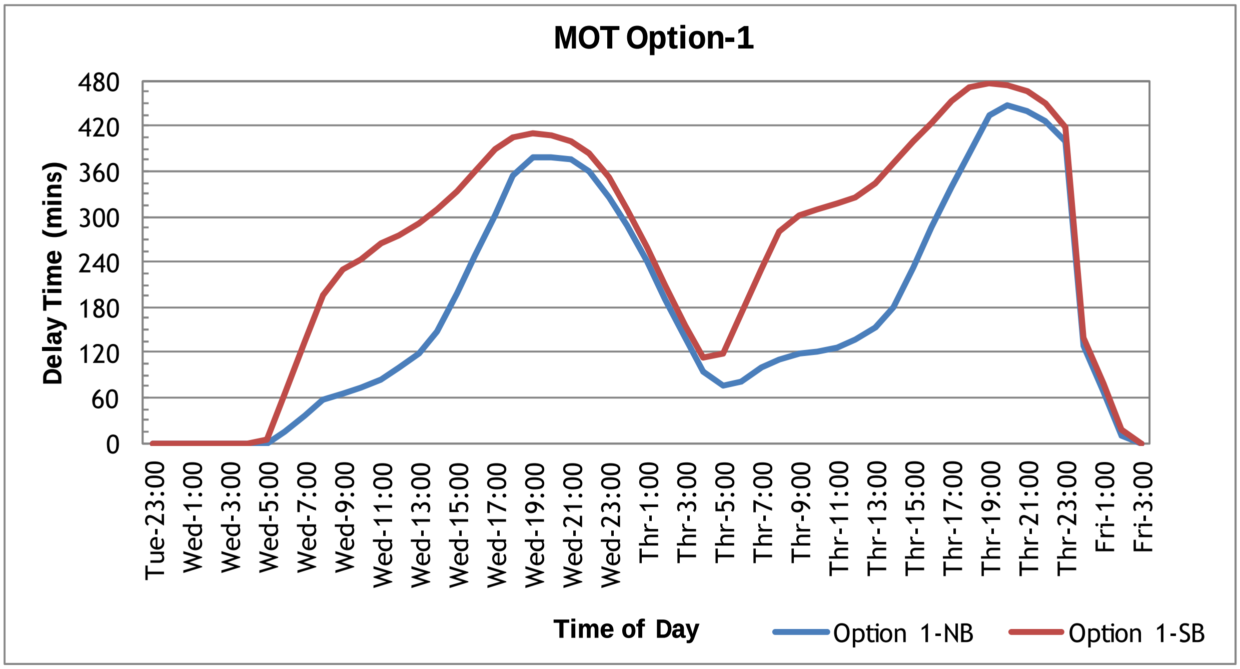

Figure 27. Eastern Avenue project: travel delay estimates for Option 1.

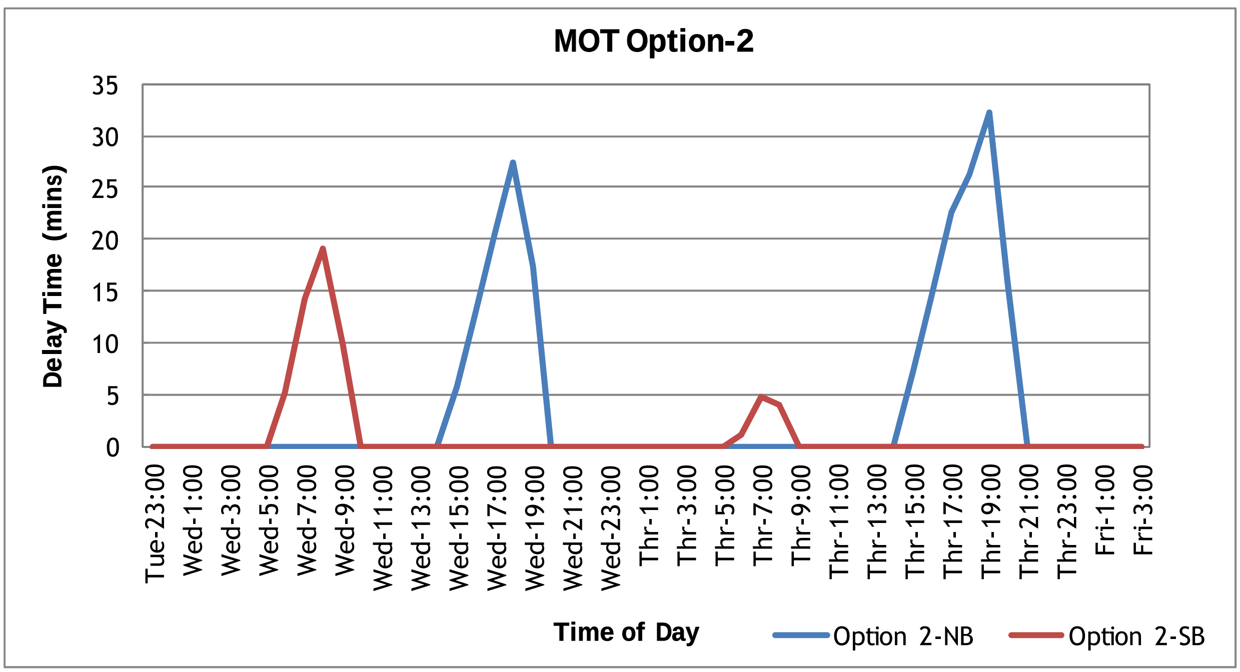

Figure 28. Eastern Avenue project: travel delay estimates for Option 2.

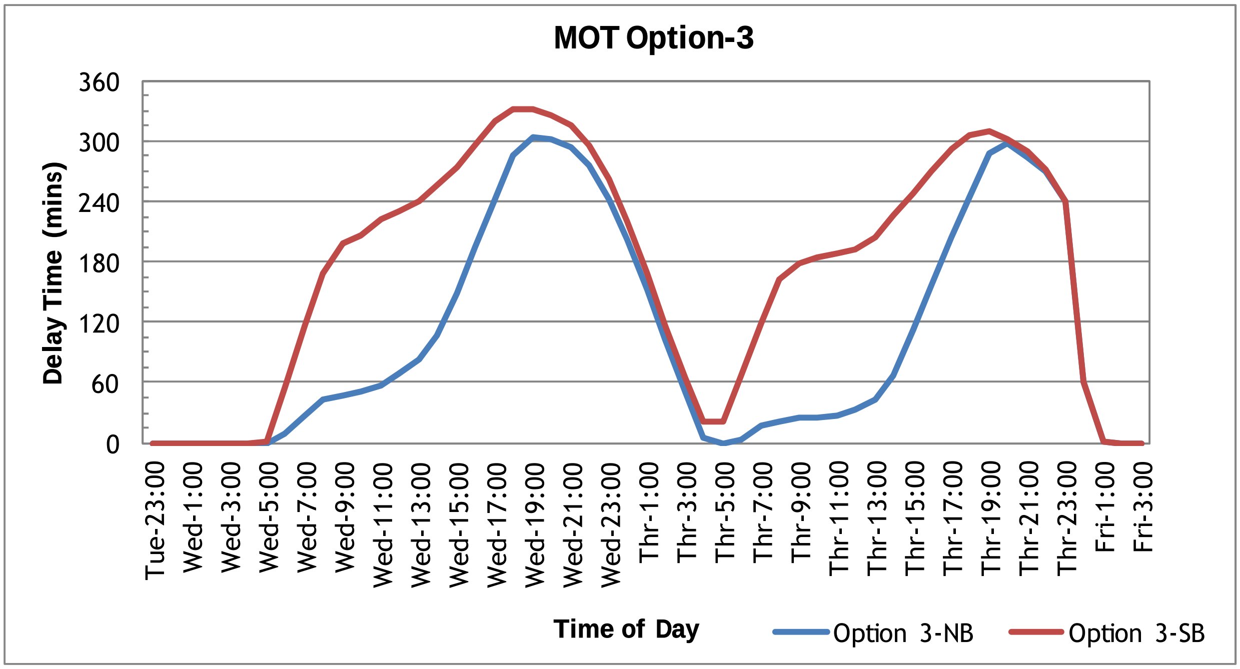

Figure 29. Eastern Avenue project: travel delay estimates for Option 3.

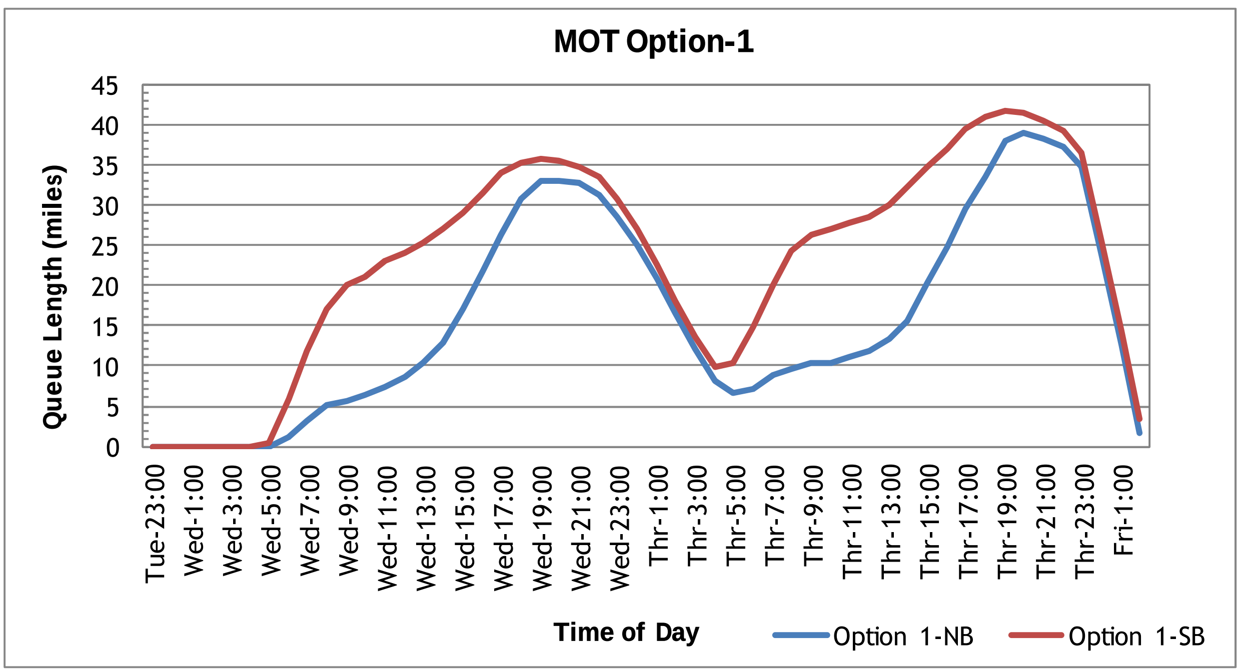

Figure 30. Eastern Avenue project: queue length estimates for Option 1.

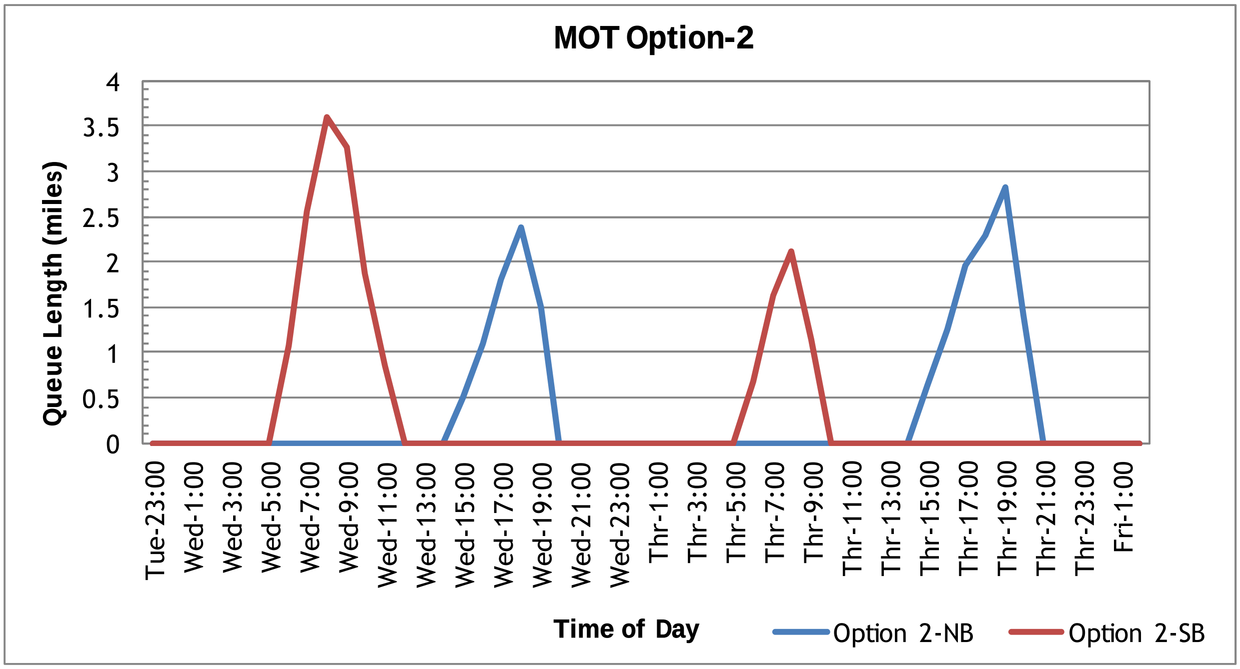

Figure 31. Eastern Avenue project: queue length estimates for Option 2.

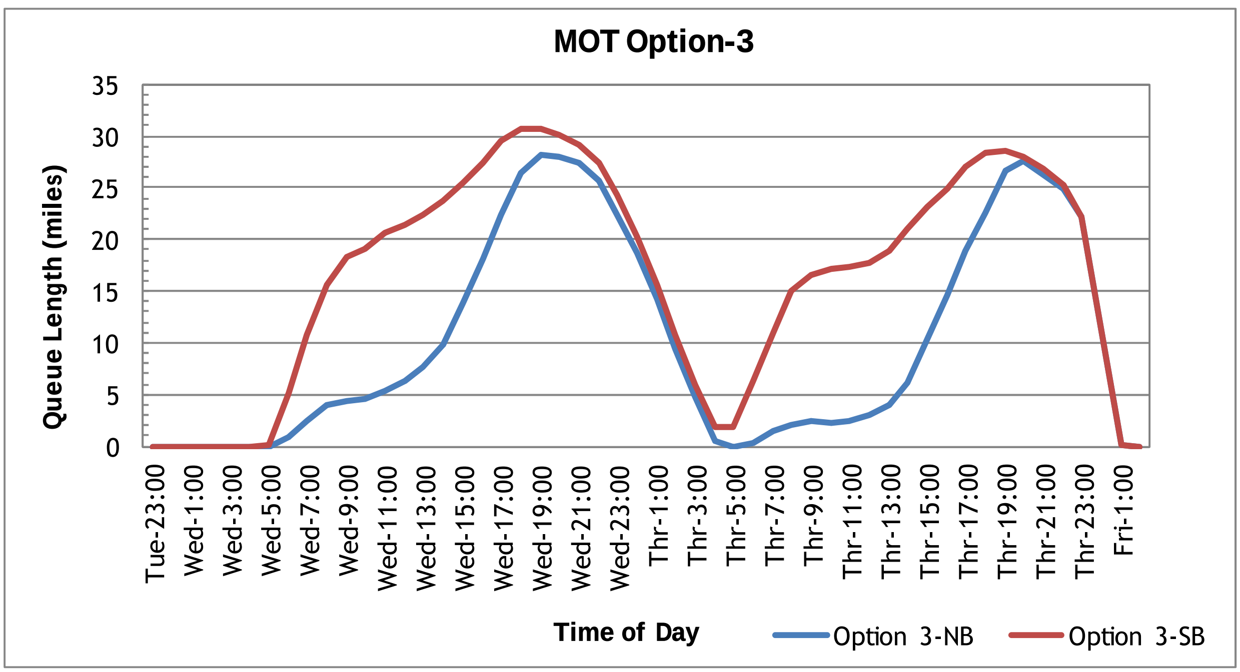

Figure 32. Eastern Avenue project: queue length estimates for Option 3.

Table 78. Eastern Avenue project: summary of LCAP analysis.

Parameter	MOT Option 1		MOT Option 2		MOT Option 3	
	NB	SB	NB	SB	NB	SB
Delay time-Average (mins)	208.0	294.4	18.4	8.3	133.0	203.7
Delay time-Maximum (mins)	448.3	477.8	32.3	19.1	304.7	332.1
Queue length-Average (miles)	18.6	26.1	1.6	1.9	12.5	19.0
Queue length - Maximum (miles)	39.1	41.6	2.8	3.6	28.2	30.8

Crash-related Risks

Based on the LCAP estimates of work zone mobility, the degree of delay and queue length estimated for Options 1 and 2 is likely to increase crash-related risks. Longer delays result in increased driver frustration and aggressiveness, and longer duration of congestion will likely increase the incidence of queues and rear-end accidents, particularly on mainline Kenilworth Avenue. On the other hand, Option 2 would produce a relatively unusual traffic pattern of dividing the lanes with all lanes proceeding through. Drivers who comprehend the posted signs relating to service roads might end up with erratic maneuvers, thus increasing the probability of crashes.

Step 6. Evaluate alternatives against MUST objective

All available alternatives were evaluated against two of the MUST objectives identified in Step 2. The discussion focusing on the availability of detour routes and constructability review (see Step 5) was used in the evaluation against MUST objectives. The results obtained from the evaluation are presented in Table 79.

Table 79. Eastern Avenue project: evaluation against MUST objectives.

MUST Objective	MOT Options				
	1	2	3	4	5
Does an MOT option satisfy constructability requirements?	✓	✓	✓	✓	×
Are there any alternate detour routes to accommodate full diversion of Kenilworth Avenue traffic?	✓	✓	✓	×	✓

Option 4 was eliminated from further consideration as it failed to meet the constructability requirements. As discussed in Step 5, restricting lane closure to nighttime only would not satisfy the constructability requirements, and hence failed to meet the first MUST objective. Similarly, Option 5 was considered unfeasible as there were no alternative detours to accommodate full closure of Kenilworth Avenue, and therefore, was eliminated from further consideration.

Options 1, 2, and 3 successfully satisfied the MUST criteria and would be evaluated further against WANT objectives.

Step 7. Evaluate alternatives against WANT objective

Options 1, 2, and 3 were evaluated against each of the WANT criteria. The discussion presented in Step 5 was used as a basis in determining how well the alternatives meet these objectives. Based on the strengths and weakness that became evident during evaluation, each alternative was assigned with a score on a 1 to 10 with 10 being most advantageous and 1 being least advantageous. The results obtained from the evaluation are presented in Table 80.

The following discussion presents the rationale behind scoring these alternatives:

- Travel delay time – As evident in Table 78, Option 2 is likely to result in shorter travel delay time when compared to other options. Option 3 is likely to produce lesser impact than Option 1, although still at an unacceptable level.
- Spillback on nearby roadways – Similar to travel delay time, Option 2 is likely to result in shorter queue lengths than the other options, and hence least likely to cause spillback on nearby roadways.
- Crash-related risks - Options 1 and 3 were assigned low scores for their high likelihood of safety risks resulting from longer work zone exposure period and severe mobility disruptions. Option 2 was assigned a score less than 10 because of the risks associated with detour patterns and split traffic at the fork of mainline and service roads.
- Inconvenience to local residents – Opening the service roads to the mainline freeway traffic would result in greater inconvenience for local residents. The bus stops would have to be relocated, and no road-side parking would be allowed. Hence, the MOT options using service roads for traffic maintenance received low scores.
- Emergency response and school transportation - Options 1 and 3 were assigned low scores based on the mobility disruptions they are expected to create. The closure of service roads to local traffic and the detour patterns in-place pose some risks for emergency responders with the implementation of Option 2.
- Pedestrian access – Opening the service roads to the mainline freeway traffic would restrictions to pedestrian access, and hence lower scores for Options 2 and 3.
- Construction duration – Since Options 1, 2, and 3 appeared to have no impact on construction duration, they were not evaluated against this objective (or receives equal scores).
- Traffic control and improvement costs – Since Options 1, 2, and 3 appeared incur similar level of traffic control/roadway improvement costs, the options were not evaluated against this objective.

Table 80. Eastern Avenue project: evaluation against WANT objectives.

<table>
<tr><th rowspan="2">WANT Objective</th><th colspan="5">MOT Options</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>Travel delay time</td><td>2</td><td>10</td><td>4</td><td colspan="2" rowspan="8">Not considered for further analysis since they did not meet MUST objectives.</td></tr>
<tr><td>Spillback on nearby roadways</td><td>2</td><td>10</td><td>4</td></tr>
<tr><td>Crash-related risks</td><td>4</td><td>8</td><td>6</td></tr>
<tr><td>Inconvenience to local residents</td><td>10</td><td>3</td><td>3</td></tr>
<tr><td>Emergency response and school transportation</td><td>5</td><td>7</td><td>5</td></tr>
<tr><td>Pedestrian access</td><td>8</td><td>4</td><td>4</td></tr>
<tr><td>Construction duration</td><td colspan="3" rowspan="2">Not considered for further analysis since these objectives will be scored equally against Options 1, 2 and 3.</td></tr>
<tr><td>Traffic control and improvement costs</td></tr>
</table>

Step 8. Calculate the weighted scores of alternatives

The weighted scores for MOT Options 1, 2, and 3 were computed by multiplying their scores by the weights identified in Step 3. The sum of these scores represents an evaluation of each alternative against the previously established criteria and weights. Table 81 presents the weighted score for each alternative. The last row in this table presented the total weighted score.

The alternative with the highest total weighted score—Option 2—was selected as a tentative choice.

Table 81. Eastern Avenue project: weighted scores.

WANT Objective	Weight	MOT Options				
		1	2	3	4	5
Travel delay time	10	20	100	40		
Spillback on nearby roadways	10	20	100	40		
Crash-related risks	10	40	80	60		
Inconvenience to local residents	5	50	15	15		
Emergency response and school transportation	4	20	28	20		
Pedestrian access	5	40	20	20		
Construction duration	8	-	-	-		
Traffic control and improvement costs	6	-	-	-		
Total Weighted Score		190	343	195		

Step 9. Evaluate adverse consequences

After the computation of total weighted score, each MOT alternative was evaluated individually against potential risks identified in the work zone impact assessment. Since the Kenilworth Avenue route serves as a homeland security evacuation route for DC wards 7 and 8, the risk of selecting an alternative against a probable event of an emergency evaluation was considered.

The likelihood of an emergency evacuation was selected on a rating scale from "Low" to "High," with a rating of "Low" indicating "an unlikely event" and "High" indicating "a most probable event." A probability rating of "Low-Medium (LM)" was selected, indicating that such an event is less likely. Next, the performance of the MOT options under this scenario was evaluated. The alternatives were rated on a similar scale, with a value of "Low" indicating "inconsequential" and "High" indicating "very severe."

As Options 1 and 3 were likely to cause longer delay times and queue lengths, a rating of "High-medium (HM)" was assigned to both options, while Option 2 was rating as "Medium (M)" (see Table 82). Option 2 appeared to perform better than other options under an adverse event.

Table 82. Eastern Avenue project: analyzing adverse consequences.

Adverse Consequence	**MOT Option 1**		**MOT Option 2**		**MOT Option 3**	
	Probability	Severity	Probability	Severity	Probability	Severity
Emergency Evacuation	LM	HM	LM	HM	LM	M

H=High M=Medium L=Low
HM=High-medium LM=Low-medium

Based on this evaluation, no MOT option was identified as a high-risk choice. All alternatives were considered as "low-risk" alternatives.

Step 10. Select the preferred MOT strategy

The total weighted score were summarized and ranked for each alternative (see Table 83). The results of adverse consequence evaluation are also summarized. Based on the information presented in Table 83, Option 2 fared better against both WANT objectives and adverse events than other alternatives, and hence was selected as the preferred MOT strategy.

Table 83. Eastern Avenue project: selection of a preferred alternative.

Alternative	Description	Total Weighted Score	Total Adverse Consequence Score	Rank
Option 1	Close one of three lanes in each direction on mainline Kenilworth Avenue.	190	Low-risk	3
Option 2	Close one of three lanes in each direction on mainline Kenilworth Avenue and supplement with two-lane service roads in each direction.	343	Low-risk	1
Option 3	Close two of three lanes in each direction on mainline Kenilworth Avenue and supplement with two-lane service roads in each direction.	195	Low-risk	2
Option 4	Full closure of this segment of Kenilworth Ave and divert traffic through detour.	Eliminated	-	-
Option 5	Close one of three lanes in each direction during nighttime only.	Eliminated	-	-

CHAPTER 6. RUC ANALYSIS REPORT STRUCTURE

The nature of work zone-related decisions often is associated with scheduling, application of techniques and methods, or TMP. The decision making process evolves over different stages of the project development process: planning, preliminary engineering/design, and construction. Decision making begins at a conceptual feasibility level in the planning stage and culminates with a detailed level in the design/construction stage. Irrespective of the stage or level of detail involved in the strategy selection, a WZ RUC analysis report should provide a complete picture of work zone configuration, potential constraints and impacts, feasible alternatives, performance measures and thresholds, and recommendations, to aid in the decision making process. The report also should present the justification for the selection of the optimal strategy.

The following sections discuss the information that should be included in the report.

6.1 BACKGROUND

The analysis report should begin with a background section presenting information on the project location and the limits of work. Inclusion of an area map indicating the project location, the study limits, and other nearby highways is suggested.

Information about the functional classification, project size, rural or urban area, traffic volume, traffic composition (percent trucks), and intersection descriptions should be included. Information also should be included regarding the degree of public interest and possible impacts on nearby roadways and businesses.

The background section should include information such as the project description, anticipated project duration, work zone length, existing lane widths and configuration, speed limits, horizontal curves and grades, turn restrictions, proposed changes to geometric features, existing traffic control, and pedestrian and bicycle facilities. Any potential right-of way and utilities conflicts should be documented.

6.2 DATA COLLECTION

This section of the report should include information about the data used in safety and traffic analysis. The report should mention whether new data or existing information was used. If new data were collected, the report should include the type of data collected, when and how the data were collected, and who collected the data. The following information is recommended for inclusion in this section:

- Safety analysis — Historical crash rate (3 to 5 year history is recommended) by crash severity, influence area, crash geometry, and crash costs (if available).
- Traffic data collection — Hourly or peak-hour traffic demand on the roadway where the work zone is located, as well as the nearby roadways, number of vehicles entering or leaving the highway through exit ramps, turn counts, and corresponding turn direction at intersections. Information about vehicle composition (percent by vehicle types or class), appropriate adjustment factors applied to traffic volumes to account for traffic growth, seasonal variations, or day of week should be included.
- Work zone capacity and operational analysis—Inputs and assumptions, the estimation model used in the capacity analysis, and the results should be documented.

Operational analysis performed for unsignalized and signalized intersections also should be documented.

- Unit cost data — Travel delay, vehicle operating costs, crashes, and emissions. Any adjustment factors used in deriving unit costs should be stated.

6.3 Field Observations

This section of report should include all field activities undertaken to characterize the existing project conditions, such as:

- Travel time studies— Data collection methodology, begin and end periods, days of the week, travel speed, distances and routes covered, sample size, and the results.
- Sight distance analysis— Field study to review the intersection and stopping sight distance conflicts.

6.4 Discussion on the Impacts of Work Zone

This section should document any efforts undertaken to assess and address the impacts on local businesses and community. Inputs gathered at public information meetings/hearings and through facilitators/ liaison officers should be documented.

6.5 Detailed Narrative

This section should provide a detailed narrative on the proposed sequence of construction, staging, and the work zone alternatives that were considered for each construction phase. The narrative should document assumptions made and justification for including the selected alternatives. It also should include the selection criteria that were used in determining feasible alternatives.

6.6 Alternatives Analysis

This section of the report should present the analysis method, tools used, summary of impact assessment, performance measures and agency goals, advantages and disadvantages of each alternative, comparative analysis of alternatives, risk assessment, and the analysis results.

6.7 Recommendations

This section of the report should present a summary of WZ RUC analysis, a description of the preferred alternative, the justification for selection, and recommendations.

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GLOSSARY

Abbreviated Injury Scale (AIS)

An anatomically based severity scoring scheme that classifies each injury in every region of the human body according to its relative severity on a six-point adjectival scale.

Air Pollutant Emissions

Air pollutant emissions include those emitted directly into the atmosphere, such as carbon monoxide (CO), volatile organic compounds, particulate matter (PM10), oxides of nitrogen (NOX), oxides of sulfur (SOX), and those formed in the atmosphere from the directly emitted pollutants, such as ozone and acidic depositions.

Annual Average Daily Traffic (AADT)

The total volume of traffic passing a point or segment of a highway facility in both directions for 1 year divided by the number of days in the year.

Benefit/Cost Analysis

A measure of economic value that compares the net discounted benefits of an alternative to its net discounted costs. B/C ratios greater than 1.0 indicate that benefits exceed cost.

Calendar Day

Every day listed on the calendar, regardless of whether work is accomplished or allowed by other specifications.

Capacity

The maximum sustainable flow rate at which vehicles or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, geometric, traffic, environmental, and control conditions; usually expressed as vehicles per hour or passenger cars per hour.

Combination Truck

Defined as vehicle classes 8 through 13 in the FHWA Traffic Monitoring Guide. Includes vehicles consisting of two or more units, one of which is a tractor or straight truck power unit.

Comprehensive Crash Cost

Includes the intangible nonmonetary losses or consequences to individuals, families, and society over the crash victim's expected life span, in addition to the human capital costs.

Construction Manager/General Contractor (CMGC)

A two-phase project delivery method where a construction manager, selected by an owner based on qualifications for both preconstruction and construction services of a project, will be at risk for the final cost and time of construction.

Construction Phasing

Refers to the sequencing of the aspects of a project, completing portions of the project one part at a time.

Construction Staging

Refers to how the contractor will position the equipment and materials.

Consumer Price Index (CPI)

A measure of the average change over time in the prices paid by urban consumers for goods and services.

Contract Time

The total time (calendar days, working days, or completion date) established to complete the project.

Cost of Acceleration

An additional cost incurred by a contractor for expediting the contract delivery.

Cost-Based Estimating

A method to estimate the bid cost of a work item by estimating the cost of resources (time, equipment, labor, and materials) for each task necessary to complete the work item, and then adding a reasonable amount for contractor's overhead and profit.

Cost-Plus-Time (A+B) Bidding

A contract provision that allows both cost and time to be considered in the low bid determination. The "A" component is the traditional bid for the contract items and is the dollar amount for all work to be performed under the contract. The "B" component is the total number of calendar days the bidder stipulates will be required to complete the project. Calendar days are used to avoid any potential controversy.

Crash

A collision involving at least one moving vehicle (car, truck, etc.) and another vehicle or object.

Crash Frequency

The number of crashes normalized to the roadway segment length and time period, typically expressed as crashes per mile per year.

Crash Modification Factor

A multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure.

Crash Rate

The number of crashes expected or observed along a roadway segment during a time period normalized to the roadway segment length and the traffic volume over the same period, typically expressed in terms for crashes per million vehicle miles of travel.

Crash Reduction Factor

An estimate of the percentage reduction in crashes due to a particular countermeasure.

Decision Analysis

A systematic process within which a choice among specific options will be made.

Delay Time

The additional travel time necessary to traverse the work zone or to detour around it.

Demand to Capacity Ratio

The ratio of demand flow rate to capacity for a traffic facility.

Design-Bid-Build

A project delivery method in which the public agency procures design and construction services from two separate entities. The agency either performs designs in-house or procures services from a private engineering services entity to perform the design work, and then makes a separate procurement with a private construction services entity to perform the construction work.

Design-Build

A project delivery method in which the public agency combines procurement for both design and construction services into a single contract and from the same private sector entity (the design-builder).

Detour Delay

The additional time necessary to travel the excess distance by selecting a detour route.

Detour VOC

The additional vehicle operating cost associated with the excess distance to be traveled by selecting a detour route under unrestricted or restricted conditions.

Discount Factor

A portion of road user cost savings that an owner specifies as incentive and disincentive amount for a project. The selection of this factor typically is an owner agency's management decision by taking factors into account such as market conditions, confidence on the accuracy of WZ RUC estimates, work zone factors, and time sensitivity of project completion.

Economic Analysis Technique

The approach used in the planning process to analyze the relative costs and benefits of a potential investment. The most common include Net Present Value (NPV), Benefit/Cost (B/C) ratios, Internal Rate of Return (IRR), Modified Internal Rate of Return (MIRR), and Equivalent Uniform Annual Costs (EUAC).

Employer Costs for Employee Compensation (ECEC)

Measures employer costs for wages, salaries, and employee benefits for nonfarm private and State and local government workers.

Employment Cost Index

A measure of the average change over time in the wages, benefits, and bonuses for a specific group of occupations.

Forced Flow

A condition where a traffic flow breaks down and a queue of vehicles develops.

Free Flow

A condition where a traffic flow is unaffected by upstream or downstream conditions.

Free Flow Capacity

The maximum capacity a facility can handle under free-flow conditions.

Free Flow Speed

The average speed of vehicles over a basic freeway, multilane highway or an urban street segment without signalized intersections under conditions of low volume.

Greenhouse Gases

Include those direct emissions that are not yet recognized as an air pollutants but trap heat within the atmosphere and thus contributing undesirable climatic effects, such as carbon dioxide (CO2).

Gross Domestic Product (GDP) Implicit Price Deflator

An economic metric that accounts for inflation by converting output measured at current prices into constant-dollar GDP. The GDP deflator shows how much a change in the base year's GDP relies upon changes in the price level.

Hourly Traffic Demand

The 24-hour hourly distribution of vehicles passing through the work zone in a single direction under normal operating conditions.

Human Capital Crash Cost

Includes the “hard dollar” costs related directly to a crash, such as property damage, medical care, compensations, and legal costs.

Incentive/Disincentive (I/D)

A contract provision which compensates the contractor for each day that identified critical work is completed ahead of schedule and assesses a deduction for each day that completion of the critical work is delayed. The primary function of an I/D provision is to motivate the contractor to complete the work on, or ahead of, schedule, and recover damages to the traveling public for late completion.

Incident

Any occurrence on a roadway that impedes the normal flow of traffic.

Interim Completion Date

A contract provision that provides a contractor with an incentive or disincentive to expedite the completion of specific portions of a contract within a set duration or by a specified date.

KABCO Injury Scale

A coding scheme designed for police officers assessing a crash scene where K, A, B, C, and O are the different levels of classification.

Lane Rental

A rental fee paid by the contractor for the time period a lane is closed to through traffic for construction activities.

Life Cycle Cost Analysis

An economic assessment of an item, area, system, or facility and competing design alternatives considering all significant costs of ownership over the economic life, expressed in equivalent dollars.

Liquidated Damages

Monetary damages recovered from the contractor to compensate the agency's additional construction oversight costs associated with the contractor's failure to complete the project on time.

Liquidated Savings

Under this provision, the contractor receives an incentive amount equal to the savings in the owner agency's construction oversight costs for completing the project ahead of schedule.

Maintenance of Traffic (MOT)

A set of coordinated transportation management strategies to meet the traffic mobility and safety needs within a work zone.

Normal Operation

Reflects the condition during which a facility is free of construction, maintenance, and/or rehabilitation that restrict the capacity of the facility.

No-Excuse Incentives (also called Locked Incentives)

An incentive paid to the contractor to complete a phase of work or the entire project on or before a firm completion date specified in the contract. There are no excuses, such as weather delays, for not meeting the completion date. No disincentives (other than normal liquidated damages) apply for not meeting the target date.

Passenger Car

Defined as vehicle classes 1 through 3 in the FHWA Traffic Monitoring Guide. Includes automobiles (small, medium, or large), pickup trucks, and vans.

Passenger-Car Equivalent (PCE)

The number of passenger cars displaced by a single heavy vehicle of a particular type under specified roadway, traffic, and control conditions.

Producer Price Index (PPI)

A measure of the average change over time in the selling prices received by domestic producers of goods and services. The PPI measures price change from the perspective of the seller. This contrasts with other measures, such as the Consumer Price Index (CPI), that measure price change from the purchaser's perspective.

Queue

A line of vehicles, bicycles, or persons waiting to be served by the system in which the flow rate from the front of the queue determines the average speed within the queue. Slowly moving vehicles or people joining the rear of the queue usually are considered part of the queue. The internal queue dynamics can involve starts and stops. A faster-moving line of vehicles often is referred to as a moving queue.

Queue Delay

The additional time necessary to travel through the queue under restricted traffic flow.

Queue Idling VOC

The additional vehicle operating cost associated with stop-and-go driving in the queue. The idling cost rate multiplied by the additional time spent in the queue is an approximation of actual VOC associated with stop-and-go conditions. When a queue exists, stopping delay and VOC replace the free-flow speed change delay and VOC.

Reduced Speed Delay

The additional time necessary to traverse the work zone at the lower posted speed; it depends on the upstream and work zone speed differential and length of the work zone under both unrestricted and restricted (forced) traffic flow.

Significant Project

A project that, alone or in combination with concurrent projects nearby, is anticipated to cause sustained work zone impacts (or high level of disruption) that are greater than what is considered tolerable based on an agency’s policy and/or engineering judgment.

Single-Unit Truck

Defined as vehicle classes 4 through 7 in the FHWA Traffic Monitoring Guide. Includes six-tire trucks and trucks on a single frame with three or more axles.

Speed Change Delay

The additional time necessary to decelerate from the upstream approach speed to the work zone speed and then to accelerate back to the initial approach speed after traversing the work zone under unrestricted (free) traffic flow.

Speed Change VOC

The additional vehicle operating cost under unrestricted conditions associated with decelerating from the upstream approach speed to the work zone speed and then accelerating back to the approach speed after leaving the work zone.

Stopping Delay

The additional time necessary to come to a complete stop from the upstream approach speed (instead of just slowing to the work zone speed) and the additional time to accelerate back to the approach speed after traversing the work zone under restricted traffic flow.

Stopping VOC

The additional vehicle operating cost under restricted conditions associated with stopping from the upstream approach speed and accelerating back up to the approach speed after traversing the work zone.

Transportation Management Plan (TMP)

A plan that lays out a set of coordinated strategies and describes how they will be used to manage the work zone impacts of a road project. Strategies include temporary traffic control measures and devices, public information and outreach, and operational strategies such as travel demand management, signal retiming, and traffic incident management.

Travel Delay Cost

A product of total travel delay time of all vehicles caused by work zone conditions and the value of travel time (by vehicle type).

Travel Speed

The average speed, in miles per hour, of a traffic stream computed as the length of a highway segment divided by the average travel time of the vehicles traversing the segment.

Value of Travel Time

Economic value of travel time usually expressed in terms of dollar per hour per vehicle or dollar per hour per person.

Vehicle Operating Costs (VOC)

The expenses incurred by the road users as a result of vehicle use.

Working Day

Any day on which work is planned and could be performed. Weekends and holidays frequently are excluded from a working day contract.

Work Zone

A segment of highway in which maintenance and construction operations impinge on the number of lanes available to traffic or affect the operational characteristics of traffic flowing through the segment. A work zone typically is marked by signs, channelizing devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign or high-intensity rotating, flashing, oscillating, or strobe lights on a vehicle to the END ROAD WORK sign or the last temporary traffic control device.

Work Zone Capacity

The maximum sustainable flow rate at which vehicles can pass a given point or uniform segment of a lane or roadway in a work zone during a specified period under prevailing roadway, traffic, and control conditions. Capacity usually is expressed as passenger cars per hour per lane (pcphpl) or vehicles per hour per lane (vphpl).

Work Zone Delay Time

The additional travel time experienced by a vehicle to traverse the work zone or to detour around it.

Work Zone Mobility

Pertains to moving road users efficiently through or around a work zone area with a minimum delay compared to baseline travel when no work zone is present, while not compromising the safety of highway workers or road users. The commonly used performance measures for the assessment of mobility include delay, speed, travel time, and queue length.

Work Zone Performance Measurement

The process of collecting and using quantifiable statistical evidence to measure, monitor, and evaluate the efficiency of work zone operations.

Work Zone Performance Measures

Well defined, outcome-based conditions or response times that are used to evaluate the success of work zone policies, procedures, and performance.

Work Zone Road User Cost

An incremental cost or value incurred by highway users and the community at-large as a result of work zone activity.

Work Zone Safety

Refers to minimizing potential hazards to travelers and highway workers in the vicinity of a work zone.

APPENDIX A. KEPNER-TREGOE DECISION ANALYSIS WORKSHEET FOR MOT STRATEGY SELECTION

Project Information

Facility Name	US 00 Pavement Reconstruction
Facility Type	Arterial
Project Number	# A600000
Route & Milepost	US 00, MP 100 to 105
District/County	District 1, Polk County
By	H. Miller
Date	05/05/2005

Step 1 - Prepare Decision Statement

To identify the most appropriate strategy for maintaining traffic on US 00 during the reconstruction of the pavement segments between mileposts 100 and 105.

Step 2A – Define MUST Objectives

List the mandatory attributes of a preferred MOT strategy for this project.

Performance Measure/Criteria	Go/No Go
Maintain a minimum of one lane each direction for work zone traffic on weekdays	
No lane closure from 7 a.m. to 10 a.m. and 4 p.m. to 8 p.m. on weekdays	
Queue length not more than 0.75 for more than 1 hour	
Delay time not more than 30 minutes	
Available detour routes exceed capacity?	
MOT alternative has no constructability issues	

Step 2B & 3 – Define & Weight WANT Objectives

List the desired attributes of a preferred MOT strategy for this project. Assign weights to each attribute based on their relative importance on a scale of 1 to 10, with 1 indicating "least preferable" and 10 indicating "most preferable" or "equally preferable."

Performance Measure/Criteria	Weight
Delay costs ($)	10
Vehicle operating costs	8
Number of days for project completion	10
Traffic control & associated construction costs ($)	8
Average time to clear a non-injury incidence (min.)	4
Maintenance of emergency services (adjectival ratings – poor, average, good)	6
Environmental impacts (adjectival ratings – low, moderate, severe)	3

Step 4 – Identify Candidate MOT Alternatives

Identify and list the candidate MOT alternatives for considered in the decision analysis.

Alternative	Description
A	Daytime partial lane closure -closed between 7 a.m. to 5 p.m
B	Nighttime partial lane closure –closed between 8 p.m. to 6 a.m.
C	Nighttime partial lane closure –closed between 9 p.m. to 7 a.m.
D	Nighttime full lane closure -closed between 9 p.m. to 7 a.m.
E	Truck traffic diverted through detour routes during peak hours.

Step 5 – Conduct Work Zone Impact Assessment and Summarize Findings

Summarize the findings of the work zone impact assessment.

Performance Measure/Criteria	A	B	C	D	E
Maintain a minimum of 1 lane each direction for WZ traffic during weekdays	No	Yes	Yes	Yes	Yes
No lane closure between 7a.m. through 10 a.m. and 4 p.m. through 8 p.m. during weekdays	No	Yes	Yes	Yes	Yes
MOT alternative has no constructability issues	No	No	No	No	No
Average delay time per vehicle (min)	19.0	6.0	3.0	10.0*	20.0**
Maximum queue length (mi.)	1.6	0.0	0.0	0.5*	0.5**
Available detour route exceed capacity?	No	No	No	No	Yes
Average time to clear a non-injury incidence (min.)	20	25	25	15	10
Delay costs	$5,300	$3,125	$2,800	$4,700	$6,800
Vehicle operating costs	$1,484	$656	$728	$1,175	$1,836
Traffic control & associated construction costs	$55,000	$94,000	$75,000	$109,000	$85,000
Number of days for project completion	150	84	84	60	90
Maintenance of emergency services	moderate	moderate	moderate	good	good
Environmental impacts	moderate	severe	severe	low	low

Step 6 – Evaluate Alternatives against MUST Objectives

Evaluate each alternative against the MUST objectives and check whether the attributes of an alternative satisfy all of the MUST requirements. Use the findings of the impact assessment summarized in Step 5. Assign Go (✓) or No Go (×) outcome based on your evaluation indicating your decision to retain or eliminate an alternative for the next step. Any alternative with a No Go (×) outcome will be eliminated from further evaluation.

Performance Measure/Criteria	A	B	C	D	E
Maintain a minimum of 1 lane each direction for WZ traffic during weekdays	✓	✓	✓	✓	✓
No lane closure between 7a.m. through 10 a.m. and 4 p.m. through 8 p.m. during weekdays	✓	✓	✓	✓	✓
Queue length not more than 0.75 for more than 1 hour	×	✓	✓	✓	✓
Delay time not more than 30 minutes	×	✓	✓	✓	✓
Alternative detour route exceeds capacity?	✓	✓	✓	✓	×
Alternative has no constructability constraints	✓	✓	✓	✓	✓

Step 7 – Evaluate Alternatives against WANT Objectives

Evaluate each alternative against the WANT objectives based on the findings of the impact assessment summarized in Step 5. Assign scores to each alternative against the listed objectives indicating how well the alternative meets that objective. Use a scale of 1 to 10, with a score of 1 indicating "least preferable" and 10 indicating "most preferable" or "equally preferable."

Performance Measure/Criteria	Alternative Score				
	A	B	C	D	E
Delay costs ($)		9	10	6	
Vehicle operating costs		10	8	7	
Number of days for project completion		7	7	10	
Traffic control & associated construction costs ($)		8	8	10	
Average time to clear a non-injury incidence (min.)		6	6	10	
Maintenance of emergency services (adjectival ratings - poor, average, good)		6	6	10	
Environmental impacts (adjectival ratings - low, moderate, severe)		3	3	10	

Step 8 – Calculate the Weighted Scores of Alternatives

Calculate the weighted scores by multiplying the alternative score (Step 7) with the corresponding objective weights (Step 2B) to determine the relative performance of the alternatives. Calculate the total weighted score for each alternative. Indicate the alternative with the highest total score as the tentative choice.

Performance Measure/Criteria	Alternative Score				
	A	B	C	D	E
Delay costs ($)		90	100	60	
Vehicle operating costs		80	64	56	
Number of days for project completion		70	70	100	
Traffic control & associated construction costs ($)		64	64	80	
Average time to clear a non-injury incidence (min.)		24	24	40	
Maintenance of emergency services (adjectival ratings – poor, average, good)		36	36	60	
Environmental impacts (adjectival ratings – low, moderate, severe)		9	9	30	
Total weighted score		373	367	426	

Tentative choice: Alternative D

Step 9 –Evaluate of Adverse Consequences (optional)

Identify the potential risk factors and list under the "Adverse Consequences" column. Indicate the probability of the event under "Pr" column for each alternative on a scale from "Low" to "High," with a rating of "Low" indicating "an unlikely event" and "High" indicating "a most probable event." Indicate the severity of the event under "Sr" column for each alternative on a similar scale, with a value of "Low" indicating "inconsequential" and "High" indicating "very severe." Identify "high-risk" and "low-risk" alternatives.

Adverse Consequences	B		C		D	
	Pr	Sv	Pr	Sv	Pr	Sv
Flood impact	LM	HM	LM	HM	LM	HM
High severity crashes	HM	L	HM	L	HM	LM
Emergency evacuation	HM	L	HM	L	HM	H

H=High M=Medium L=Low
HM=High-medium LM=Low-medium

High-risk choice: Alternative D

Low-risk choice: Alternatives B and C

Step 10 –Select the Preferred MOT Strategy

Summarize the total weighted score (from Step 8) as well as the risk score (from Step 9) for each alternative and rank them.

Alternative	Description	Weighted Score	Risk Score	Rank
A	Daytime partial lane closure -closed between 7 a.m. to 5 p.m	Eliminated		
B	Nighttime partial lane closure - closed between 8 p.m. to 6 a.m.	373	Low-risk	1
C	Nighttime partial lane closure - closed between 9 p.m. to 7 a.m.	367	Low-risk	2
D	Nighttime full lane closure -closed between 9 p.m. to 7 a.m.	426	High-risk	Eliminated
E	Truck traffic diverted through detour routes during peak hours.	Eliminated		

Result

Indicate the preferred MOT strategy from Step 9.

Alternative	Description
B	Nighttime partial lane closure -closed between 8 p.m. to 6 a.m.

U.S. Department of Transportation
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