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**CONTRACT TIME OPTIMIZATION
METHODOLOGIES FOR HIGHWAY
CONSTRUCTION PROJECTS**

Yi Jiang

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Contract Time Optimization Methodologies for Highway Construction Projects

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16. Abstract This study was conducted to develop methodologies for appropriately determining the monetary values of I/D rates of highway construction projects in Indiana. In this study, a comprehensive literature review was performed to identify possible effective methodologies for work zone effects, construction impacts, and contract time optimization. The highway production rates were developed in a previous study. The production rates were validated and adjusted with the help from INDOT field engineers. The weigh-in-motion (WIM) collected traffic data were obtained, processed, and analyzed to provide input data for user cost calculations at highway work zones. Construction data were obtained and processed to develop the relationship between the construction cost and construction time. With the traffic and construction data, the methods for user cost calculations were developed as the basis of determining appropriate I/D rates. User costs resulting from traffic delays at Indiana highway work zones were analyzed. A series of equations for estimating user costs at work zones were developed. User cost calculation sheets using MS Excel were developed based on the traffic data on Indiana highway network. Finally, a method was developed to determine I/D rates based on the relationship between construction cost and construction time in combination with the estimated user costs at given work zones. Guidelines for developing A+B bidding and I/D provisions were provided.					
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CHAPTER 1: INTRODUCTION

Highway construction projects affect people's daily lives because highway work zones reduce roadway traffic capacities and limit motorists' access to certain roadway routes and other facilities. Although ultimately bringing long term economic benefit, highway construction projects temporarily increase highway user costs and non-user costs, and affect highway safety and environment. The magnitude of these effects is directly related to the durations of highway construction projects, so one of the first questions INDOT must answer is "How quickly does the public need this project completed?" It can be done in less time but with potentially greater cost, or it can be done with the traditional Monday to Friday schedule. In order to maximize the positive effects and minimize the negative effects of construction projects, the State highway agencies have been using incentive/disincentive (I/D) clauses in contracts to encourage early completion. Incentive clauses are used to reward the contractors for their early completion of projects. On the other hand, disincentive clauses are used to recover the engineering and administrative costs incurred when contractors fail to complete highway projects on time (Gillespie, 1998).

The Indiana Department of Transportation (INDOT) has only used I/D clauses on a limited basis. INDOT typically charges liquidated damages as a disincentive to recover the added INDOT field administrative costs. However, sometimes the liquidated damages could be as great as the damages to the traveling public when considering intermediate completion dates for restriction or closure. I/D provisions for time are currently only being applied on a handful of contracts at the Area Engineer's discretion. The I/D amount is justified by a user cost calculation from the Design Manual and/or by the estimated additional costs to contractors and to INDOT.

The duration of a project depends primarily on the magnitude of the construction work and the productivity of the construction crew. In addition, many other factors may also affect the duration, such as the type of construction, traffic features, location (urban or rural site), and any special features of the project. When a state highway construction project contract is bid, a reasonable time must set and specified in the contract documents for completion of the contracted project. The time for contract completion (often called "contract time") is estimated

based on the average completion times of individual construction items within a specific project. INDOT utilizes the average production rates of itemized highway and bridge work as a general guide for setting workdays for construction contracts.

This study was conducted to develop methodologies for appropriately determining the monetary values of I/D rates of highway construction projects in Indiana. In this study, a comprehensive literature review was performed to identify possible effective methodologies for work zone effects, construction impacts, and contract time optimization. The highway production rates were developed in a previous study (Jiang, 2004). The production rates were validated and adjusted with the help from INDOT field engineers. The weigh-in-motion (WIM) collected traffic data were obtained, processed, and analyzed to provide input data for user cost calculations at highway work zones. Considerable effort was made to gather and analyze the WIM traffic data and to process the data into the desired formats. Highway construction data were identified with the help of the Study Advisory Committee members of this study. The construction data were obtained and processed to develop the relationship between the construction cost and construction time. With the traffic and construction data, the methods for user cost calculations were developed as the basis of determining appropriate I/D rates. User costs resulting from traffic delays at Indiana highway work zones were analyzed. A series of equations for estimating user costs at work zones were developed. User cost calculation sheets using MS Excel were developed based on the traffic data on Indiana highway network. Finally, a method was developed to determine I/D rates based on the relationship between construction cost and construction time in combination with the estimated user costs at given work zones.

CHAPTER 2: LITERATURE REVIEW

User costs caused by highway work zones have been studied by many researchers. Burns, Dudek, and Pendleton (1989) conducted a study for the Federal Highway Administration to determine construction and road user costs and safety impacts associated with traffic control through work zones on rural four-lane divided highways. The study was based on data collected from highway construction projects in 16 states. Through their study, an informational guide for use in selecting cost-effective traffic control strategies for proposed construction projects was prepared.

A West Virginia Study (Martinelli & Xu 1996) examined the relationship between traffic delay and work zone length. The work zone under study was formed by closing the roadway in one direction and diverting the traffic to share the roadway in the opposite direction. The traffic delay was dissected into speed reduction delay and congestion delay. Through mathematical modeling, they developed procedures for determining the optimal work zone length.

Arudi, Minkarah, and Morse (1997) analyzed the impact of user costs at work zones on the pavement management decisions in the Ohio Department of Transportation. They showed that when road user costs were incorporated during construction, the selections of pavement maintenance and rehabilitation alternatives might be significantly affected.

A Japanese study (Taniguchi & Yoshida, 2003) introduced a graphical method for estimating work zone user costs. The study applied the graphical method to estimate life-cycle cost at work zones on the national highway in the densely inhabited district of Tokyo metropolitan area.

In a recent study (Salem, Genaidy, Deshpande, & Geara, 2008), two alternative approaches were proposed to integrate user costs in pavement type selection process. The methods were developed for the Ohio Department of Transportation to minimize the impact of construction on the users of infrastructure. It was indicated that Ohio currently uses user delay days as a factor

in the pavement type selection. The study recommended using user costs instead of user delay days because user costs directly quantify the work zone impact.

The use of incentives and disincentives for project completion time has been gradually increasing. A West Virginia study (Jaraiedi, Plummer, & Aber, 1995) proposed that to include an I/D provision in a contract the contracting agency should address a series of questions as listed below.

- Why is it important to expedite completion of the project?
- What particular aspect of this project would reduce or eliminate?
- How much time can be saved by using I/D procedures?
- Can cost of incentive payments to contractor be economically justified by reduced road user costs?
- If I/D provisions are economically justified, what are daily and maximum incentive amounts?
- What options exist if additional road user costs do not justify use of I/D provisions?
- What additional considerations must be addressed to ensure that project can be expedited?

Arditi, Khisty, and Yasamis (1997) compared contracts that include I/D provisions against contracts that do not include I/D provisions in Illinois. They found that all of the I/D contracts included in their study sample were completed ahead of or on schedule whereas only 41.4% of the non-I/D contracts in the study sample were completed ahead of or on schedule. The average maximum incentive amount allowed per project was 5.13% of the contract amount. The average incentive amount paid per project was 4.71% of the contract amount.

Shr and Chen (2004) developed a model that describes the functional relationship between the construction cost and time duration. The function of the relationship is combined with the estimated I/D values to determine the optimum maximum days for I/D amounts.

Arditi and Yasamis (1998) conducted a survey to identify the perceptions of Illinois DOT engineers and contractor superintendents regarding the use of I/D provisions. They found that there was a statistically significant agreement in the engineers' and superintendents' perceptions regarding a number of critical issues, such as the calculation of project duration, the definition of "completion of the project," the importance of certain project objectives, the type of expedited work schedule used by contractors, and the frequency and magnitude of change orders in I/D contracts. On the other hand, they seemed to disagree on some other issues, including the project stage at which I/D provisions are included, and the nature of difficulties contractors face during I/D implementations, the general measures taken, the technical and/or managerial improvements introduced, the personnel/manpower polices adopted by contractors to fulfill I/D targets, and whether bids would be lower for non-I/D contracts as opposed to I/D contracts.

CHAPTER 3: TRAFFIC DELAYS AND USER COSTS AT WORK ZONES

It is often necessary to establish work zones on roadways for pavement and bridge repair and rehabilitation activities. Work zone is defined in the 2000 Highway Capacity Manual (TRB, 2000) as “an area of highway in which maintenance and construction operations are taking place that impinge on the number of lanes available to moving traffic or affect the operational characteristics of traffic flowing through the area.” A work zone reduces the available lanes for traffic and therefore causes vehicle deceleration and merging. When traffic flow is below the capacity of a work zone, traffic is delayed primarily by the reduced vehicle speed through the work zone. When traffic flow exceeds the work zone capacity, vehicle queues would form at the work zone and result in additional traffic delays. Consequently, during congestion vehicles go through the work zone at reduced speeds and with fluctuated traffic flow rates. Motorists endure considerably greater traffic delays at the work zone under congested traffic conditions than under uncongested conditions. The additional travel time and change of driving maneuvers at work zones result in excess costs to motorists in terms of the value of time, consumption of fuel and oil, and wearing of vehicle parts.

With a high traffic volume, the user costs caused by a work zone can be significant so that it is desirable to minimize the user costs by expediting construction process. Therefore, user costs at highway work zones have become one of the important factors for highway agencies to consider in setting contract times of highway construction projects. User costs at work zones are often used as the basis of determination of the monetary values for incentive or disincentive clauses in highway contracts for early or late completions of highway construction projects. In this study, the user costs at highway work zones were computed based on the estimated traffic delays with the weigh-in-motion (WIM) recorded traffic data provided by the Indiana Department of Transportation (INDOT). Work zone user costs affect many aspects of highway construction projects, including traffic control, life cycle cost, project selection, and management decision making. The main purpose of this part of the study was to provide an effective tool for INDOT to estimate work zone user costs so that appropriate incentive and disincentive monetary values can be determined for early or later completions of highway construction projects.

3.1: Weigh-in-Motion Traffic Data

Weigh-in-motion (WIM) devices are designed to capture and record truck axle weights, axle spacings, and gross vehicle weights as they drive over a sensor. Based on the axle weights, axle spacings, and time intervals between the tires passing the WIM plate, the WIM device also provides the data of traffic volumes, vehicle speeds, and vehicle types. The INDOT WIM system consists of 47 WIM sites installed on interstate and other state owned primary highways. The vertical loading applied to the pavement by a moving vehicle consist of two components: the static load and the dynamic load. The static load depends on the weight and the layout of the axles and tires of the vehicle. The dynamic load is generated by vibration of the vehicle.

All WIM raw data have to be screened for errors before they are put in a database in the form of a monthly traffic data file. A monthly WIM data file generally consists of all traffic information that is necessary to generate traffic summary reports. The traffic database from the WIM measurements can be used for many purposes, including the Long-Term Pavement Performance (LTPP) monitoring, pavement design, and truck weight enforcement by Indiana State Police (ISP). As part of this study, the database was utilized to obtain hourly traffic volumes, vehicle speeds, and percentages of tucks and passenger cars.

The WIM raw data files are binary data files containing all traffic information. In general, the binary data files must be converted into American Standard Code for Information Interchange (ASCII) data files that are usually very large in size. In order to extract the necessary traffic information from the binary WIM data files, the authors utilized the vendor's software to generate the ASCII raw vehicle report (IRD, 1999). An ASCII raw vehicle report consists of the traffic information, including time, lane number, vehicle type, speed, axle weight, and axle spacing. Since an ASCII raw vehicle report file is also large in size, a Visual Basic® computer program was developed to generate traffic data for the analysis of user costs at work zones that contain hourly traffic volumes, vehicle speeds, and vehicle types.

The WIM data recorded in 2008 on Indiana highways were used in this study for user cost computation. At each of the 47 WIM stations, the average daily traffic (ADT) in vehicles per day was calculated with the WIM data. The hourly traffic distributions were calculated as a percent of the ADT. Since user cost is different for passenger cars and trucks, the percentages of trucks for each hour of a day were also obtained. As an example, Tables 1 and 2 show the calculated ADT, hourly traffic distribution, and percentages of trucks at the WIM station on I-65 near Lafayette, Indiana. At this WIM station, I-65 is a four-lane divided freeway (two lanes in each direction). The ADT values are the total traffic volumes on the four lanes of the roadway. Therefore, each of the ADT values shown in the last row in Table 1 is the average ADT in a month at the WIM station on the four-lane freeway. For example, the ADT value of 33878 (the first value in the last row in Table 1) means that in January the average ADT is 33878 vehicles per day on the four lanes in the two traveling directions. The table contains the proportions of the hourly traffic volumes as the percentages of the total ADT. As shown in Table 1, from 0:00 to 1:00 in January the traffic volume is 1.6% of the total ADT of 33878. Thus, the hourly traffic volume from 0:00 to 1:00 at the I-65 WIM station can be calculated as $(1.6\%)(33878) = 542$ vehicles.

To estimate the user costs caused by work zones, it is necessary to obtain the proportions of passenger cars and trucks in the traffic flows. These proportions are readily available in the WIM recorded traffic data because of WIM's vehicle classification functions. For the purpose of user cost estimation, the "passenger cars" also include mini vans and pick-up trucks and the "trucks" include single unit trucks (such as delivery trucks), buses, and semi-trucks. The values in Table 2 are the average percents of trucks in each hour of a day in each month. As shown in Table 2, from 0:00 to 1:00 in January, the percent of trucks is 61.7 at the I-65 WIM station. As calculated above, the hourly traffic volume for the period is 542 vehicle, the number of trucks in the hour can be obtained as $(542) \times 61.7\% = 334$. Thus, the number of passenger cars is $542 - 334 = 208$. That is, among the hourly traffic volume of 542 vehicles, there are 208 passenger cars and 334 trucks.

Most of the highway agencies routinely collect traffic data in terms of ADT values. However, the hourly traffic volumes may not be always available. It is important to have the hourly traffic

volumes for work zone user cost calculations because they are needed to estimate the hourly traffic delays caused by work zones. Therefore, the average percents of ADT and percents of trucks were computed with the traffic data recorded at the 47 WIM sites in Indiana. Table 3 presents the average percentages for Indiana's state roads, US routes, and interstate highways. The values in Table 3 are provided for estimating the hourly traffic volumes (numbers of passenger cars and trucks) at any locations where only ADT values are available.

Table 1. Average daily traffic (ADT) and hourly percentages of ADT at the I-65 WIM station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Time	% ADT	% ADT	% ADT	% ADT	% ADT	% ADT	% ADT	% ADT	% ADT	% ADT	% ADT	% ADT
0:00-1:00	1.6	1.8	1.9	1.7	1.6	1.7	1.7	1.8	1.9	1.6	1.8	1.9
1:00-2:00	1.4	1.5	1.6	1.3	1.3	1.4	1.3	1.5	1.6	1.3	1.4	1.6
2:00-3:00	1.3	1.3	1.4	1.2	1.2	1.3	1.2	1.4	1.5	1.2	1.3	1.4
3:00-4:00	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.4	1.5	1.3	1.3	1.3
4:00-5:00	2.1	1.7	1.5	1.5	1.4	1.4	1.4	1.6	1.6	1.5	1.5	1.5
5:00-6:00	2.7	2.3	2.2	2.2	2.2	2.3	2.1	2.3	2.3	2.2	2.1	2.0
6:00-7:00	3.9	3.2	2.9	3.2	3.2	3.3	3.1	3.4	3.4	3.2	2.8	2.6
7:00-8:00	4.1	4.1	4.2	4.5	4.3	4.4	4.0	4.3	4.6	4.4	3.9	3.5
8:00-9:00	4.6	4.4	4.3	4.6	4.6	4.6	4.5	4.5	4.6	4.6	4.1	3.7
9:00-10:00	5.0	4.6	4.7	4.9	5.0	5.1	5.1	4.9	5.0	5.1	4.7	4.3
10:00-11:00	5.5	5.0	5.1	5.2	5.4	5.5	5.7	5.4	5.2	5.5	5.2	5.0
11:00-12:00	6.0	5.5	5.4	5.6	5.8	6.0	6.1	5.7	5.6	5.8	5.7	5.6
12:00-13:00	6.4	5.7	5.8	5.8	6.0	6.1	6.2	5.8	5.6	6.1	6.1	6.2
13:00-14:00	7.2	6.3	6.1	6.0	6.2	6.1	6.2	6.0	5.7	6.3	6.3	6.5
14:00-15:00	7.3	7.0	6.6	6.7	6.7	6.5	6.5	6.4	6.4	6.8	6.8	7.2
15:00-16:00	7.2	7.2	6.8	6.7	6.9	6.6	6.6	6.5	6.5	6.9	6.9	7.4
16:00-17:00	7.2	7.2	6.9	7.0	6.8	6.6	6.5	6.4	6.6	6.9	7.0	7.3
17:00-18:00	5.9	6.7	6.9	6.8	6.6	6.4	6.4	6.4	6.6	6.7	6.9	7.0
18:00-19:00	4.9	5.8	6.0	5.9	5.7	5.6	5.8	5.7	5.8	5.7	5.8	5.9
19:00-20:00	4.3	4.9	5.1	5.0	5.0	4.9	5.1	5.0	5.0	4.8	4.9	5.0
20:00-21:00	3.8	4.1	4.3	4.3	4.2	4.2	4.4	4.3	4.3	4.0	4.4	4.2
21:00-22:00	3.1	3.5	3.7	3.6	3.5	3.6	3.6	3.8	3.6	3.4	3.7	3.6
22:00-23:00	2.5	2.9	3.1	2.8	2.8	2.8	2.8	3.0	2.9	2.6	3.1	3.0
23:00-0:00	0.7	1.9	2.6	2.2	2.1	2.3	2.3	2.4	2.2	2.0	2.4	2.4
ADT	33878	36950	40816	44185	43857	47585	47024	50681	45962	43988	43052	33253

Table 2. Average percentages of trucks at the I-65 WIM station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Time	% Trucks	% Trucks	% Trucks	% Trucks	% Trucks	% Trucks	% Trucks	% Trucks	% Trucks	% Trucks	% Trucks	% Trucks
0:00-1:00	61.7	58.3	53.8	54.3	61.5	53.1	48.1	45.3	45.5	58.2	52.8	54.5
1:00-2:00	68.3	65.6	59.8	61.8	65.6	59.3	54.7	47.3	48.6	62.7	60.3	60.0
2:00-3:00	69.4	70.8	67.0	67.7	65.9	63.7	59.8	50.0	49.2	69.9	63.7	65.3
3:00-4:00	66.3	69.6	68.3	67.4	62.3	64.3	61.1	51.4	49.1	70.4	67.6	68.4
4:00-5:00	47.9	58.9	65.5	63.6	43.2	60.3	54.8	48.2	46.5	63.2	63.7	66.2
5:00-6:00	39.4	45.5	49.3	45.5	36.8	42.1	39.6	37.5	35.2	44.6	46.5	51.1
6:00-7:00	30.5	35.8	39.4	37.1	29.1	37.1	33.4	31.3	31.0	35.1	37.1	41.5
7:00-8:00	32.8	32.3	32.0	29.9	29.5	29.0	26.9	28.3	27.6	30.1	31.2	34.2
8:00-9:00	33.7	33.7	33.0	30.4	28.7	28.8	25.6	28.8	29.6	30.8	31.7	34.5
9:00-10:00	31.9	33.2	32.4	31.0	27.3	28.8	25.1	28.7	30.1	30.1	29.6	32.5
10:00-11:00	30.7	31.3	30.9	30.0	25.9	27.3	23.8	28.2	30.4	28.6	27.5	29.3
11:00-12:00	28.6	30.3	29.5	28.6	25.3	25.7	23.3	27.6	29.4	27.2	26.2	27.0
12:00-13:00	27.9	28.4	28.3	27.4	24.9	25.2	23.0	27.2	28.8	26.1	25.1	25.2
13:00-14:00	25.6	27.0	27.5	26.3	23.7	24.4	22.4	27.1	29.4	25.8	24.8	24.1
14:00-15:00	25.5	25.2	25.4	24.6	22.9	24.4	22.3	26.4	29.6	24.0	23.7	23.6
15:00-16:00	24.6	24.7	25.0	23.6	22.2	23.7	21.9	25.8	27.8	23.4	23.0	23.8
16:00-17:00	24.4	24.1	24.6	22.7	22.1	23.1	21.1	25.2	27.1	22.8	22.1	23.5
17:00-18:00	26.7	24.5	24.1	21.8	23.8	22.3	20.7	24.5	25.9	22.2	22.1	23.8
18:00-19:00	30.2	27.0	26.5	24.0	26.2	24.8	22.6	25.6	27.0	24.6	24.4	25.8
19:00-20:00	32.3	29.7	29.3	26.7	29.4	27.0	24.7	27.1	28.5	27.8	26.8	28.8
20:00-21:00	36.6	32.8	31.2	29.0	32.5	30.2	27.0	28.7	31.5	31.0	28.2	31.3
21:00-22:00	42.3	37.5	34.9	33.4	38.5	33.3	29.6	30.6	34.1	35.3	32.0	34.8
22:00-23:00	48.4	44.3	40.2	39.2	44.3	39.6	34.4	34.8	38.6	41.9	37.3	39.9
23:00-0:00	42.9	46.3	45.3	44.6	53.0	45.2	39.6	38.1	41.2	48.9	44.6	45.5

Table 3. Average percentages of ADT and percentages of trucks on different types of highways

Time	State Roads		US Roads		Interstate	
	% ADT	% Trucks	% ADT	% Trucks	% ADT	% Trucks
0:00-1:00	1.08	11.12	1.10	34.83	1.53	35.01
1:00-2:00	0.62	15.14	0.83	41.41	1.19	39.95
2:00-3:00	0.46	19.17	0.75	45.01	1.06	43.48
3:00-4:00	0.54	20.42	0.82	45.83	1.12	43.26
4:00-5:00	0.97	17.66	1.31	37.96	1.46	38.18
5:00-6:00	2.21	13.42	2.62	28.25	2.42	29.61
6:00-7:00	4.46	11.31	4.12	24.60	3.89	23.50
7:00-8:00	5.92	10.70	5.07	24.22	4.88	21.45
8:00-9:00	5.21	13.26	5.14	26.68	4.93	22.61
9:00-10:00	4.84	14.52	5.39	26.72	5.07	23.30
10:00-11:00	5.12	14.20	5.74	26.59	5.40	23.21
11:00-12:00	5.50	13.35	6.12	25.92	5.67	22.90
12:00-13:00	5.81	12.61	6.25	25.70	5.85	22.64
13:00-14:00	6.00	12.57	6.29	25.48	6.06	22.17
14:00-15:00	6.54	12.00	6.54	24.19	6.40	21.30
15:00-16:00	7.62	10.40	7.17	21.75	6.89	19.96
16:00-17:00	8.09	8.96	7.39	20.00	7.15	18.83
17:00-18:00	7.85	7.76	7.14	18.29	6.78	18.51
18:00-19:00	6.15	7.61	5.70	18.95	5.63	19.88
19:00-20:00	4.53	7.81	4.25	21.22	4.59	21.76
20:00-21:00	3.58	7.97	3.53	21.81	3.90	23.38
21:00-22:00	2.94	7.96	2.96	22.71	3.36	24.84
22:00-23:00	2.27	8.41	2.23	24.86	2.73	27.27
23:00-0:00	1.70	9.19	1.52	27.88	2.05	30.31

3.2 Work Zone Capacity Values

Two types of work zones on four-lane divided highways are commonly utilized in Indiana as shown in Figures 1 and 2. They are defined as follows (FHWA, 1989a):

1. Partial Closure (or single lane closure) - when one lane in one direction is closed, resulting in little or no disruption to traffic in the opposite direction.
2. Crossover (or two-lane two-way traffic operations) - when one roadway is closed and the traffic which normally uses that roadway is crossed over the median, and two-way traffic is maintained on the other roadway.

As can be seen, the partial closure work zone disrupts traffic in only one direction and the crossover work zone affects traffic in both directions (the median crossover direction and the

opposite direction). However, the crossover work zone allows the construction crew to work on two lanes and also provides a safer work area because the work area in a crossover work zone is separated from traffic while the work area in a partial closure work zone is adjacent to traffic.

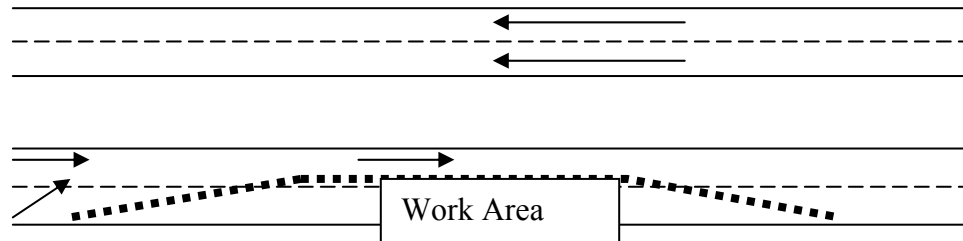


Figure 1. Partial closure work zone

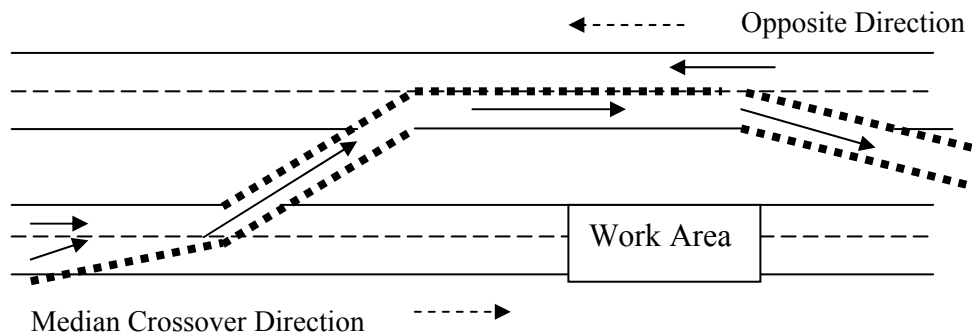


Figure 2. Crossover work zone

In order to estimate traffic delays and related user costs at work zones, the capacity of the work zones must be determined based on the actual traffic conditions. The capacity values of Indiana's highway work zones were determined in a previous study (Jiang, 1999). Work zone capacity was defined as "the traffic flow rate just before a sharp speed drop followed by a sustained period of low vehicle speed and fluctuated traffic flow rate." To express work zone capacity in passenger car per hour, the traffic flow rate was converted to hourly volume and the adjustment factors from the 2000 Highway Capacity Manual were used to convert trucks and buses to passenger car equivalents. The capacity values and several other traffic measures of Indiana highway work zones identified in the previous study (Jiang, 1999) are listed in Table 4.

Table 4. Mean values of work zone capacities, queue-discharge rates and vehicle speeds

Work Zone Type	Mean Capacity (passenger cars/hour)	Mean Queue-Discharge Rate (passenger cars/hour)	Mean Speed During Uncongestion	Mean Speed During Congestion
Crossover (Opposite Direction)	1745	1393	56 mph (90 km/hour)	25 mph (40 km/hour)
Crossover (Crossover Direction)	1612	1587	57 mph (92 km/hour)	25 mph (40 km/hour)
Partial Closure (Right Lane Closed)	1537	1216	59 mph (95 km/hour)	31 mph (50 km/hour)
Partial Closure (Left Lane Closed)	1521	1374	57 mph (92 km/hour)	39 mph (63 km/hour)

3.3 Traffic Delays Caused by Work Zones

Traffic delays at work zones are caused by reduced number of lanes for traffic and lower speed limit. Traffic delays consist of those under uncongested traffic condition and those under congested traffic condition. When the arrival traffic flow rate exceeds the work zone capacity, traffic congestion may occur and therefore result in vehicle queues and traffic delays. On the other hand, when the arrival traffic flow rate is below the work zone capacity, vehicles may pass a work zone smoothly but at a lower speed than normal driving. Vehicles at this reduced travel speed through the work zone need a longer time to pass the work zone than the time needed to pass the same length of the roadway without a work zone. This additional time spent at the work zone is also a traffic delay caused by the work zone. Furthermore, because of the stochastic feature of traffic flow, vehicle queues may also form at a work zone even when the arrival traffic flow rate is below the work zone capacity. All these types of traffic delays at work zones should be accounted and estimated to examine the impact of work zones on highway traffic and the resulted user costs.

3.3.1 Delay Due To Vehicle Deceleration before Entering Work Zone

Assuming a uniform deceleration, the delay for each vehicle before entering a work zone can be calculated using the basic equations of dynamics. It was observed in Indiana that as vehicles approach a work zone they normally decelerate to the work zone speed from the highway speed over a distance of about 2 miles (3.2 kilometers). Without a work zone, the travel time (t_f) of a vehicle over a section of length s at the highway speed (v_f) is:

$$t_f = \frac{s}{v_f} \quad (1)$$

With a work zone, the approach travel time (t_a) of the vehicle with a uniform deceleration over the same section to reduce its speed from the highway speed (v_f) to the work zone speed (v_z) is:

$$t_a = \frac{2s}{v_f + v_z} \quad (2)$$

Then the delay (d_d) due to a vehicle deceleration (from v_f to v_z) when approaching a work zone is:

$$d_d = t_a - t_f = \frac{2s}{v_f + v_z} - \frac{s}{v_f} \quad (3)$$

This delay is called deceleration delay because it occurs when vehicles decelerate before entering a work zone.

3.3.2 Delay Due To Reduced Speed through Work Zone

The traffic delay when vehicles travel through a work zone is the difference between the travel time needed to pass the work zone at the reduced speed and the travel time to pass the same length of the roadway without a work zone at the normal highway speed. If the length of a work zone is L , then the delay (d_z) of a vehicle travelling within the work zone can be calculated as:

$$d_z = L \left(\frac{1}{v_z} - \frac{1}{v_f} \right) \quad (4)$$

3.3.3 Delay for Resuming Highway Speed after Exiting Work Zone

Vehicles travel at reduced speed through a work zone and accelerate to their original highway speed after exiting the work zone. The extra time for this speed resuming is a delay compared to highway traffic without a work zone interruption. If the average acceleration is denoted as a , then the distance (S) traveled to change speed from v_z to v_f is:

$$S = \frac{v_f^2 - v_z^2}{2a} \quad (5)$$

The time needed for a vehicle to accelerate from v_z to v_f is

$$t_1 = \frac{v_f - v_z}{a} \quad (6)$$

If there is no work zone, the time needed for a vehicle to travel the same distance is

$$t_2 = \frac{S}{v_f} = \frac{v_f^2 - v_z^2}{2av_f} \quad (7)$$

Therefore, the delay for a vehicle to accelerate to its original speed is the difference between t_1 and t_2 :

$$d_a = t_1 - t_2 = \frac{v_f - v_z}{a} - \frac{v_f^2 - v_z^2}{2av_f} = \frac{(v_f - v_z)^2}{2av_f} \quad (8)$$

During the traffic data collection at work zones on Indian highways, it was observed that the average acceleration of vehicles was about 2 miles (3.2 kilometers) per hour per second after exiting a work zone. This average value of acceleration can be used in Equation 8 with the appropriate speed values to estimate the delay caused by speed resuming.

3.3.4 Delay Due to Vehicle Queues

Vehicle queues at work zone can occasionally form even when traffic volume is less than the work zone capacity. This type of delay can be attributed to the stochastic nature or the randomness of traffic flow. It can be analyzed and estimated using queuing theory (Bhat 1984; Gerlough and Huber 1975).

Queuing theory is used to mathematically predict the characteristics of a queuing system. A queuing system consists of a servicing facility, a process of arrival of customers to be served by the facility, and the process of service. For a queuing system, it is necessary to specify the following system characteristics and parameters:

1. Input process -- average rate of arrival and statistical distribution of time between arrivals;
2. Service mechanism -- service time average rates and distribution and number of customers that can be served simultaneously;
3. Queue discipline -- the rules followed by the server in taking the customers into service, such as “first-come, first-service”, or “random selection for service”.

A notational representation is often used to describe the input distribution, service time distribution, and the number of servers of a queuing system. The notational representation can be written as: Input distribution/Service time distribution/Number of servers. Some standard notations used in queuing theory include G for an arbitrary distribution, M for Poisson (if arrivals) or exponential distribution (for interarrival or service times), D for a constant length of time (for interarrival or service times). For example, M/M/1 represents a queuing system with Poisson arrivals, exponentially distributed service times, and one server.

To estimate traffic delays with queuing theory, a work zone can be modeled as a server for vehicles to enter the work zone in order of vehicle arrivals. A work zone with one lane open is thus a one server queuing system and the queue discipline is apparently first-come first-service. The average arrival rate of the vehicles is the traffic flow rate and the service rate of the system is the traffic capacity of the work zone. Because of the randomness of highway traffic, the queuing system can be represented as a system with Poisson arrivals, exponentially distributed service times, and one server. That is, a highway work zone with one lane open can be modeled as a M/M/1 queuing system.

If the average arrival rate of vehicles is denoted as F_a , then the average interval between arrivals is $1/F_a$. If the service rate of the system is the work zone capacity F_c , the average service time is $1/F_c$. The ratio $\rho = F_a / F_c$ is called the traffic intensity. If $\rho < 1$ (that is, $F_a < F_c$, or the traffic

flow rate is below the work zone capacity), the vehicle queues can be mathematically estimated with queuing theory. On the other hand, if $\rho \geq 1$ (traffic flow rate exceeds the work zone capacity), queuing theory cannot be used to analyze queues.

In this queuing system, the vehicles in the queuing system are defined as those vehicles that have already merged from the closed lane into the open lane leading to the work zone. Based on queuing theory (Bhat 1984; Gerlough and Huber 1975), the average number of vehicles in the system is

$$E(n) = \frac{\rho}{1 - \rho} = \frac{F_a}{F_c - F_a} \quad \text{for } \rho < 1 \quad (9)$$

The average waiting time that an arrival vehicle spent before entering the work zone is

$$d_w = E(w) = \frac{F_a}{F_c(F_c - F_a)} \quad (10)$$

The average queue length (or the average number of vehicles in the waiting line) is

$$E(m) = \frac{F_a^2}{F_c(F_c - F_a)} \quad (11)$$

Equation 11 is the average queue length over all time, including the period when there is no queue (i.e., queue length is 0). In practice, it is more helpful to know the average vehicle queue length if there is indeed a vehicle waiting line before the work zone. This is defined as the average queue length, given that the queue length is greater than 0. The equation for estimating this queue length is

$$\bar{Q} = E(m | m > 0) = \frac{F_c}{F_c - F_a} \quad (12)$$

In analyzing traffic delays at work zones, Equations 10 and 12 can be utilized to estimate the average vehicle delay time and the average queue length under uncongested traffic conditions.

Traffic congestion occurs when traffic flow rate exceeds the work zone capacity. As given in Table 4, under congested traffic conditions the average speeds were lower than under uncongested traffic conditions and the average flow rates were below the capacity values.

Apparently, these average values of speeds and flow rates should be used in estimating work zone traffic delays under congested traffic conditions.

Once the flow rate of arrival vehicles exceeded the work zone capacity, for a given time period the number of vehicles arrived would be larger than the number of vehicles departed at the work zone. The difference between the number of vehicles arrived and the number of vehicles departed is the vehicle queue formed at the work zone. This can be written as

$$Q = (F_a - F_d)t \quad (13)$$

where t = time;

Q = vehicle queue formed during time t ;

F_a = traffic flow rate of arrival vehicles;

F_d = vehicle queue-discharge rate (traffic flow rate of departure vehicles during congestion).

If there was an original queue (Q_0) at the beginning of the time ($t=0$), then the total queue length at time t is

$$Q_t = Q_0 + (F_a - F_d)t \quad (14)$$

If vehicles arrive at a constant rate and depart the work zone at the vehicle queue-discharge rate within a given hour, then the total vehicle queue at the end of hour i can be calculated as follows:

$$Q_i = Q_{i-1} + F_{ai} - F_d \quad (15)$$

where Q_i = total vehicle queue at the end of hour i ;

F_{ai} = hourly volume of arrival vehicles at hour i ;

F_d = vehicle queue-discharge rate.

This equation is equivalent to

$$Q_m = Q_0 + \sum_{i=1}^m (F_{ai} - F_d) = Q_0 + \sum_{i=1}^m F_{ai} - mF_d \quad (16)$$

It should be pointed out that in Equation 15 or 16 F_{ai} and F_d are hourly traffic volumes under congested traffic conditions and time t is not explicitly expressed because it equals 1.0 hour. If time t is less than 1.0, i.e., t is somewhere between hour $i-1$ and hour i , the equation should be written as

$$Q_i(t) = Q_{i-1} + (F_{ai} - F_d)t \quad (17)$$

$Q_i(t)$ represents the vehicle queue length at time t within hour i , where t is measured starting at the beginning of hour i .

In Equation 15, only if $F_{ai} > F_d$, the queue length increases during hour i , or $Q_i > Q_{i-1}$. On the other hand, if $F_{ai} < F_d$, the queue length decreases during hour i , or $Q_i < Q_{i-1}$. If the calculated Q_i from Equation 15 is less than 0, it implies that F_{ai} was less than F_d and that the vehicle queue has dissipated at some point in time within hour i . If $Q_i = 0$ from Equation 15, then the queue dissipated exactly at the end of hour i . If $Q_i < 0$, then the queue was cleared at a time point t before the end of hour i . Setting Equation 17 equal to 0, i.e., $Q_i(t) = Q_{i-1} + (F_{ai} - F_d)t = 0$, the time t at which the last vehicle in the queue was cleared can be obtained as

$$t = \frac{Q_{i-1}}{F_d - F_{ai}} \quad (18)$$

Here t is less than 1.0 hour because the queue was cleared before the end of hour i .

The traffic delay associated with the queued vehicles can be calculated based on the vehicle queue lengths. As given in Equation 17, the vehicle queue length at time t within hour i is $Q_i(t) = Q_{i-1} + (F_{ai} - F_d)t$. The delay (in vehicle-hours) of these $Q_i(t)$ vehicles during an infinitesimal time interval $(t, t + \Delta t]$ within hour i can be expressed as

$$\Delta D_i = Q_i(t) \Delta t \quad (19)$$

The total traffic delay during a time period from $t = 0$ to $t = T$ is

$$D_i \Big|_{t=0}^{t=T} = \int_0^T \Delta D = \int_0^T Q_i(t) dt = \int_0^T [Q_{i-1} + (F_{ai} - F_d)t] dt = Q_{i-1}T + \frac{1}{2}(F_{ai} - F_d)T^2 \quad (20)$$

For $T = 1$, then Equation 20 results in the total delay (in vehicle-hours) in hour i , that is

$$D_i = Q_{i-1} + \frac{1}{2}(F_{ai} - F_d) \quad (21)$$

If the traffic congestion started at hour 1 and ended during hour I , then $D_1, D_2 \dots D_{I-1}$ can be calculated with Equation 21. Because the traffic congestion ended during hour I , the time t , at which the last vehicle in the queue was cleared, should be first calculated using Equation 18.

$$t_I = \frac{Q_{I-1}}{F_d - F_{ai}} \quad (22)$$

With t_I , the delay can be estimated using Equation 20.

$$D_{i=I} = D_i \Big|_{t=Q_{i-1}/(F_d - F_{ai})} = Q_{I-1} \left(\frac{Q_{I-1}}{F_d - F_{ai}} \right) + \frac{1}{2}(F_{ai} - F_d) \left(\frac{Q_{I-1}}{F_d - F_{ai}} \right)^2$$

or

$$D_i = \frac{Q_{I-1}^2}{2(F_d - F_{ai})} \quad (23)$$

3.3.5 Total Traffic Delay At Work Zone

The total traffic delay at a work zone is then the sum of the individual delays discussed above. Under uncongested traffic conditions, the total traffic delay at a work zone in hour i is

$$DELAY_i = F_{ai} (d_d + d_z + d_a + d_w) \quad (24)$$

Under congested traffic conditions, the total delay at a work zone in hour i is

$$DELAY_i = F_{ai} (d_d + d_z + d_a) + D_i \quad (25)$$

As Equation 22 shows, traffic congestion exists only during a portion (t_I) of the last hour (hour I). Therefore, the total delay in hour I should include the discharged queued vehicles during the

first portion of the hour (t_I) and the expected vehicle queues due to the randomness of traffic flow during the second portion of the hour ($1-t_I$).

$$DELAY_I = F_{ai} [d_d + d_z + d_a + (1-t_I)d_w] + D_I \quad (26)$$

where t_I and D_I are defined in Equations 22 and 23, respectively.

3.3.6 Equations of Vehicle Queue Characteristics

In addition to traffic delay estimations, also derived are the equations of other characteristics of vehicle queues caused by traffic congestion. These equations can be utilized to calculate such values as maximum and average queue lengths, time needed to clear a given vehicle queue, and waiting time of vehicles in queue.

According to Equation 15, Q_i increases as long as F_{ai} is greater than F_d . Therefore, the maximum queue length occurs just before F_{ai} drops below F_d . For example, if $F_{ai} > F_d$ during hour 0 through hour I-1 and $F_{ai} < F_d$ at hour I, then the maximum of the vehicle queue up to hour I is $\max(Q) = Q_{I-1}$.

At the beginning of hour i the queue length (in number of vehicles) is Q_{i-1} , and at the end of hour i the queue length is Q_i . According to Equation 17, the queue length changes linearly with time within each hour. Therefore, the average queue length of hour i is the mean of Q_{i-1} and Q_i :

$$\bar{Q}_i = \frac{1}{2}(Q_{i-1} + Q_i) = Q_{i-1} + \frac{1}{2}(F_{ai} - F_d) \quad (27)$$

It is interesting to note that Equation 27 is the same as Equation 21, however, the difference is that \bar{Q}_i is queue length in number of vehicles and D_i is traffic delay in vehicle-hours.

Queue length at any time t between hour i-1 and hour i is given by Equation 17 as $Q_i(t)$, which is the number of vehicles in the waiting line (or queue). Therefore, when a vehicle arrived at time t, this vehicle became the $Q_i(t)$ th vehicle in the queue. That is, the queue length at time t is

$Q_i(t) = Q_{i-1} + (F_{ai} - F_d)t$. Since the queue-dissipating rate is F_d and the number of vehicles in the queue at time t is $Q_i(t)$, the time needed to clear all $Q_i(t)$ vehicles from the queue is

$$W_t = \frac{Q_i(t)}{F_d} = \frac{Q_{i-1} + (F_{ai} - F_d)t}{F_d} \quad (28)$$

W_t is also the waiting time for the $Q_i(t)$ th vehicle to be cleared from the queue. This waiting time is nothing but the delay incurred to the vehicle that arrived at time t . Therefore, Equation 28 can be used to estimate the delay for any vehicle after it joined the queue. The values of W_t are not only important to traffic engineers, but also important to motorists. For example, the values of W_t can be used in changeable traffic message boards along highway as the “expected delay time” at the work zone. Because delay for the n th vehicle is given as $\frac{n}{F_d}$ by Equation 28, the total delay of all $Q_i(t)$ vehicles in the queue is

$$W_{total} = \frac{1}{F_d} + \frac{2}{F_d} + \dots + \frac{Q_i(t)-1}{F_d} + \frac{Q_i(t)}{F_d} = \frac{Q_i(t)[1+Q_i(t)]}{2F_d} \quad (29)$$

or

$$W_{total} = \frac{[Q_{i-1} + (F_{ai} - F_d)t] \times [1 + Q_{i-1} + (F_{ai} - F_d)t]}{2F_d} \quad (30)$$

It should be emphasized that W_{total} obtained from Equation 29 or Equation 30 is the total delay counted from time t , because the vehicles that joined the queue before time t had already sustained delays between the time they arrived and time t . The average delay time per vehicle in the queue (counted from time t) is then equal to the total queue delay, W_{total} , divided by the total number of vehicles in the queue, $Q_i(t)$.

$$W_{avg} = \frac{W_{total}}{Q_i(t)} = \frac{1 + Q_i(t)}{2F_d} \quad (31)$$

3.4 Excess User Costs at Work Zones

The excess user costs of traffic delays caused by the presence of a work zone are essential for assessment of the impact of the work zone on traffic. They are basically the costs incurred to the motorists because of reduced travel speed and capacity at work zones. The excess user costs include traffic delay costs and additional vehicle operating costs resulting from the speed changes at work zones. The traffic delay costs are estimated on the basis of the equations for traffic delay estimation, which were described in the last chapter.

3.4.1 Deceleration Delay Cost

When approaching a work zone on a highway, a vehicle gradually reduces its speed from the highway speed (v_f) to the work zone speed (v_z) over a deceleration distance (s). The deceleration delay (d_d) is expressed in Equation 3 as:

$$d_d = \frac{2s}{v_f + v_z} - \frac{s}{v_f}$$

The deceleration delay cost of hour i can then be calculated by multiplying d_d with the related traffic flow rates and unit costs of time for the given types of vehicles.

$$C_{di} = d_d \cdot F_{ai} (P_c \cdot U_c + P_t \cdot U_t) \quad (32)$$

where

- C_{di} = deceleration cost of hour i (\$)
- d_d = deceleration delay per vehicle (hour)
- F_{ai} = approach traffic flow rate of hour i (vph)
- P_c = percentage of cars
- U_c = unit cost of time for cars (\$/hour)
- P_t = percentage of trucks
- U_t = unit cost of time for trucks (\$/hour)

The values of unit time for vehicles in 1975 dollar values can be found in the AASHTO Red Book (AASHTO, 1977). In order to assess the current impact of work zones, the values of unit time from the AASHTO Red Book should be updated to the current dollar values. The Red Book introduced the procedures for updating the time values using the Consumer Price Indexes (CPI) or the Wholesale Price Indexes (WPI). The updating procedures use CPI to update time values

for cars and WPI for trucks. In 1978, the Wholesale Price Indexes (WPI) were renamed as Producer Price Indexes (PPI). Therefore, PPI is now used in place of WPI for updating the values of costs and prices. The indexes are published by the U.S. Bureau of Labor Statistics and are available on the Internet. Using appropriate indexes, the time values were determined as \$24 per hour for passenger cars and \$39 per hour for trucks in 2008 dollar values.

3.4.2 Reduced Speed Delay Cost

The traffic delay due to reduced speed at a work zone of length L is given by Equation 4:

$$d_z = L \left(\frac{1}{v_z} - \frac{1}{v_f} \right)$$

Substituting d_z for d_a in Equation 32, obtained is the delay cost of hour i due to reduced speed at a work zone:

$$C_{zi} = d_z \cdot F_{ai} (P_c \cdot U_c + P_t \cdot U_t) \quad (33)$$

Using the appropriate work zone speed v_z in calculation of d_z , this equation can be used to estimate the delay cost for either congested or uncongested traffic.

3.4.3 Acceleration Delay Cost

After exiting a work zone, a vehicle accelerates from the work zone speed to the highway speed. Assuming a constant acceleration rate a , the delay for the vehicle to accelerate to the highway speed is shown in Equation 8:

$$d_a = \frac{(v_f - v_z)^2}{2a v_f}$$

The delay cost of hour i for accelerating to the highway speed is

$$C_{ai} = d_a \cdot F_{ai} (P_c \cdot U_c + P_t \cdot U_t) \quad (34)$$

This equation is also applicable for both congested and uncongested traffic conditions.

3.4.4 Vehicle Queue Delay Cost

The calculations of vehicle queues are different for traffic flow rate below the capacity and for traffic flow rate above the capacity. Therefore, the calculations of the corresponding delay costs are also different. When traffic flow rate is less than the work zone capacity, vehicle queues may form because of the stochastic nature of traffic flows. Using the hourly flow rate, F_{ai} , as the arrival traffic flow rate of hour i and the traffic flow at work zone capacity, F_c , as the departure traffic flow rate, the average waiting time per vehicle can be written as in Equation 10:

$$d_w = \frac{F_{ai}}{F_c (F_c - F_{ai})}$$

Then when traffic flow rate is below the capacity, the cost of vehicle waiting time of hour i at the work zone is

$$C_{wi} = d_w \cdot F_{ai} (P_c \cdot U_c + P_t \cdot U_t) \quad (35)$$

Traffic congestion occurs with the formation of vehicle queues when the traffic flow rate exceeds the work zone capacity. If traffic congestion started at hour 1 and ended during hour I , then the traffic delay for hour $i=1, 2, 3 \dots I-1$ is calculated with Equation 21:

$$D_i = Q_{i-1} + \frac{1}{2} (F_{ai} - F_d)$$

The traffic delay for hour $i=I$ is given by Equation 23:

$$D_I = \frac{Q_{I-1}^2}{2(F_d - F_{ai})}$$

Then when traffic flow rate exceeds the capacity, the cost of traffic delay of hour i due to vehicle queues at the work zone is

$$C_{qi} = D_i (P_c \cdot U_c + P_t \cdot U_t) \quad (36)$$

3.4.5 Excess Cost of Speed Change Cycles

Speed changes at work zones result in additional operating costs of vehicles as a result of excess consumption of fuel, engine oil, tires, and vehicle parts. The AASHTO Red Book tabulated the

excess costs of speed change cycles above costs of continuing at initial speed for vehicles in 1975 dollar value. The Red Book also presented the formulas of multipliers for updating the cost values to the dollar values of future years. For example, the multiplier formula for updating costs of speed change cycles of passenger cars is

$$M_{car} = 0.0022 CPI_F + 0.0001 CPI_O + 0.0033 CPI_T + 0.0001 CPI_M + 0.0017 CPI_D$$

The multiplier formula for updating costs of speed change cycles of combination trucks is

$$M_{truck} = 0.0008 PPI_F + 0.0047 PPI_T + 0.0001 CPI_M + 0.0003 PPI_D$$

where

CPI_F = Consumer Price Index – Private Transportation, Gasoline Regular and Premium

CPI_O = Consumer Price Index – Private Transportation, Motor Oil, premium

CPI_T = Consumer Price Index – Private Transportation, Tires, new, tubeless

CPI_M = Consumer Price Index – Private Transportation, Auto Repairs and Maintenance

CPI_D = Consumer Price Index – Private Transportation, Automobile, new

PPI_F = Producer Price Index – Diesel Fuel to Commercial Consumers

PPI_O = Producer Price Index – Motor Oil, Premium Grade

PPI_T = Producer Price Index – Truck Tires

PPI_D = Producer Price Index – Motor Truck

If S_{car} and S_{truck} denote the excess cost values (in 2008 dollar value) of speed change cycles for passenger cars and trucks (in dollars per 1000 cycles), then the excess cost of speed change cycles of hour i is calculated in dollars as

$$C_{ci} = F_{ai} (P_c \cdot S_{car} + P_t \cdot S_{truck}) / 1000 \quad (37)$$

If the cost values of speed change cycles from the AASHTO Red Book are used directly, then the updating multipliers should be applied to the appropriate costs in the above equation. Consequently, the equation should be written as

$$C_{ci} = F_{ai} (P_c \cdot M_{car} \cdot S_{car} + P_t \cdot M_{truck} \cdot S_{truck}) / 1000 \quad (38)$$

3.4.6 Excess Running Cost of Vehicles at Reduced Speed through Work Zone

Vehicles travel through work zones at lower than normal highway speeds. The differences in travel speeds would result in different vehicle running costs. The AASHTO Red Book tabulated the running costs of passenger cars and trucks for different speeds in 1975 dollar value. Similar

to the excess cost of speed change cycles, the running cost values listed in the Red Book should also be updated to a future year using the formulas of multipliers. The updating multiplier of passenger cars running on general and level tangents is given in the Red Book as

$$M_{car} = 0.0017CPI_F + 0.0001CPI_O + 0.0004CPI_T + 0.0016CPI_M + 0.0032CPI_D$$

The updating multiplier of combination trucks running on general and level tangents is given as

$$M_{truck} = 0.0013PPI_F + 0.0001PPI_O + 0.0007PPI_T + 0.0022CPI_M + 0.0013PPI_D$$

To convert the running costs from the dollar values of 1975 to the dollar values of 2008, the cost values from the Red Book should be multiplied by the appropriate multipliers. If R_{f-car} , $R_{f-truck}$, R_{w-car} , and $R_{w-truck}$ denote running costs in 2008 dollar value for cars on highway, trucks on highway, cars at work zone, and trucks at work zone, respectively, then the excess running cost of hour i caused by a work zone of L miles long is

$$C_{ri} = L \cdot F_{ai} [P_t (R_{w-truck} - R_{f-truck}) + P_c (R_{w-car} - R_{f-car})] / 1000 \quad (39)$$

If the cost values from the AASHTO Red Book are used directly, the updating multipliers should be multiplied by the corresponding running costs to convert the costs from 1975 dollars to 2008 dollars.

3.4.7 Total Hourly Excess User Cost

The above individual user costs are the hourly excess user costs at a work zone in one direction. Therefore, the total hourly excess user cost at the work zone in that direction is the sum of these individual user costs. As presented above, the calculations of delay costs due to vehicle queues are different under congested and uncongested traffic conditions. Consequently, the delay cost due to vehicle queues, C_{wi} , should be used to calculate the total hourly excess user cost when traffic flow rate is less than the work zone capacity. The corresponding equation for total hourly excess user cost under uncongested traffic conditions is

$$C_{total} = (C_{di} + C_{zi} + C_{ai} + C_{wi} + C_{ci} + C_{ri}) \quad (40)$$

When traffic flow rate is greater than the work zone capacity, the delay cost C_{qi} should be used in place of C_{wi} . Then the equation for total hourly excess user cost under congested traffic conditions should be

$$C_{\text{total}} = (C_{\text{di}} + C_{\text{zi}} + C_{\text{ai}} + C_{\text{qi}} + C_{\text{ci}} + C_{\text{ri}}) \quad (41)$$

3.5 Work Zone User Costs Based on WIM Data

As discussed in the previous section, the excess user costs caused by highway work zones can be estimated using a series of formulas based on the traffic volumes at the work zones. Traffic volumes vary from hour to hour and from month to month. For an accurate estimation of user costs, traffic flow data should contain not only ADT, but also hourly and monthly variations in terms of traffic volumes and proportions of trucks and passenger cars. Although ADT values are usually available from state highway agencies at many highway locations, they do not always contain detailed information on hourly distributions and truck percentages. Traffic data recorded by WIM devices, however, provide the information needed for work zone user cost estimation. With such WIM data as shown in Tables 1 and 2, the user cost at a work zone can be estimated at the planning stage of a highway construction project to determine the appropriate contract time and incentive and disincentive values. If there is not a WIM station near a highway construction project, the average values of hourly ADT and truck percentages shown in Table 3 can be used to convert the ADT to hourly traffic flow values.

To demonstrate and analyze the work zone user costs at a highway work zone, the traffic data recorded at the I-65 WIM station shown in Tables 1 and 2 were utilized. The formulas (Equations 1 to 16) were programmed into Microsoft Excel so that the user costs at a work zone can be instantly computed once the work zone type and traffic data were provided. The work zone capacity values and vehicle speeds in Table 4 were incorporated in the Excel program as default values for the user cost calculations. At this WIM station, the traffic volumes were about equal in the two directions. Thus, in each direction the traffic volume was about 50% of the total ADT. Figure 3 shows an example of the Excel user cost calculation sheet. As can be seen, the input information for user cost calculation includes hourly and daily traffic volumes and work zone characteristics.

ROAD USER COST CALCULATIONS-Crossover					
Project NO:	110	Road No.:	165		
Type of Road:	4 lanes divided	Open lane(Opp):	1	Dir-Coffe(Opp):	0.50
Length Miles:	1.00	Open lane(Cross):	1	Dir-Coffe(Cross):	0.50
Normal Speed (mph):	70.00	Workzone Speed (mph):	45.00		
S _{car} :	12.56	S _{truck} :	54.16		
R _{w-car} :	73.2	R _{w-truck} :	171.85		
R _{car} :	88.81	R _{truck} :	216.48		
EXCESS COST OF SPEED CHANGE CYCLES:					
CPI of Private Transportation, Gasoline (all types),CPI _g :			257.85		
CPI of Private Transportation, Motor oil, coolant, and fluids,CPI _o :			247.51		
CPI of Private Transportation,Tires,CPI _t :			113.86		
CPI of Private Transportation, Motor vehicle maintenance and repair,CPI _m :			228.73		
CPI of Private Transportation,New vehicles,CPI _v :			136.28		
PPI of #2 Diesel Fuel, PPI _f :			286.70		
PPI of Motor gasoline, including finished base stocks and blending agents,PPI _g :			277.60		
PPI of Truck and bus pneumatic tires, PPI _t :			115.00		
PPI of Motor vehicles,PPI _v :			135.60		
CPI of Construction year based on 1982-84=100 _o :			211.69		
PPI of Construction year based on 1982=100 _o :			172.20		
DO NOT MAKE ANY CHANGES HERE					

Hour	% Vehicle	% TRUCK	User Cost
0->1	1.7	53.1	\$535
1->2	1.4	59.3	\$418
2->3	1.3	63.7	\$382
3->4	1.3	64.3	\$411
4->5	1.4	60.3	\$458
5->6	2.3	42.1	\$696
6->7	3.3	37.1	\$1,014
7->8	4.4	29.0	\$1,360
8->9	4.6	28.8	\$1,428
9->10	5.1	28.8	\$1,705
10->11	5.5	27.3	\$1,714
11->12	6.0	25.7	\$2,627
12->13	6.1	25.2	\$1,890
13->14	6.1	24.4	\$1,893
14->15	6.5	24.4	\$2,069
15->16	6.6	23.7	\$2,152
16->17	6.6	23.1	\$2,174
17->18	6.4	22.3	\$2,140
18->19	5.6	24.8	\$1,841
19->20	4.9	27.0	\$1,574
20->21	4.2	30.2	\$1,306
21->22	3.6	33.3	\$1,119
22->23	2.8	39.6	\$879
23->24	2.3	45.2	\$710
ADT	47585		
Total User Cost Per Day			\$32,496
Average User Cost Per Vehicle			\$0.68
Average User Cost Per Hour			\$1,354

Figure 3. User cost calculation sheet

With the traffic data in Tables 1 and 2, the user costs were calculated with the Excel program for a partial closure work zone and a crossover work zone. It was assumed that the right side lane in one direction was closed for the partial closure work zone with a length of one mile. The user costs for the partial closure work zone are presented in Table 5. The length of the crossover work zone was also assumed to be one mile. The user costs for the crossover work zone are listed in Table 6. The user costs were calculated in 2008 dollar values. The two tables include the estimated user costs in terms of the hourly user cost, the total user cost per day, the average user cost per vehicle, and the average user cost per hour. In order to compare the average user costs at the two types of work zones, the monthly average daily user costs are plotted in Figure 4. The curves in Figure 4 show that the trends of the user costs at the two types of work zones. The user costs at the crossover work zone are always higher than those at the partial closure work zone. This is because at the crossover work zone two of the four roadway lanes were closed and construction was on two lanes while at the partial closure work zone only one lane was closed and construction was on one lane. In addition, at the crossover work zone the traffic flows in both directions were affected while at the partial closure work zone only the traffic flows in only

one direction were affected. The ratios of the user costs at the crossover work zone to those at the partial closure work zone were calculated as shown in Figure 5. The ratios are different from month to month, ranging from 1.76 to 2.00. In other words, the user costs at the crossover work zone are 1.76 to 2.00 times of those at the partial closure work zone. The monthly variations of the user cost ratios are caused by the traffic volume levels. User cost ratios are highest (2.00) in January and December when the ADT values are lowest (Table 1), while the user cost ratio is lowest (1.76) in August when the ADT (Table 1) is highest. When the ADT is high, such as in July and August, traffic volumes during some periods in the day may exceed the work zone capacities show in Table 4 and then cause traffic congestion and vehicle queues at the work zone. As can be seen in Table 4, the work zone capacities and queue discharge rates are all different for different types of work zones. Thus, the resulted traffic delays and user costs at the crossover work zone are different from those at the partial closure work zone. Consequently, the ratios of the user costs are not the same under uncongested (low traffic volume months) and congested (high traffic volume months) traffic conditions.

INDOT issued “interstate Highway Lane Closure Policy” in July 2003 and “Interstate Highway Lane Closure Policy for Routine Maintenance, Traffic and Miscellaneous Activities” in January 2004. The user cost calculation method outlined in this chapter can also be used to evaluate the roadway closure restrictions at different time periods. As shown above, the hourly and daily user costs can be calculated with values of ADT, hourly proportions of ADT, and % trucks. With the calculated hourly and daily user costs, the appropriateness of roadway closure restrictions can be examined.

Table 5. User costs at a one-mile partial closure freeway work zone on I-65 (in \$)

Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0:00-1:00	183	217	257	256	238	268	262	304	286	234	257	209
1:00-2:00	159	183	215	200	189	215	209	254	240	198	207	176
2:00-3:00	143	155	174	172	168	191	187	241	232	170	176	144
3:00-4:00	170	175	189	192	186	205	192	242	227	193	190	143
4:00-5:00	233	210	211	215	202	229	216	263	246	214	213	165
5:00-6:00	311	297	309	334	332	377	343	394	360	332	318	232
6:00-7:00	435	385	385	465	462	507	472	554	510	462	394	282
7:00-8:00	449	498	557	642	619	680	619	717	689	634	552	381
8:00-9:00	505	528	571	656	654	714	683	748	689	659	570	406
9:00-10:00	549	561	628	712	710	788	775	817	743	728	659	466
10:00-11:00	606	608	673	755	778	867	875	894	789	788	731	541
11:00-12:00	666	667	716	806	834	950	960	984	838	841	806	603
12:00-13:00	703	686	771	842	872	996	1003	1027	848	901	859	664
13:00-14:00	789	759	807	878	911	1023	1032	1119	885	911	911	706
14:00-15:00	801	840	915	987	988	1154	1130	1269	1004	1021	969	773
15:00-16:00	793	867	908	1040	1059	1238	1203	1386	1063	1080	1021	802
16:00-17:00	789	868	936	1124	1089	1291	1227	1455	1141	1126	1070	787
17:00-18:00	648	806	943	1145	1075	1314	1249	1535	1183	1119	1089	756
18:00-19:00	545	700	793	992	919	1172	1151	1458	1065	950	905	634
19:00-20:00	476	588	678	783	732	1025	1000	1315	877	724	686	541
20:00-21:00	417	497	571	615	607	806	790	1134	667	581	610	461
21:00-22:00	344	426	490	515	509	559	549	929	541	494	524	395
22:00-23:00	285	353	411	409	397	439	437	612	435	381	438	331
23:00-0:00	74	227	345	321	308	355	349	391	337	298	346	264
Total User Cost Per Day	11074	12100	13453	15057	14838	17366	16913	20044	15894	15040	14501	10863
Average User Cost Per Vehicle	0.654	0.655	0.659	0.682	0.677	0.730	0.719	0.791	0.692	0.684	0.674	0.653
Average User Cost Per Hour	461.4	504.2	560.6	627.4	618.3	723.6	704.7	835.2	662.2	626.7	604.2	452.6

Table 6. User costs at a one-mile crossover freeway work zone on I-65 (in \$)

Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0:00-1:00	367	434	514	513	477	535	525	608	572	469	514	418
1:00-2:00	311	358	418	389	368	418	405	490	463	386	403	343
2:00-3:00	285	308	347	343	336	382	373	481	464	339	351	287
3:00-4:00	340	350	378	385	371	411	384	485	455	386	380	287
4:00-5:00	466	421	423	431	405	458	432	527	492	429	426	330
5:00-6:00	576	545	562	612	612	696	635	731	670	610	582	421
6:00-7:00	870	769	771	930	924	1014	944	1109	1020	924	787	565
7:00-8:00	898	996	1113	1284	1239	1360	1237	1434	1378	1269	1103	762
8:00-9:00	1011	1056	1143	1311	1308	1428	1366	1494	1377	1318	1140	812
9:00-10:00	1182	1204	1350	1535	1538	1705	1692	1767	1605	1572	1425	1002
10:00-11:00	1212	1215	1345	1509	1554	1714	1733	1782	1575	1573	1460	1081
11:00-12:00	1331	1333	1431	1609	1662	2627	1872	1894	1667	1675	1609	1206
12:00-13:00	1405	1372	1540	1675	1725	1890	1905	1920	1684	1746	1707	1328
13:00-14:00	1576	1517	1610	1729	1756	1893	1911	2025	1723	1813	1757	1412
14:00-15:00	1599	1673	1755	1917	1918	2069	2032	2239	1937	1956	1887	1544
15:00-16:00	1585	1719	1808	1959	1991	2152	2097	2388	1983	2003	1933	1602
16:00-17:00	1576	1721	1842	2050	1990	2174	2076	2441	2059	2027	1970	1573
17:00-18:00	1295	1610	1829	2028	1916	2140	2059	2516	2068	1961	1952	1510
18:00-19:00	1089	1398	1581	1717	1630	1841	1841	2274	1812	1633	1620	1267
19:00-20:00	952	1175	1355	1430	1422	1574	1564	1915	1486	1364	1370	1081
20:00-21:00	833	994	1141	1229	1213	1306	1340	1603	1289	1160	1219	921
21:00-22:00	688	851	980	1029	1017	1119	1097	1286	1082	987	1048	790
22:00-23:00	570	705	822	817	793	879	873	994	869	761	875	662
23:00-0:00	149	454	691	642	617	710	697	782	673	597	692	527
Total User Cost Per Day	22165	24179	26747	29074	28782	32496	31089	35185	30404	28958	28211	21732
Average User Cost Per Vehicle	0.654	0.654	0.655	0.658	0.656	0.683	0.661	0.694	0.662	0.658	0.655	0.654
Average User Cost Per Hour	923.5	1007.5	1114.4	1211.4	1199.3	1354.0	1295.4	1466.1	1266.8	1206.6	1175.5	905.5

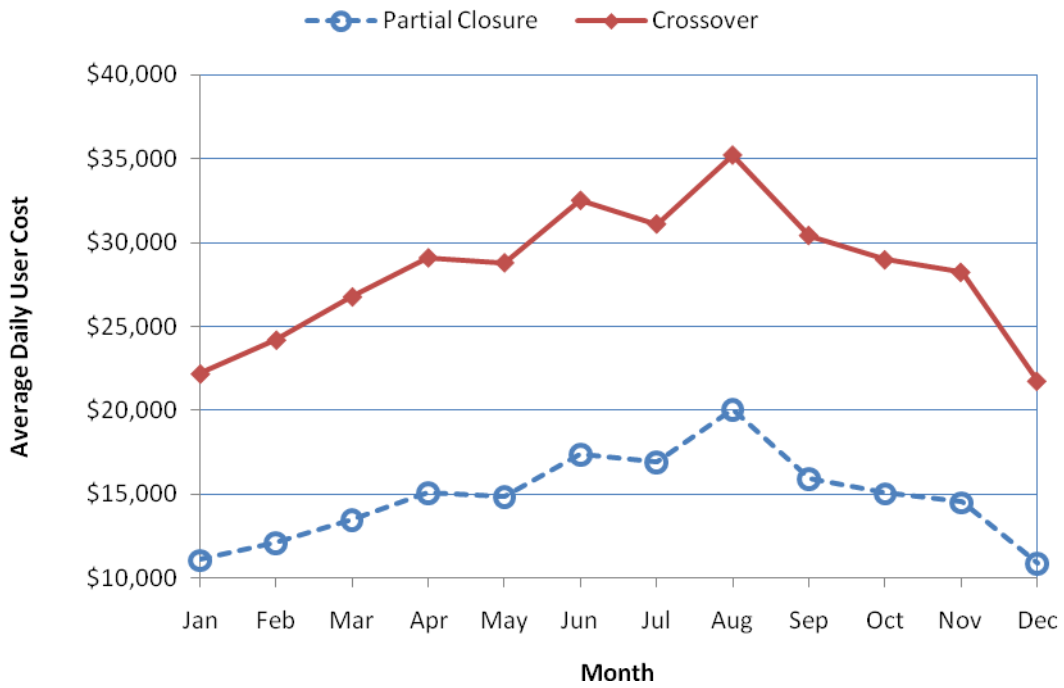


Figure 4. Average daily user costs at partial closure and crossover work zones

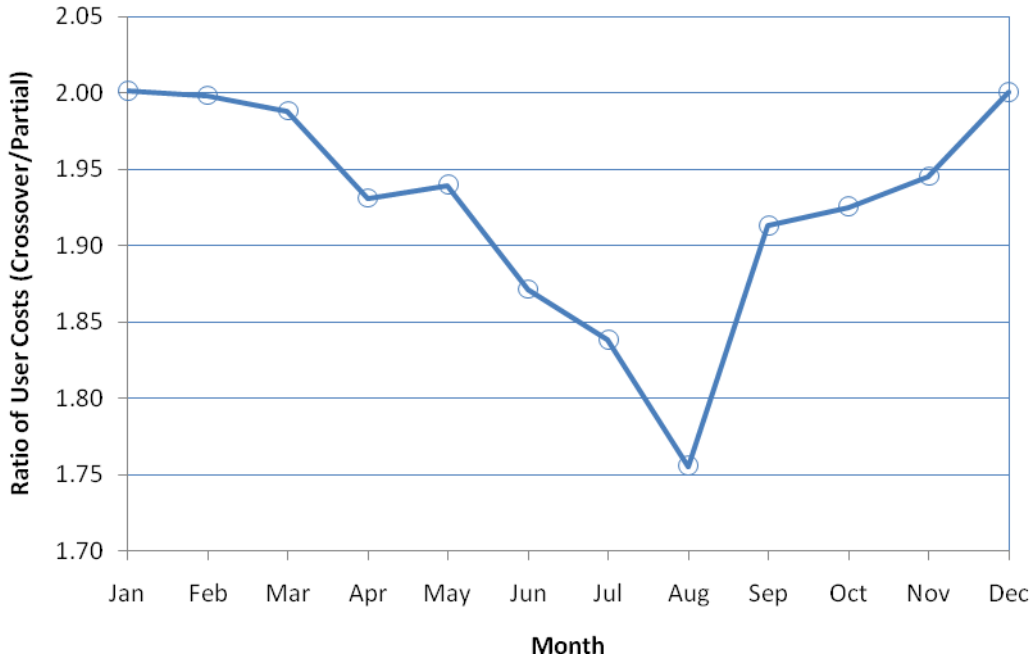


Figure 5. Ratio of crossover user costs to partial closure user costs

It should be noted that even though the total daily user costs are different for the two types of work zones, the average user costs per vehicle are nearly the same for the two types of work zones as shown in Tables 5 and 6. This is because the crossover work zone causes delays for all the vehicles in both travel directions while the partial closure work zone only affects the vehicles in one direction.

User costs at work zones are directly related to traffic volumes as expressed in the user cost equations. To examine the relationship between the user cost and traffic volume at the I-65 site, the hourly traffic volume and user cost at the partial closure work zone in August are plotted in Figure 6. The curves in Figure 6 clearly demonstrate that as the traffic volume goes up the user cost increases. However, the traffic volume reaches the peak point earlier than the user cost. As shown in the figure, the traffic volume is in its maximum at 15:00 and the user cost reaches its peak point at 18:00. This can be attributed to the fact that as the traffic volume increases to the highest level at 15:00 the traffic starts to become congested and a vehicle queue starts to form. As the vehicle queue grows longer, the user cost increases until at 18:00 when the traffic volume has decreased to a certain level and the vehicle queue has cleared from the work zone. Such curves as in Figure 6 would be useful for both highway agencies and contractors to assess the effects of traffic condition on highway construction and user costs.

The work zone user costs discussed above were obtained with a specified work zone length of one mile. To examine the effect of work zone lengths, the user costs were also computed for work zone lengths of five miles and ten miles with the same WIM traffic data. Shown in Figure 7 are the average daily user costs for a partial closure work zone with different lengths. The figure demonstrates that the patterns of the three curves are similar but not identical. This indicates that the work zone lengths affect the user costs differently for different traffic volumes.

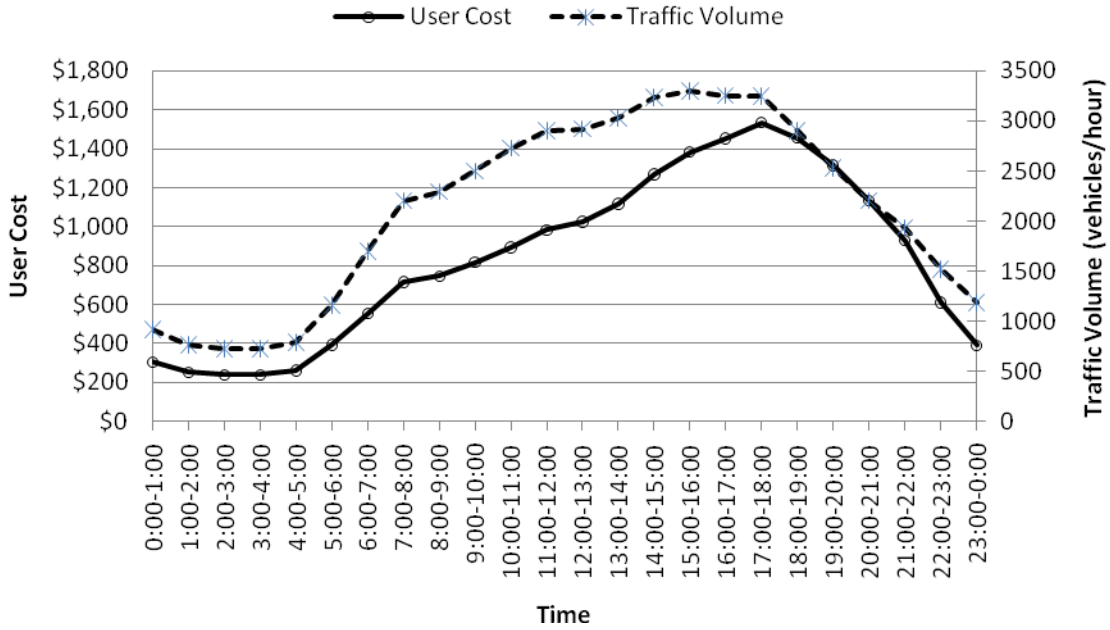


Figure 6. Hourly user costs and traffic volumes at the partial closure work zone in August

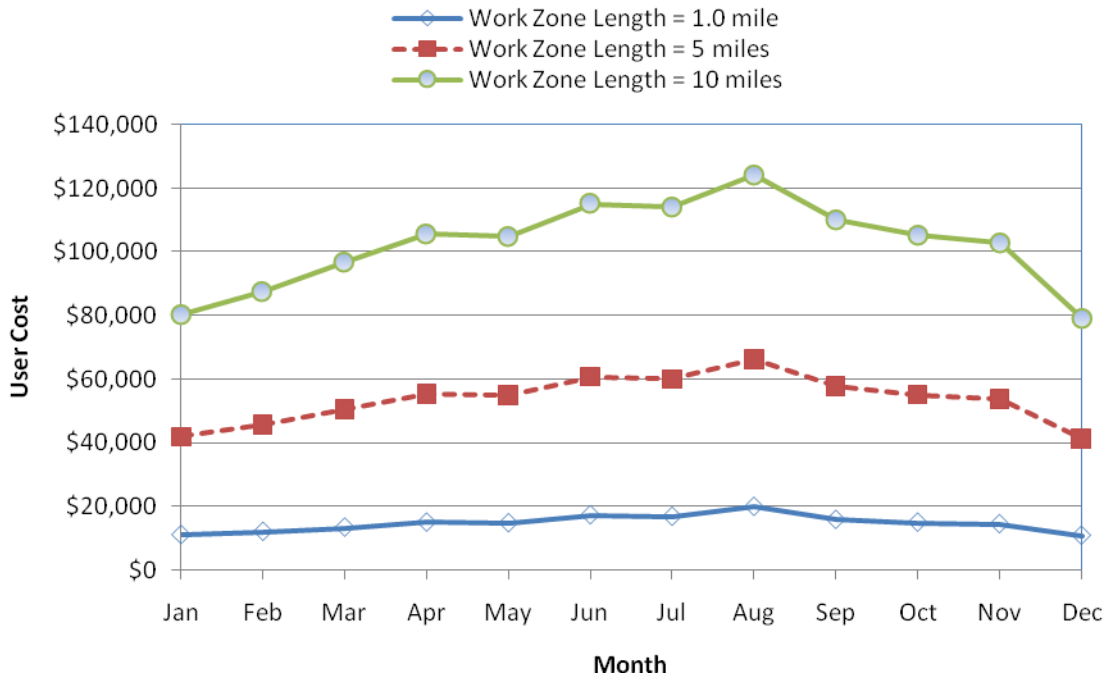


Figure 7. Average daily user costs at the partial closure work zones with different lengths

To exhibit the combined effect of traffic volume and work zone length, the computed user costs in May and August are plotted against work zone length in Figure 8. The ADT values can be found in Table 1 to be 43857 and 50681 in May and August, respectively. As can be seen in Figure 8, the two lines are both straight lines. This means that, for a given traffic volume, the user cost and work zone length have a linear relationship. The figure also clearly shows that the two curves are not parallel and the August line has a greater tangent. This is because the traffic volume (ADT) in August was higher than that in May and the higher traffic volume might have caused more congestion. As traffic congestion occurs, the user cost increases much more than under uncongested conditions and thus results in a steeper line as the August line in Figure 8.

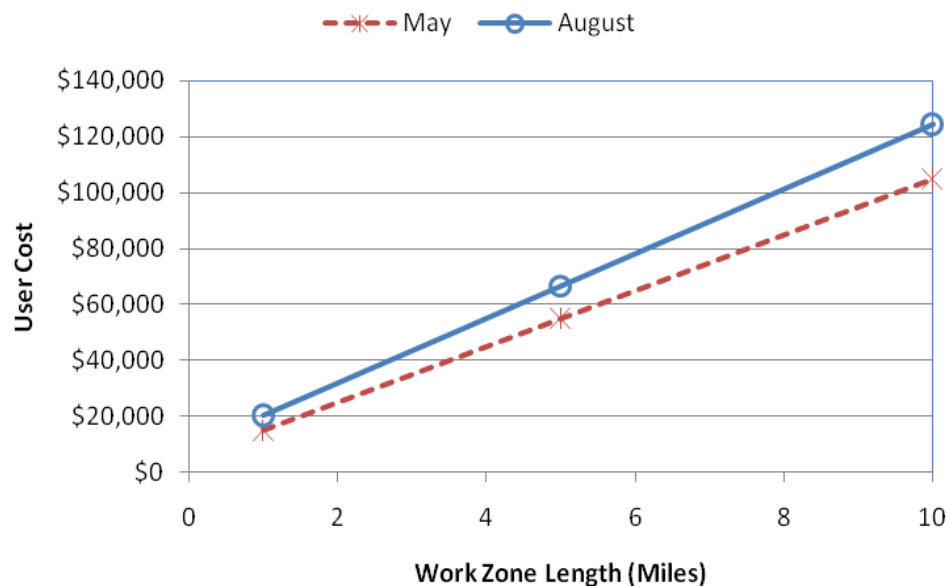


Figure 8. Relationship between work zone length and user cost

CHAPTER 4: INDOT HIGHWAY CONSTRUCTION PRODUCTION RATES

4.1 Mean Production Rates

Currently, INDOT uses a list of mean production rates of common highway construction items. Since production rates change with time because of changes in construction methods, materials, management, equipment, and technology, it is necessary to update the values of the production rates with the most recent data. The mean production rates produced in a previous study (Jiang & Wu, 2004) were sent to the construction engineers of the six INDOT Districts for validation. Mr. Chriss Jobe of the Vincennes District validated the mean production rates based on his experience and calculations. He agreed with most of the mean production rates and adjusted some of them. The mean production rates after Mr. Chriss Jobe's validation and adjustments are listed in Tables 7 through 10. The mean production rates were computed in terms of appropriate production quantity per working day. A working day is defined as an 8-hour continuous highway construction operation within a calendar day. The production rates are listed in four categories, i.e., roadways, bridges, excavations, and removals. The mean production rates in the urban and rural areas are also given in the tables. The production rate values indicate that almost all of the new production rates are greater than their corresponding existing values. Although the differences between the new and the existing values are generally not significant, they certainly show a trend of production rate increases in highway construction. This should be attributed to the improvement of construction technology and efficiency.

Table 7. Mean daily (8-hour) production rates (roadways)

CONSTRUCTION ACTIVITY	UNIT	NEW PRODUCTION RATE	NEW PRODUCTION RATE BY LOCATION	
			URBAN	RURAL
AGGREGATE SHOULDER	TONS	840		
BACKFILL, ROCK	TONS	580	560	600
BARRIER DELINEATOR	EACH	20		
BARRIER WALL-PERMANENT	LFT	200		
BITUMINOUS APPROACHES	TONS	230	200	260
BITUMINOUS BASE	TONS	820	760	900
BITUMINOUS BINDER	TONS	1400	1200	1600
BITUMINOUS BINDER WITH FIBERS	TONS	1840	1670	2000
BITUMINOUS PATCHING	TONS	120	80	80
BITUMINOUS SHOULDERS	TONS	750		
BITUMINOUS SURFACE	TONS	1200	1000	1400
BITUMINOUS WEDGE & LEVEL	TONS	530	510	610
BITUMINOUS WIDENING	TONS	940	910	960
BOX CULVERTS	CYS	50		
CATCH BASINS	EACH	5		
CHAIN LINK FENCE	LFT	1330		
COMPACTED AGGREGATE FOR BASE	TONS	350	270	420
COMPACTED AGGREGATE FOR SHOULDER	TONS	490	420	540
CONCRETE DRIWAYS	SYS	250		
CONCRETE GUTTER	LFT	590		
CONCRETE MEDIAN BARRIER	LFT	910		
CONCRETE PATCHING	SYS	120	110	130
CONCRETE PAVEMENT	SYS	2870	2680	3100
CONCRETE SIDEWALK	SYS	1080	1060	1090
CONTRACTION JOINT	LFT	290		
CRACK & SEATING PVMT	SYS	6580		

Table 7 (continued)

CONSTRUCTION ACTIVITY	UNIT	NEW PRODUCTION RATE	NEW PRODUCTION RATE BY LOCATION	
			URBAN	RURAL
CRACKS, TRANSVERSE, ROUT CLEAN AND SEAL	LFT	9180		
CULVERTS	LFT	220		
CURB AND GUTTER	LFT	330	290	360
CURB AND GUTTER, COMBINED	LFT	330	310	350
CURB RAMP, CONCRETE	SYS	24	20	28
CURB, INTEGRAL, C, CONCRETE	LFT	200		
DRILLED HOLES	EACH	270		
ELECTRIC CABLE	LFT	2600		
EMBANKMENT	CYS	2380	2170	2600
GABIONS	CYS	80	76	82
GEOTEXTILES	SYS	500	470	540
GEOTEXTILES FOR UNDERDRAIN	SYS	150	140	170
GRANULAR BACKFILL	CYS	330		
GRAVEL OR CRUSHED STONE BASE COURSE	TONS	800		
GRAVEL OR CRUSHED STONE SHOULDERS	TONS	800		
GRAVEL OR CRUSHED STONE SURFACE COURSE	TONS	800		
GROUND OR CRUSHED STONE	TONS	860		
GUARDRAIL	LFT	520		
GUARDRAIL, CHANNEL	LFT	240		
GUARDRAIL, RESET	LFT	380		
HANDHOLE	EACH	6		
HMA INTERMEDIATE, MAINLINE	TONS	1400		

Table 7 (continued)

CONSTRUCTION ACTIVITY	UNIT	NEW PRODUCTION RATE	NEW PRODUCTION RATE BY LOCATION	
			URBAN	RURAL
INLET	EACH	6		
JACKED PIPE	LFT	50		
JOINT AND CRACK CLEANING AND SEALING	LFT	210		
LAYING SIGNAL CONDUIT	LFT	220		
LOOP TESTING	EACH	17		
MANHOLES	EACH	3		
MARKINGS	LFT	7200		
PAVED SIDE DITCH	LFT	380		
QC/QA HMA SURFACE, MAINLINE	TONS	980		
REINFORCED CEMENT CONCRETE PAVEMENT	SYS	160		
RIP-RAP	TONS	240	200	260
RUBBLIZING PAVEMENT	SYS	3200		
SEAL COAT	SYS	12030		
SEEDLING	ACRES	10		
SIGN,PANEL,ENCAPSULATED LENS WITH LEGEND	LFT	560		
SLOPE WALL	SYS	50		
SODDING	SYS	1020	990	1040
SOIL STABILIZATION	CYS	4870		
STABILIZED ROADBED	SYS	5000		
STABILIZED SHOULDERS	SYS	1600		
STORM SEWERS	LFT	200		
SUBBASE	TONS	860	840	890
TEMP. CONC. BARRIER	LFT	2590		
TEMP. CROSSOVERS	EACH	1/5		
TRAFFIC SIGNAL HEAD ALTERATIONS	EACH	4		
TRAFFIC SIGNAL POSTS	EACH	4		
TRENCH AND BACKFILL	LFT	450		
UNDERDRAINS	LFT	1090		
UNDERSEAL	TONS	45		

Table 8. Mean daily (8-hour) production rates (bridges)

CONSTRUCTION ACTIVITY	UNIT	NEW PRODUCTION RATE	NEW PRODUCTION RATE BY LOCATION	
			URBAN	RURAL
ACROW BRIDGE	LFT	7.5		
BEAM ERECTION-PRECAST	LFT	400		
BEAM ERECTION-STEEL	LFT	150		
BENT CAP	CYS	10		
BENT COFFERDAMS	SYS	300		
BENT FORM & POUR	CYS	10		
BENT FORM & POUR FOOTING	CYS	10		
BENT PILING	LFT	500		
BRIDGE BARRIER	LFT	80		
BRIDGE DECK	CYS	250		
BRIDGE DECK OVERLAY	SYS	360	340	370
BRIDGE HANDRAILS	LFT	230		
BRIDGE RAIL	LFT	600		
CLASS "A" CONCRETE IN STR'S	CYS	170		
CLASS "B" CONCRETE IN STR'S	CYS	110		
CONCRETE, C, IN SUPERSTRUCTURE	CYS	80		
CONSTRUCT FILL	CYS	500		
DEWATER, FORM & POUR BENT STEM	CYS	10		
DITCH PAVING	SYS	200		
DRILLED SHAFTS-BRIDGE	EACH	0.3		
DRIVING CONCRETE PILES	LFT	300		
DRIVING STEEL PILES	LFT	400		
DRIVING TIMBER PILES	LFT	350		

Table 8 (continued)

CONSTRUCTION ACTIVITY	UNIT	NEW PRODUCTION RATE	NEW PRODUCTION RATE BY LOCATION	
			URBAN	RURAL
ERECTING HANDRAIL	LFT	80		
ERECTING STRUCTURE STEEL	LBS	27500		
EXPANSION BOLTS	EACH	27		
FLOWABLE MORTAR	CYS	150		
FOOTINGS	CYS	30		
FORM & POUR DIAPHRAGMS	CYS	5		
FORM & POUR FOOTING	CYS	10		
FORM & POUR TOP WALL	CYS	15		
LIGHTING STANDARDS	EACH	5		
PARAPET	LFT	100		
PILING	LFT	300		
PLACE BITUMINOUS MIX	TONS	1300		
PLACE COMPACTED AGGREGATE	TONS	2000		
PLACE DECK W/O SUPPORT CUTTOUS	CYS	150		
PRISMATIC REFLECTOR	EACH	930		
REBAR	LBS	20000		
REINFORCED CONCRETE APPROACHES	CYS	30		
REINFORCEMENT BARS (SUBSTRUCTURE)	LBS	2500		
REINFORCEMENT BARS (SUPERSTRUCTURE)	LBS	5000		
REINFORCING STEEL	LBS	14780		
REINFORCING STEEL, EPOXY COATED	LBS	9220		

Table 9. Mean daily (8-hour) production rates (excavations)

CONSTRUCTION ACTIVITY	UNIT	NEW PRODUCTION RATE	NEW PRODUCTION RATE BY LOCATION	
			URBAN	RURAL
BORROW	CYS	990	890	1100
BORROW LARGE AREAS	CYS	2610		
CHANNEL	CYS	650		
COFFERDAM	CYS	80		
COMMON SMALL AREAS	CYS	520		
EXCAVATION, COMMON SMALL AREAS	CYS		490	540
EXCAVATION, SUBGRADE TREATMENT	CYS		1140	1180
EXCAVATION, UNCLASSIFIED	CYS		3270	3640
EXCAVATION, WATERWAY	CYS		620	700
PEAT	CYS	860		
ROCK	CYS	1130		
SUBBALLAST	TONS	270	250	290
SUBGRADE TREATMENT	CYS	1160		
UNCLASSIFIED	CYS	3460		
WATERWAY	CYS	660		
WET	CYS	80		

Table 10. Mean daily (8-hour) production rates (removals)

CONSTRUCTION ACTIVITY	UNIT	NEW PRODUCTION RATE	NEW PRODUCTION RATE BY LOCATION	
			URBAN	RURAL
CURB & GUTTER	LFT	860	780	960
FENCE	LFT	150		
HEADWALL	EACH	3		
PAVEMENT (CONC.)	SYS	920	870	980
SIDEWALK	SYS	1690	1580	1820
STUMP	EACH	12		
SURFACE (MILLING)	SYS	14000	6000	16000
SURFACE MILLING, BITUMINOUS	SYS		2860	3400
TOP SOIL	CYS	380		
TREE	ACRES	2		

4.2 Baseline Production Rates

In addition to mean production rates, sometimes it is also necessary to know the production rates with minimum negative effects. In other words, it is desirable to obtain the production rates under ideal construction conditions. The production rates under ideal construction conditions are called the baseline production rates. The baseline production rates can be obtained from the recorded construction data as described by Thomas and Završki (1999) follow the steps below:

1. Determine 10% of the total working days.
2. Round this number to the next highest odd number; this number should not be less than 5. This number n defines the size of number of working days in the baseline production rate subset.
3. The contents of baseline production rate subset are selected as the n working days that have the highest daily production rates.
4. For these working days, make note of the daily production rates.
5. The baseline production rate is the median of the daily production rate values in the baseline production rates subset.

As these steps imply, a baseline production rate is the median value of the 10% working days of a highway construction project with the highest production rates. The baseline production rates calculated in this manner for INDOT highway projects are presented in Tables 11 through 14.

Table 11. Mean baseline production rates (roadways)

CONSTRUCTION ACTIVITY DESCRIPTION	UNIT	MEAN BASELINE PRODUCTION RATES
ROADWAYS		
AGGREGATE SHOULDER	TONS(Mg)	840(760)
BACKFILL, ROCK	TONS(Mg)	610(555)
BITUMINOUS APPROACHES	TONS(Mg)	240(220)
BITUMINOUS BASE	TONS(Mg)	980(890)
BITUMINOUS BINDER	TONS(Mg)	1,200(1,090)
BITUMINOUS BINDER WITH FIBERS	TONS(Mg)	2,030(1,840)
BITUMINOUS PATCHING	TONS(Mg)	110(100)
BITUMINOUS SHOULDERS	TONS(Mg)	810(735)
BITUMINOUS SURFACE	TONS(Mg)	1,080(980)
BITUMINOUS WEDGE AND LEVEL	TONS(Mg)	600(545)
BITUMINOUS WIDENING	TONS(Mg)	980(890)
BOX CULVERTS	CYS(m ³)	54(40)
CHAIN LINK FENCE	LFT(m)	1,390(425)
COMPACTED AGGREGATE FOR BASE	TONS(Mg)	380(345)
COMPACTED AGGREGATE FOR SHOULDER	TONS(Mg)	520(470)
CONCRETE DRIWAYS	SYS(m ²)	280(235)
CONCRETE GUTTER	LFT(m)	640(195)
CONCRETE MEDIAN BARRIER	LFT(m)	1,010(310)
CONCRETE PATCHING	SYS(m ²)	120(100)
CONCRETE PAVEMENT	SYS(m ²)	2,990(2,500)
CONCRETE SIDEWALK	SYS(m ²)	1,090(910)
CONTRACTION JOINT	LFT(m)	300(90)
CRACK & SEATING PVMT	SYS(m ²)	6,910(5,775)
CRACKS, TRANSVERSE, ROUT CLEAN AND SEAL	LFT(m)	11,070(3,375)
CURB AND GUTTER	LFT(m)	380(115)
CURB AND GUTTER, COMBINED	LFT(m)	340(105)
CURB RAMP, CONCRETE	SYS(m ²)	28(23)
CURB, INTEGRAL, C, CONCRETE	LFT(m)	210(65)
DRILLED HOLES	EACH	290
EMBANKMENT	CYS(m ³)	2,570(1,965)
GABIONS	CYS(m ³)	82(63)

Table 11 (continued)

CONSTRUCTION ACTIVITY DESCRIPTION	UNIT	MEAN BASELINE PRODUCTION RATES
GEOTEXTILES	SYS(m ²)	540(450)
GEOTEXTILES FOR UNDERDRAIN	SYS(m ²)	200(165)
GRANULAR BACKFILL	CYS(m ³)	360(275)
GROUND OR CRUSHED STONE	TONS(Mg)	900(815)
GUARDRAIL	LFT(m)	590(180)
GUARDRAIL, CHANNEL	LFT(m)	270(80)
GUARDRAIL, RESET	LFT(m)	390(120)
HMA INTERMEDIATE, MAINLINE	TONS(Mg)	1,470(1,335)
JACKED PIPE	LFT(m)	52(16)
JOINT AND CRACK CLEANING AND SEALING	LFT(m)	250(75)
LAYING SIGNAL CONDUIT	LFT(m)	230(70)
MARKINGS	LFT(m)	7,660(2,335)
PAVED SIDE DITCH	LFT(m)	400(120)
PIPES, CULVERTS	LFT(m)	230(70)
PIPES, UNDERDRAINS	LFT(m)	1,160(355)
QC/QA HMA SURFACE, MAINLINE	TONS(Mg)	1,010(915)
REINFORCED CEMENT CONCRETE PAVEMENT	SYS(m ²)	170(140)
RIP-RAP	TONS(Mg)	260(235)
RUBBLIZING PAVEMENT	SYS(m ²)	3,290(2,750)
SEAL COAT	SYS(m ²)	12,990(10,860)
SIGN,PANEL,ENCAPSULATED LENS WITH LEGEND	LFT(m)	580(175)
SLOPE WALL	SYS(m ²)	53(44)
SODDING	SYS(m ²)	1,060(885)
SOIL STABILIZATION	CYS(m ³)	4,930(3,770)
SUBBASE	TONS(Mg)	920(835)
TEMP. CONC. BARRIER	LFT(m)	2,780(845)
UNDERSEAL	TONS(Mg)	47(43)

Table 12. Mean baseline production rates (bridges)

CONSTRUCTION ACTIVITY	UNIT	MEAN BASELINE PRODUCTION RATES
BRIDGES		
BEAM ERECTION-PRECAST	LFT(m)	420(130)
BEAM ERECTION-STEEL	LFT(m)	160(50)
BENT COFFERDAMS	SYS(m ²)	320(270)
BRIDGE BARRIER	LFT(m)	80(24)
BRIDGE DECK	CYS(m ³)	16(12)
BRIDGE DECK OVERLAY	SYS(m ²)	490(410)
BRIDGE HANDRAILS	LFT(m)	240(75)
BRIDGE RAIL	LFT(m)	640(195)
CLASS "A" CONCRETE IN STR'S	CYS(m ³)	180(140)
CLASS "B" CONCRETE IN STR'S	CYS(m ³)	110(85)
CONCRETE, C, IN SUPERSTRUCTURE	CYS(m ³)	86(65)
CONSTRUCT FILL	CYS(m ³)	530(405)
DITCH PAVING	SYS(m ²)	210(175)
FLOWABLE MORTAR	CYS(m ³)	160(120)
FOOTINGS	CYS(m ³)	31(24)
PARAPET	LFT(m)	100(30)
PILING	LFT(m)	330(100)
PLACE BITUMINOUS	TONS(Mg)	1,390(1,260)
PLACE COMPACTED AGGREGATE	CYS(m ³)	2,190(1,675)
PLACE DECK W/O SUPPORT CUTOOTS	TONS(Mg)	160(145)
PRISMATIC REFLECTOR	EACH	940
REBAR	LBS(Kg)	21,640(9,825)
REINFORCED CONCRETE APPROACHES	CYS(m ³)	32(24)
REINFORCEMENT BARS (SUBSTRUCTURE)	LBS(Kg)	2,680(1,215)
REINFORCEMENT BARS (SUPERSTRUCTURE)	LBS(Kg)	5,420(2,460)
REINFORCING STEEL	LBS(Kg)	16,360(7,425)
REINFORCING STEEL, EPOXY COATED	LBS(Kg)	9,400(4,270)
RETAINING WALLS	SYS(m ²)	18(15)
SIGN SMALL	EACH	22
WINGWALLS	SYS(m ²)	19(16)

Table 13. Mean baseline production rates (excavations)

CONSTRUCTION ACTIVITY DESCRIPTION	UNIT	MEAN BASELINE PRODUCTION RATES
EXCAVATIONS		
BORROW	CYS(m ³)	1,070(820)
BORROW LARGE AREAS	CYS(m ³)	2,810(2,150)
CHANNEL	CYS(m ³)	660(505)
COMMON SMALL AREAS	CYS(m ³)	540(415)
PEAT	CYS(m ³)	880(675)
ROCK	CYS(m ³)	1,180(905)
SUBBALLAST	TONS(Mg)	290(265)
SUBGRADE TREATMENT	CYS(m ³)	1,180(905)
UNCLASSIFIED	CYS(m ³)	3,620(2,770)
WATERWAY	CYS(m ³)	720(550)
WET	CYS(m ³)	90(69)

Table 14. Mean baseline production rates (removals)

CONSTRUCTION ACTIVITY DESCRIPTION	UNIT	MEAN BASELINE PRODUCTION RATES
REMOVALS		
CURB & GUTTER	LFT(m)	880(270)
FENCE	LFT(m)	180(55)
PAVEMENT (CONC.)	SYS(m ²)	940(785)
SIDEWALK	SYS(m ²)	1,730(1,445)
STUMP	EACH	14
SURFACE (MILLING)	SYS(m ²)	11,600(9,700)
TOP SOIL	CYS(m ³)	390(300)

The mean baseline production rates reflect the production rates under ideal conditions. They can be used to evaluate construction process with minimal interruptions and delays. For example, the minimum time period for a highway construction project may be estimated with mean baseline production rates, so that the negative effect of highway construction on motorists and local businesses can be minimized.

CHAPTER 5: DETERMINATION OF MAXIMUM DAYS FOR INCENTIVE AND MAXIMUM INCENTIVE

5.1 Determination of Daily I/D Amount

As discussed in Chapter 3, user costs caused by work zones can be estimated based on traffic flows passing through the work zones. However, if the whole user cost is used as the daily I/D amount, the incentive or disincentive will be too large for the contractor to pay for the disincentive or for the highway agency to pay for the incentive. The daily I/D amount can be determined by considering savings in user costs as well as benefit to the contractor. Jaraiedi, Plummer, and Aber (1995) presented a method to determine the I/D amount as a portion of the total estimated user cost. The method is based on the number of days, X , that can be saved by the use of an I/D provision in the contract. The number of days to be saved can be estimated by the highway agency. Extra equipment and crews will be needed for the contractor to complete the project ahead of schedule. This will result in two types of extra costs: (1) the fixed one-time cost, A , for obtain the extra equipment, crews, and materials; and (2) the variable cost per day, B , for using the additional equipment and crews. Thus, the total cost to the contractor for completing the project X days ahead of schedule is $A+BX$. If the daily user cost is estimated as C , the total reduction in user costs resulting from the project being shortened by X days will be CX . The incentive that is paid to the contractor for early completion under the I/D provisions is justified by savings in user cost if the following inequality is satisfied (Jaraiedi, Plummer & Aber, 1995).

$$CX \geq A+BX \quad (42)$$

This inequality requires that total user cost savings is greater or equal to total cost to the contractor. If the inequality is true, then the contract may be worthy of an I/D provision. However, if this inequality is not true, the cost to the contractor for expediting the work is greater than the user cost savings, then the I/D provision should not be used.

In an I/D contract, the contractor may increase his/her profits by completing the project earlier than the specified date. The daily I/D amount, R , is the bonus amount for each day of early completion. For the contractor to be motivated to bid on the I/D contract and actively work to accelerate the construction by X days, the total bonus amount to be paid must be greater than the extra costs for the accelerated work (Jaraiedi, Plummer & Aber, 1995).

$$RX \geq A + BX \quad (43)$$

Dividing both sides of the inequality by the number of days the contract is to be expedited, X , gives:

$$R \geq (A/X) + B \quad (44)$$

This inequality means that the daily I/D amount should be greater than the extra cost to the contractor. If (44) is not true, the contractor will not be motivated to complete the project earlier as he/she will have nothing to gain.

The daily I/D amount, R , represents a portion of the user cost savings to be passed on to the contractor. If the portion of the user cost savings to be shared with the contractor is p , the value of p should be between 0 and 1, or $0 < p \leq 1$. The magnitude of the I/D amount will be limited to the portion of user cost savings that the contractor will share (Jaraiedi, Plummer & Aber, 1995):

$$RX \leq pCX \quad (45)$$

Dividing both sides by X yield:

$$R \leq pC \quad (46)$$

Combining (44) and (46) results in:

$$(A/X) + B \leq R \leq pC \quad (47)$$

This inequality (47) can be used to determine appropriate value of p if A , B , and X values are estimated. For example, if it is estimated that one-time cost to the contractor to expedite is $A=\$2,000$; the daily cost to the contractor to expedite is $B=\$5,000$ per day; the number of days the contract to be expedited is $X=10$ days, and the user cost is $C=\$10,000$ per day, then the following results can be obtained for different values of p as shown in Table 15 (Jaraiedi, Plummer & Aber, 1995).

Table 15. Range of daily incentive amounts

Value of p	User cost savings, C (\$/day)	Contractor costs, (A/X)+B (\$/day)	Range of daily I/D amount (\$)
0.10	10,000	5,200	$5,200 \leq R \leq 1,000$
0.20	10,000	5,200	$5,200 \leq R \leq 2,000$
0.30	10,000	5,200	$5,200 \leq R \leq 3,000$
0.40	10,000	5,200	$5,200 \leq R \leq 4,000$
0.50	10,000	5,200	$5,200 \leq R \leq 5,000$
0.60	10,000	5,200	$5,200 \leq R \leq 6,000$
0.70	10,000	5,200	$5,200 \leq R \leq 7,000$
0.80	10,000	5,200	$5,200 \leq R \leq 8,000$
0.90	10,000	5,200	$5,200 \leq R \leq 9,000$
1.00	10,000	5,200	$5,200 \leq R \leq 10,000$

As shown in Table 15, as the value of p changes, the range of daily I/D amount changes. In this example, the value of p should be at least 0.52 so that the contractor can be motivated to expedite the construction activities. If the value of p is less than 0.52, the range will not be valid for the inequality. When selecting daily I/D amount, the accuracy of the estimate of the contractor's costs should be considered. If the highway agency is confident in the estimate of the contractor's additional costs (A and B), then a lower value of p that yields a valid range should be used. Otherwise, a relatively higher value of p should be selected as a minimum incentive value so as not to negatively influence the smaller firms from bidding the contract (Jaraiedi, Plummer & Aber, 1995).

5.2 Cost-Time Relationship and Maximum Incentive

The main purpose of using incentive/disincentive (I/D) contracts is to motivate contractors to complete highway construction early so that the interruption to the normal traffic can be mitigated and the user costs caused by construction can be reduced. The incentive part of an I/D contract is used to reward the contractor for early completion of a project, while the disincentive is used to discourage contractor for late completion of the project. To ensure such a contract to work as intended, appropriate amount of incentive and disincentive should be determined. The incentive amount should be sufficient to motivate the contractor to make effort for early completion of the project. On the other hand, the incentive amount must be limited to avoid unreasonable increase of construction cost. Similarly, the contract time should be reasonably set so that the early completion of the project is achievable, but not without additional effort. FHWA (1989b) recommended that the maximum incentive value do not exceed 5% of the total construction cost of the project. Shr and Chen (2004) found that most state highway agencies use a fixed amount or fixed percents of construction cost as the maximum incentive. Many states used 5% of the total construction cost as the limit, but some states used up to 10% of the total construction cost as the limit. Other states set a flat-rate dollar amount to cap the total incentive amount. Several states did not have restrictions on the total incentive amount.

For a highway project, the construction cost and the duration of construction are the two major parameters for highway agencies to consider. To appropriately determine incentive and disincentive values, the cost-time relationship should be incorporated into the process. In addition, user cost should also be included as a factor in determining incentive and disincentive values. Shr and Chen (2004) developed a quantified model based on the Florida Department of Transportation's data. To develop such a model, the cost-time relationship must be established. For a highway construction project, the relationship between construction cost and construction time can be illustrated through Figure 9. As can be seen in Figure 9, there exists a construction time (T_0) that corresponds to a minimum construction cost (C_0) for a given highway project with a given construction crew. If the construction duration (T) is delayed beyond T_0 , or ($T > T_0$), the effectiveness will be reduced and the cost will be increased. On the other hand, if an early

completion is needed ($T < T_0$), the construction crew must make additional effort, such as increasing work hours, manpower, or equipment, which will result in an additional cost.

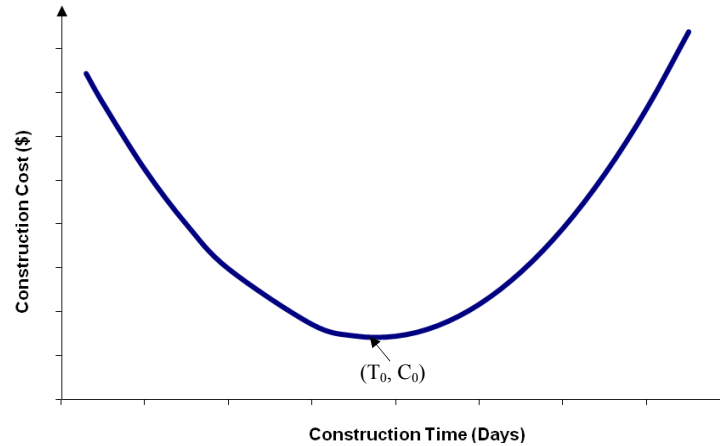


Figure 9. Cost-time relationship of highway construction project

The construction cost in Figure 9 does not include the excess costs to the roadway users and highway agency. In order to optimize the amount of incentive, the daily I/D values must be obtained based on the user costs and other costs associated with the construction activities. The I/D values should then be included as a type of costs to determine the maximum amount of incentive money and time. The concept of this incentive optimization is illustrated in Figure 10 (Shr & Chen, 2004). In the figure, the solid curve is the construction costs; the straight line represents the incentive and disincentive rates; and the dashed curve is the combined values of construction costs and I/D costs. The maximum days for incentive and maximum incentive are determined as shown in Figure 10 through the relative positions of the three curves, i.e., the construction cost curve, the I/D rate curve, and the construction cost plus I/D curve. It should be pointed out that the costs in Figure 10 are the costs to a contractor. The I/D curve is based on the perspective of a contractor so that the incentive values are considered negative costs and disincentive values are positive costs to the contractor. For a highway agency, the incentives are additional costs used to motivate the contractor to accelerate the construction and to reduce user costs.

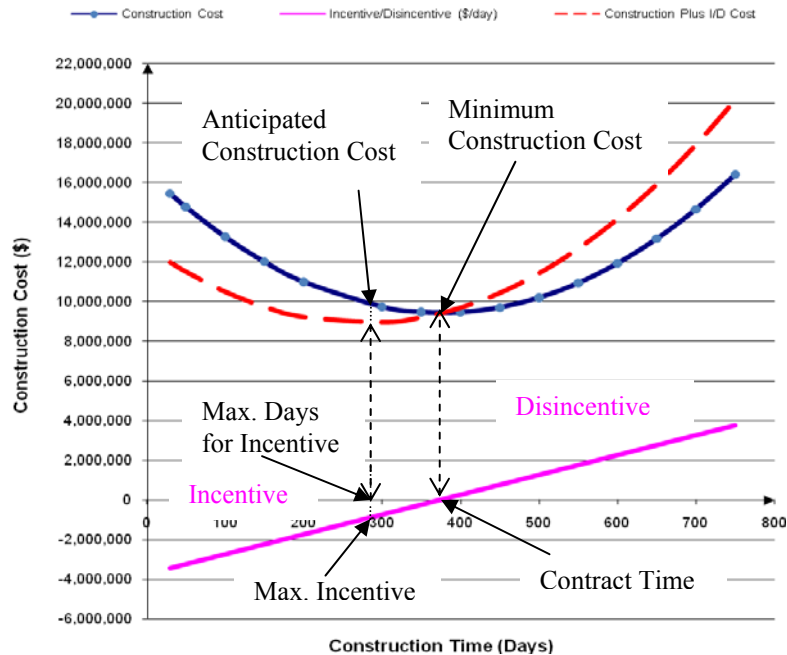


Figure 10. Determination of maximum days for incentive and maximum incentive

If should be pointed out that values obtained through this method are provided to help highway engineers and planners select appropriate incentive values. However, the maximum incentive values should also be based on how much the highway agency can afford to pay for the early completion. If the fund is not enough to cover the maximum incentive, then the daily incentive should be adjusted to the lowest possible figure that would still provide incentive to the contractor.

5.3 Cost-Time Equations of Highway Construction Projects in Indiana

In order to determine the maximum days for incentive and maximum incentive for Indiana projects, highway construction data were obtained for various types of highway construction projects. The construction data were from the INDOT construction data files, including IB, IIB, IIIB, and IIC files. The construction data include highway construction projects completed in 2006, 2007, and 2008. In addition, part of the construction data collected in the previous study of highway construction productivities were also used to analyze the cost-time relationships of various types of highway construction types.

The cost-time equations were then derived based on the construction data through statistical analysis and regressions. The cost-time equations were developed with polynomial regressions. The cost-time relationship equations of 11 types of highway construction projects are listed Table 16.

Table 16. Cost-time equations of highway construction projects

Construction Types	Time-Cost Relationship Equations [x is construction time (days), y is construction cost (\$)]
Asphalt Resurface	$y = 318.55x^2 - 41,652.97x + 2,784,769.51$
Pavement/Road Rehabilitation	$y = 358.14x^2 - 143,281.93x + 20,377,661.15$
New Road Construction	$y = 289.50x^2 - 87,839.33x + 11,896,755.64$
Bridge Replacement (Interstate)	$y = 146.51x^2 - 57,139.08x + 7,173,044.13$
Bridge Replacement (US Routes)	$y = 255.56x^2 - 51,425.02x + 4,130,888.40$
Bridge Replacement (State Roads)	$y = 64.14x^2 - 14,780.32x + 1,863,168.68$
Bridge Rehabilitation (Interstate)	$y = 100.17x^2 - 39,911.97x + 5,579,225.97$
Bridge Rehabilitation (US Routes)	$y = 75.89x^2 - 27,354.68x + 3,861,342.10$
Bridge Rehabilitation (State Roads)	$y = 77.62x^2 - 18,320.74x + 1,971,154.59$
Bridge Painting	$y = 33.46x^2 - 6,423.46x + 608,462.48$
Intersection Improvement	$y = 123.22x^2 - 16,025.90x + 860,631.96$

For each type of construction projects in Table 16, the corresponding polynomial function represents the general relationship between construction cost and time. This general relationship can be considered the average pattern of many highway projects in the specified construction type. To apply this general relationship to a given construction project, the cost-time curve can be shifted according to the estimated construction cost and contract time of the particular project. The curve shifting process is illustrated in Figure 11. The polynomial equation of the general curve is expressed as $y=ax^2+bx+c$. The lowest point of the curve is at (T_0, C_0) . The values of T_0 and C_0 can be obtained by the derivative of the polynomial equation of the construction type:

$$dy/dx = 2ax+b \quad (48)$$

Setting $dy/dx=2ax+b=0$ and solving for the minimum point of the curve:

$$C_0 = x_{\min} = -b/(2a) \quad (49)$$

$$T_0 = y_{\min} = -b^2/(4a)+c \quad (50)$$

For a given construction project, under normal contract condition (without I/D clauses), the point at the contract time T_1 and the estimated construction cost C_1 , or (T_1, C_1) , can be considered the lowest point of the cost-time curve of the project. To determine the I/D values, the general curve of the construction type should be shifted from (T_0, C_0) as the lowest point to (T_1, C_1) as the lowest point of the curve. The distance to be shifted is $g=T_0-T_1$ in the horizontal direction and is $h=C_0-C_1$ in the vertical direction. The equation of the shifted curve is then expressed as $y+h=a(x+g)^2+b(x+g)+c$.

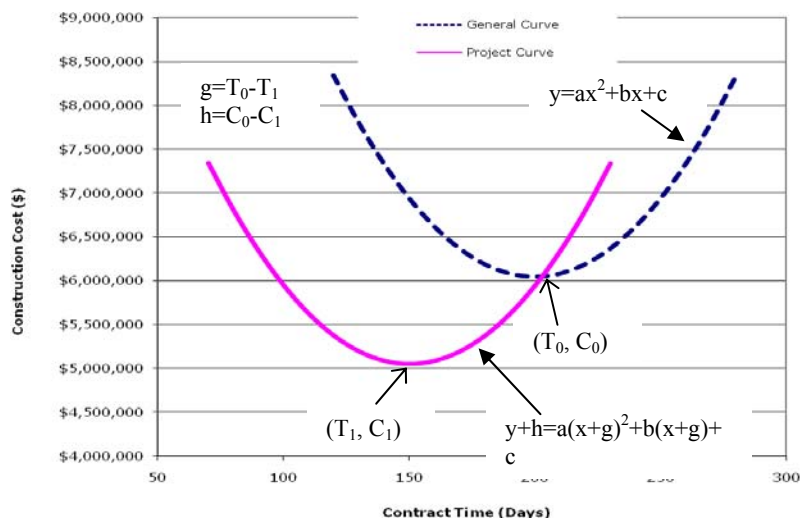


Figure 11. Shifting from general curve to project curve

With the curve shifting technique, the cost-time curve of a highway project can be obtained through an appropriate polynomial equation in terms of construction type in Table 15. Once the cost-time curve is obtained, the maximum days for incentive and maximum incentive can be determined with user cost information as illustrated in Figure 10. For each application, the curve shifting and the maximum incentive determination processes were incorporated into an Excel based computer program. A copy of the Excel program is shown in Figure 12. With this program, a user only needs to input estimated contract time, construction cost, and I/D value. The output is instantly calculated, including maximum incentive days and maximum incentive money amount.

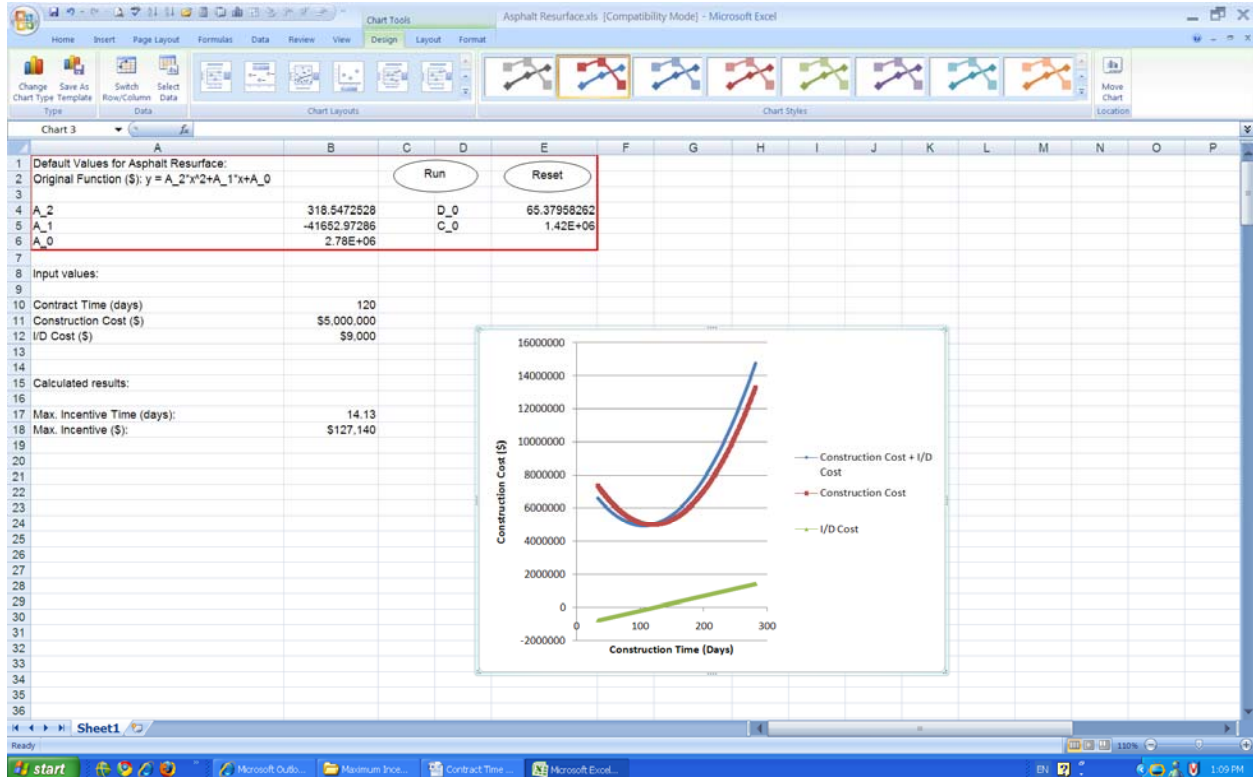


Figure 11. Example of incentive determination

5.4 Indiana AADT Distributions and Characteristics

One of the conditions for A+B bidding and/or I/D provisions is that traffic volume should be high. However, the meaning of “high traffic volume” is not usually defined. In order to define traffic volume levels in Indiana, the traffic volumes on the Indiana highway system was analyzed. The AADT values in 2007 collected by INDOT were used for the analysis. The traffic data include AADT values at more than 6200 locations throughout Indiana. In order to reflect the roadway traffic capacities, the AADT values were analyzed in different groups according to the types of highways. The groups include interstate highways with four lanes, interstate highways with six or more lanes, US routes with two lanes, US routes with four lanes, and state roads.

The major statistics of AADT values on interstate highways with four lanes are shown in Table 17. The AADT distribution for interstate highways with four lanes is shown in Figure 12 as a frequency histogram. Figure 12 indicates that in most cases the AADT values in Indiana are in the range from 16,000 to 46,000. The cumulative frequency percentages are shown in Figure 13. The curve in Figure 13 shows a turning point, beyond which the curve becomes flatter. The turning point is at the AADT value of 51,000 and the corresponding cumulative frequency is 87.35%. This means that 87.35% of the 253 highway sections have AADT values less than 51,000. In other words, 12.65% of the highways sections have AADT values greater than 51,000. Therefore, it is recommended that an AADT value greater than 51,000 be classified as “high traffic volume” for interstate highways with four lanes in selecting construction projects as candidates for A+B bidding or I/D provisions.

Table 17. AADT statistics on interstate highways with four lanes

AADT Characteristics	Values
Minimum	11,128
Maximum	79,353
Median	31,974
Mean	33,847
Standard Deviation	15,608

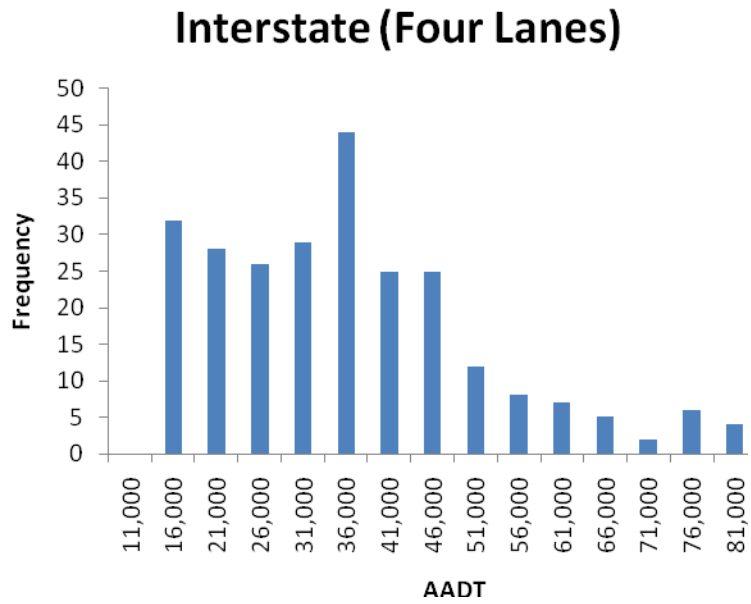


Figure 12. AADT distributions on interstate highways with four lanes

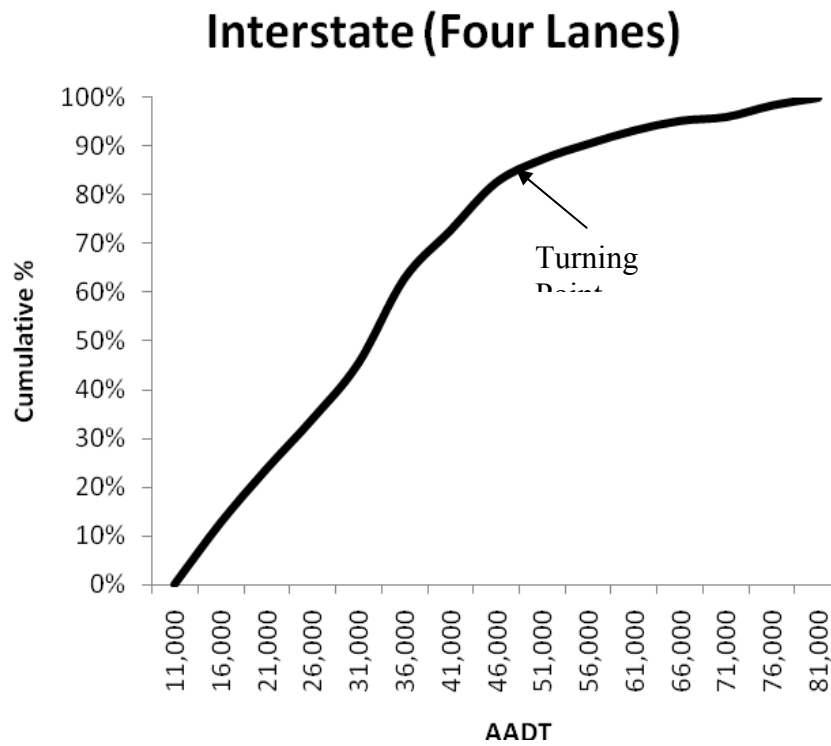


Figure 13. Cumulative % of AADT values on interstate highways with four lanes

Similarly, the statistics, frequency distribution, and cumulative frequency percentages for each of the other highway groups are shown in Tables 18 through 21 and Figures 14 through 21.

Table 18. AADT statistics on interstate highways with six or more lanes

AADT Characteristics	Values
Minimum	11,128
Maximum	79,353
Median	31,974
Mean	33,847
Standard Deviation	15,608

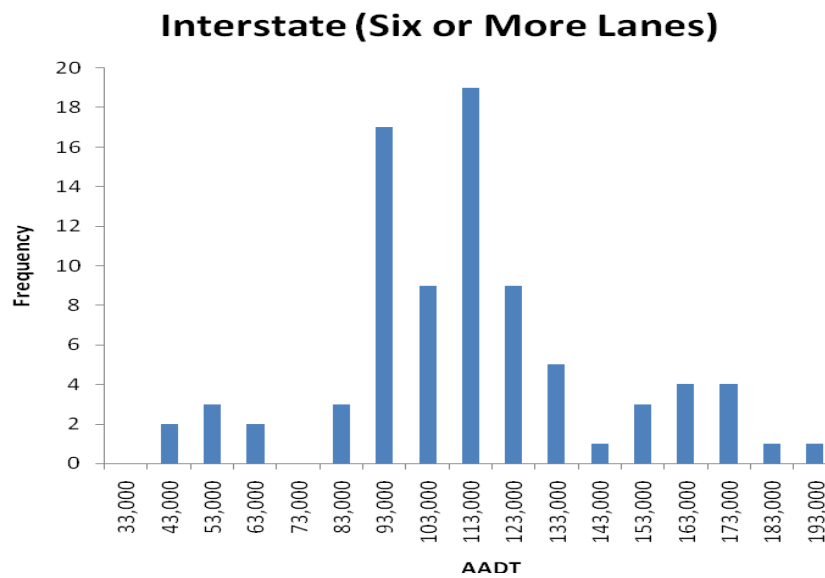


Figure 14. AADT distributions on interstate highways with six or more lanes

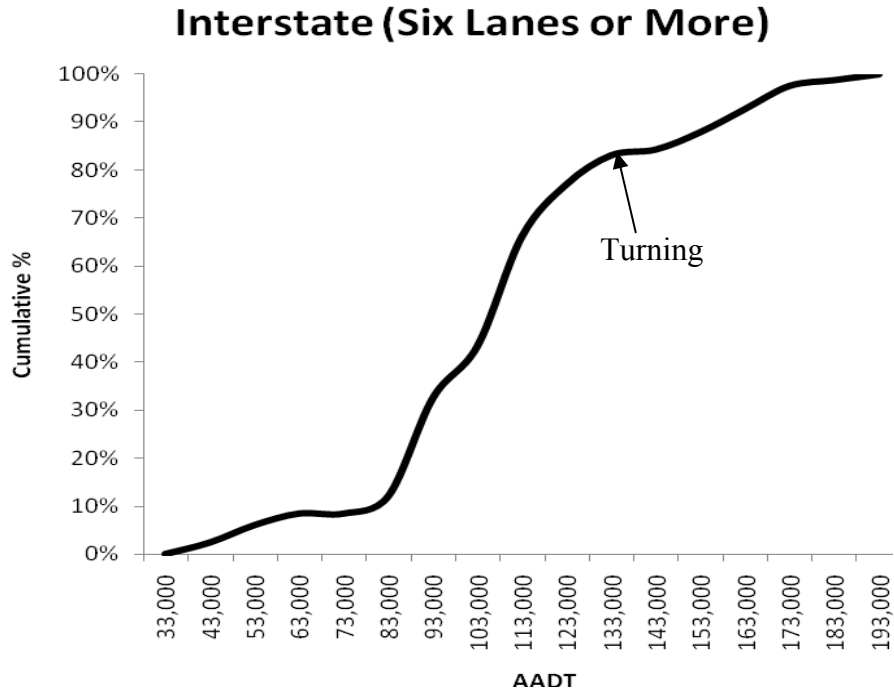


Figure 15. Cumulative % of AADT values on interstate highways with six or more lanes

Table 19. AADT statistics on US routes with two lanes

AADT Characteristics	Values
Minimum	67
Maximum	61,155
Median	7,932
Mean	10,771
Standard Deviation	8,618

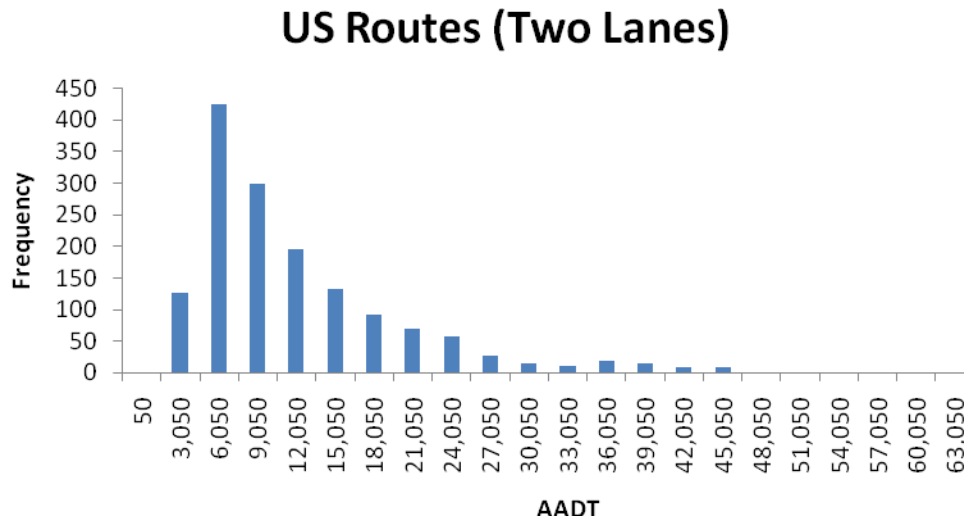


Figure 16. AADT distributions on US routes with two lanes

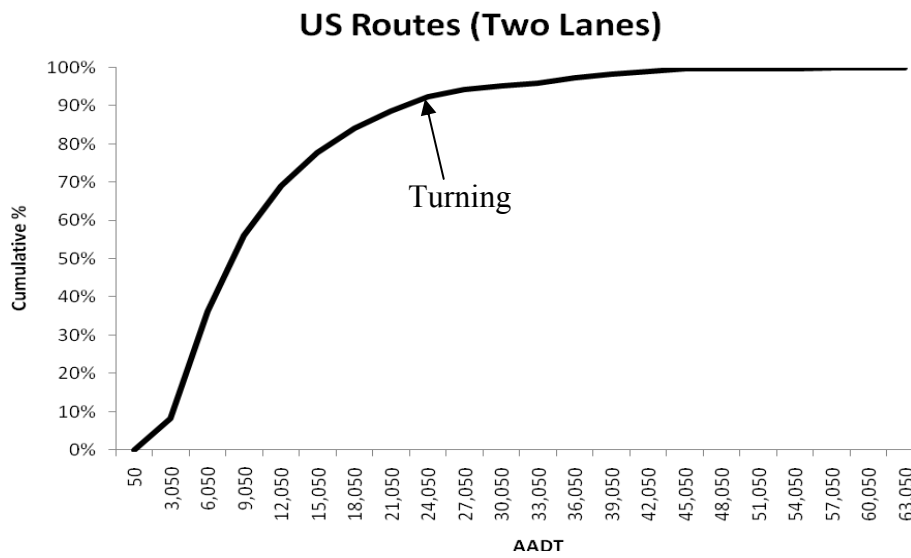


Figure 17. Cumulative % of AADT values on US routes with two lanes

Table 20. AADT statistics on US routes with four lanes

AADT Characteristics	Values
Minimum	908
Maximum	81,901
Median	14,114
Mean	16,651
Standard Deviation	12,664

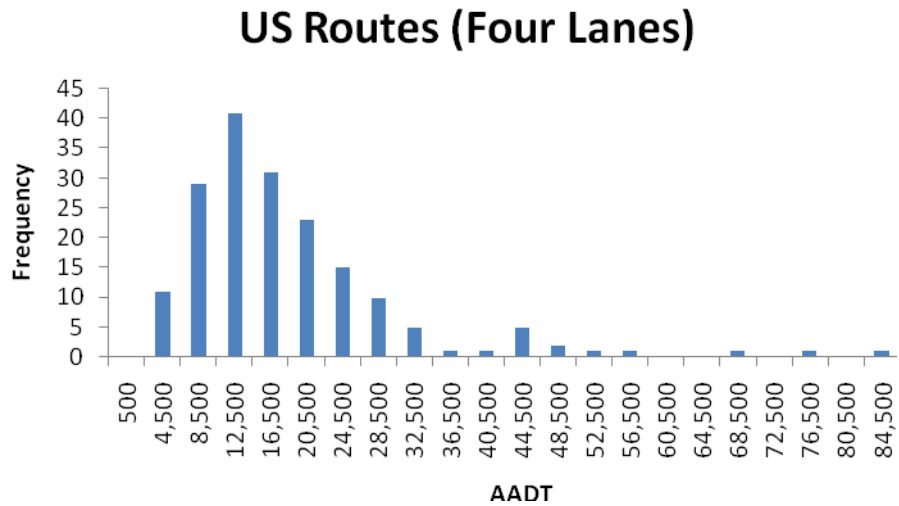


Figure 18. AADT distributions on US routes with four lanes

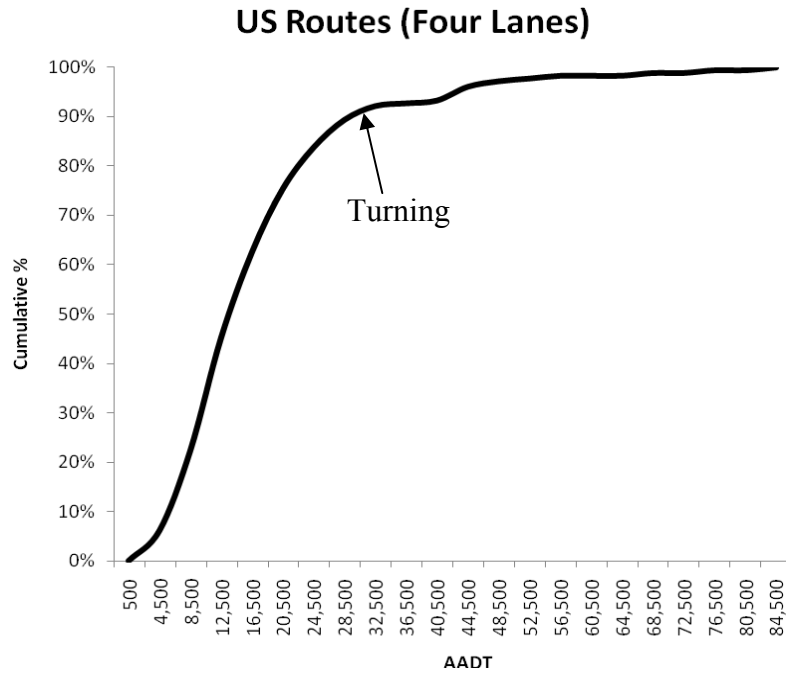


Figure 19. Cumulative % of AADT values on US routes with four lanes

Table 21. AADT statistics on state roads

AAADT Characteristics	Values
Minimum	15
Maximum	53,752
Median	3,897
Mean	6,051
Standard Deviation	6,605

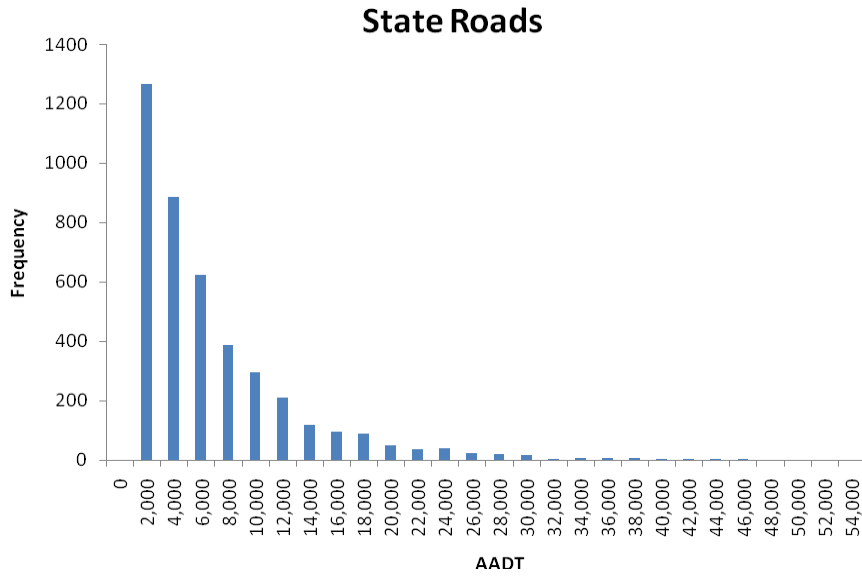


Figure 20. AADT distributions on state roads

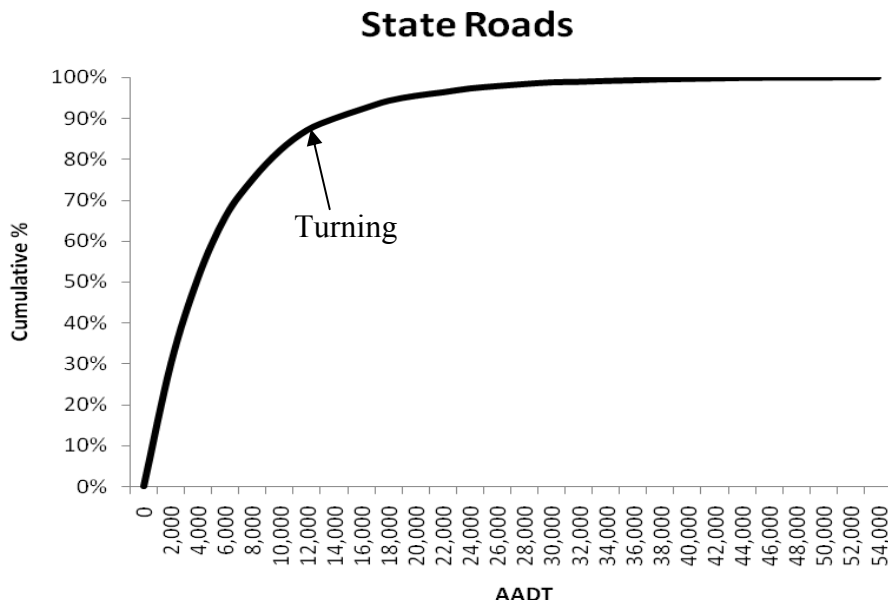


Figure 21. Cumulative % of AADT values on state roads

Based on these tables and figures, the values of “high traffic volumes” for the highway groups can be determined by locating the turning points on the cumulative frequency curves. The values of “high traffic volumes” are listed Table 22. It is recommended that AADT value greater than the values listed in Table 22 be used to identify construction projects as candidates for A+B bidding or I/D provisions.

Table 22. Recommended AADT values of “high traffic volumes”

Type of Highway	High Traffic Value (AADT)	% of Locations with Higher AADT
Interstate (Four Lanes)	≥51,000	12.65
Interstate (Six or More Lanes)	≥133,000	16.87
US Routes (Two Lanes)	≥21,050	11.29
US Routes (Four Lanes)	≥28,500	10.61
State Roads	≥12,000	12.94

CHAPTER 6: CONSTRUCTION CONTRACT TIME DETERMINATION PROCEDURES

6.1 General Elements of Contract Time Determination

FHWA (2002) recommends the following three elements in determining contract time:

1. Application of written procedures for the determination of contract time is important so that production rates and other considerations are applied uniformly throughout the State.
2. The reasonableness of the contract time included in contracts is important. If time is insufficient, bid prices may be higher and there may be an unusual number of time overruns and contractor claims. The agency needs to take into consideration in available contractors and their workload.
3. For most projects the essential elements in determining contract time include: (1) establishing production rates for each controlling item; (2) adopting production rates to a particular project; (3) understanding potential factors such as business closures and environmental constraints; and (4) computation of contract time with a progress schedule.

Many State DOTs established written procedures for contract time determination. Literature shows that, even though there are no identical procedures among the state DOTs, the general components of these guidelines are similar. The contract time determination procedures of some State DOTs are briefly described in the following.

Minnesota Department of Transportation (MnDOT) classifies highway construction projects in to three categories as shown in Table 23 (MnDOT, 2005). Projects in the major impact category can be considered candidates for accelerated construction schedules. The MnDOT document indicates that in many cases it is important to complete the project as quickly as possible to reduce traffic impacts, meet construction deadlines, minimize environmental impacts, or for other reasons specifically related to the project. To accelerate projects, the determination of contract time should consider extra crews to increase productivity and longer work days. In

addition, the use of A+B bidding and specifying lane rentals may also help accelerate contract time and/or reduce impacts to the traveling public.

Table 23. General MnDOT projects categories

Minor Projects	Minimum Impact Projects	Major Impact Projects
Aesthetics	Bituminous Overlays	Long Detour Route Projects
Turn Lanes	Rural NHS Projects	Reconstruction of Roadways with Lane Closures
Signals	Local Road System Projects	Major River Crossing
Landscaping		Urban Construction Projects

The procedure of contract time determination in Idaho Transportation Department (ITD) includes eight steps as listed below (ITD, 2006).

1. Review the plans, specifications and other items to obtain a scope or understanding of the work involved by the person who is estimating the working time.
2. Identify all critical or time consuming activities necessary to complete the project.
3. Assign production rates to construction activities.
4. Calculate duration for each activity that has been identified.
5. Establish the construction logic for the project and identify the relationship between work activities.
6. Identify factors that may influence job construction.
7. List the identified construction activities on a worksheet. The worksheet will create a bar chart showing critical items and their durations to determine the minimum necessary working days to complete the project.
8. Use the bar chart to determine the total number of working days.

Missouri Department of Transportation (MoDOT) recommends the progress schedule be developed late in the design phase of the project (MoDOT, 2004). The progress schedule shows the items of work and durations associated with the chosen production rates. Once the progress schedule is developed, then a decision must be made on which procedure to use for setting the contract time. The MoDOT guideline indicates that the working-day and calendar-day methods

have an advantage over the completion-date method in that the contractor is not liable for circumstances beyond his control; however, each day that is charged must be carefully documented. In setting contract time it is recommend that a completion date be applied only when project completion is critical or when a large volume of traffic is affected.

A NCHRP synthesis study (NCHRP, 1995) found that most DOTs use a similar process to determine contract time even though procedural details and analysis methods in individual agencies' practices vary. The contract time determination process followed by most state DOTs commonly contains the following steps (NCHRP, 1995).

Phase 1: The Input Data

The scheduler gathers and reviews all the data necessary for estimating construction time, generally including design drawings, specifications, special provisions, bills of quantities, correspondence, and any other relevant data.

Phase 2: List of Activities

After reviewing the input data, the scheduler prepares a list of activities representing the major tasks to be accomplished in the project's construction.

Phase 3: The Use of Production Rate for Determining Activities Duration

The scheduler determines the duration for each activity in the list using production rates and work quantities. Realistic production rates are the key in determining reasonable contract times.

Phase 4: Sequence of Construction

Based on experience, and with the aid of the list of activities and their durations, the scheduler describes the logical sequence of activities needed to construct the project. The sequence of activities shows the sequence of individual steps in the construction process, which activities depend on or must follow completion of others, and which activities can be carried out concurrently. The sequence is generally shown as a precedence diagram suitable for scheduling, such as bar chart, and the critical path method (CPM) typically is used to compute the total project duration.

Phase 5: Adjusting

The scheduler next adjusts the preliminary contract time, as calculated in Phase 4, to reflect the particular condition under which the project will be constructed. The scheduler considers the effect of specific factors such as location, weather, and traffic.

Phase 6: Review

The adjusted contract time, as estimated in Phase 5, is reviewed by experienced agency practitioners. Some factors that reviewers consider are state budget, agency work load, contractors' availability, and current labor market.

Phase 7: Final Contract Time

The review may lead to additional adjustments of the earlier estimate of contract time. Following these adjustments and final agency approval, the final contract time is incorporated into the bid documents and subsequently becomes part of the contract between the construction contractor and the agency.

6.2 INDOT Guidelines for Setting Contract Time*6.2.1 Current Procedures for Setting Contract Time*

On August 28, 1989, the Division of Operations Support of Indiana Department of Highways issued the following guidelines for setting work days on road, traffic and maintenance contracts (IDOH, 1989).

1. A general review of the plans and special provisions for the contract is made to determine type of construction, length, number of bridges, traffic features, urban or rural, magnitude, and specific features of the project.
2. Determine if a commitment has been made by other departments or parties to complete this contract by a certain date.
3. How are schools, businesses, local festivals, farmers, rush hour traffic, other projects, etc., affected?
4. Review plans to determine controlling operations.

5. Decide if the project can be completed in one or two construction seasons.
6. Determine if the date of letting affects the controlling operation or when the contractor can start. Can the final stages be completed in either cold or hot weather?
7. How do adjacent contracts, up and coming contracts, and/or detours have any effect on this project?
8. Run a copy of the itemized proposal for the contract. Look at every item shown and decide at what stage during the life of the project that item will be started and completed. Certain items have to be constructed before others can be started. Disregard items that can be worked on simultaneously while other controlling operations are being performed. Set work days on the remaining items using the attached charts (production rates), if possible.
9. Total up the number of work days that each item has generated and determine if the completion of the project should be controlled by work days or a calendar completion date.
10. Adjust the item to fit job circumstances.
11. Determine if any intermediate completion dates or times need to be written into the contract so that certain roads, bridges, entrances, etc., are put back into normal use by that time.
12. At times, certain projects have items which are subject to securement of specific materials, such as Steel Strain Poles. These materials may take 4 to 6 weeks from placement of order until delivery is made to the site. This should be considered when setting time.
13. Because of the district's construction manpower, certain holidays or other various influencing factors, certain projects, such as resurface contracts, may require delayed starting dates specified in their special provisions. These dates must be considered when setting time on these contracts.
14. Decide if the standard schedule of Liquidated Damage shown on page 47 of our standard specifications (Article 108.07) should be used for the contract or if a higher amount of Liquidated Damage should be specified.
15. When you set the final Completion Date or number of Work Days for the contract, review the plans again and determine if an Incentive Clause should be included in the

contract. A clause of this nature should be used only on special occasions for special unique reasons (i.e., road openings before school starts, before a holiday etc; road opening to permit other job coordination etc.). Such a clause usually contains a dollar figure that pays the contractor for each day he completes the work ahead of time and states a maximum amount of Incentive pay the contractor can earn.

16. Last keep your work sheets in a file for future reference in case questions arise as to how you determined the work time on a specific contract.

The above guidelines were updated in 1997 through the INDOT Memorandum 97-27 dated December 10, 1997. The guidelines include the following steps:

1. A general review of the plans and special provisions for the contract is made to determine type of construction, length, number of bridges, traffic features, urban or rural, magnitude, and specific features of the project.
2. If possible the person setting contract time should visit the site to get a feel for the extent that utilities or other features might impact construction.
3. Determine if a commitment has been made by others to complete the contract, unrestricted lanes, open a road etc, by a certain date.
4. How are schools, businesses, local festivals, farmers, rush hour traffic, other contracts in the area, etc., affected by the contract?
5. Review plans to determine controlling operations.
6. Decide if contract can be completed in one or two construction seasons.
7. Determine how letting date may affect the controlling operations, starting times, completion times, etc.
8. Determine how adjacent contracts, existing or future, can affect detours, restrictions, access on this contract.
9. Using the Itemized Proposal, determine when each item can be done. Certain items control other items while some items can be done simultaneously. Use the controlling items to set the time. Normally the time is set in work days and if a completion date is desired, attached charts will convert work days to calendar days depending on letting days.

10. Determine if any intermediate times need to be addressed in the contract so that certain roads, bridges, entrances, ramps, etc., are put back into normal use by certain times.
11. Some contracts have items involving specific materials that take considerable time to obtain. Delivery time for mast arm poles, strain poles, and hi mast poles is about 10 to 12 weeks. Material delivery times should be considered when setting contract time. Delivery time for structural steel is a minimum of three months unless singular members are being used. Singular members delivery time is three weeks. Delivery time for concrete structural members is about six weeks.
12. Because of the construction staffing, certain holidays, or other various influencing factors, some contracts can require delayed starting times specified in the contract provisions. Delayed starting times are normally used on resurface or maintenance type contracts but they might be considered for other types of contracts.
13. Permit restrictions can have a major effect on construction schedules. They often control time on bridge contracts. Therefore they should be addressed when time is set for a contract.
14. Once contract time is established and incentive/disincentive clause might be considered. These types of clauses are normally only used on special contracts that involve high traffic volumes. User costs are used to establish time costs and one way to quickly determine a reasonable time cost is to use the following formula:
 Cost to restrict one lane of traffic during peak lane closure period

$$= [AADT(1+2 \times \%Trucks)] / (\text{Number of Lanes})$$

 The non-peak lane closure period = 1/3 of peak lane closure period
15. Adjusting the time to fit contract circumstances should always be considered.
16. Keep your work sheets in a file for future reference.

In addition to the above guidelines, the Indiana Design Manual (INDOT, 2009) contains the following information on incentive/disincentive justification and A+B bidding procedures.

Incentive/Disincentive Justification (Section 81-3.05, Indiana Design Manual):

Incentive/disincentive is used to minimize the time that a facility may be affected by construction. The contractor is provided additional funds if the project is completed early, or is assessed damages if the project is not completed on time. Due to administrative concerns of

implementing this concept, limit incentive/disincentive to a project that has one or more of the characteristics as follows:

1. high traffic volume occurs in an urban area;
2. it completes a gap in the highway facility;
3. it severely disrupts traffic or highway services;
4. it significantly increases road user's costs;
5. it significantly impacts adjacent neighborhoods or businesses;
6. it replaces a major bridge that is out of service; or
7. it includes lengthy detours.

The worksheet for determining the appropriate incentive/disincentive amount is shown in Figure 22, which is Figure 81-3D in the Indiana Design Manual.

A + B Bidding (Section 81-3.06, Indiana Design Manual): Where the impact of the work site is significant, an A + B bidding incentive may be used to encourage the contractor to minimize these impacts by reducing the exposure time. A + B bidding consists of two parts as follows.

1. Part A. The total dollar amount required to complete the work.
2. Part B. The total dollar amount based on peak- and non-peak-traffic-volume lane-closure periods, and the total contract days proposed by the contractor to complete the work.

Part A is determined using the contractor's unit prices and the estimate of quantities determined by the Department. Part B is established by adding together the costs for each of the following:

1. Peak-traffic-volume lane-closure periods = (no. of periods) x (cost / lane / period);
2. Non-peak-traffic-volume lane = (no. of periods) x (cost / lane / period); plus
3. Contract days = (no. of days) x (cost / day)

The contractor is required to estimate the number of periods that the facility will be closed during peak- and non-peak-traffic-volume hours and the overall number of calendar days required to complete the contract. The cost for each of the above items is determined by the Department and is the same for each bidder. A+B bidding is used only for comparison purposes to determine a successful bidder. It is not used to determine payments to the contractor. A+B

bidding is used in conjunction with incentive/disincentive as discussed in Section 81-3.05 (Indiana Design Manual). Before adding an A+B bidding special provision to a contract, the designer should coordinate its use with the Highway Operations Division and the district construction engineer.

INCENTIVE / DISINCENTIVE (I/D) AMOUNT DETERMINATION
English-Units Project

I. PROJECT CHARACTERISTICS

Route Contract No. Project No.
 Des. No. District:
 National Highway System (NHS) Route? Yes No
 Location:
 Estimated Start Date of Work:
 Estimated Completion Date Without I/D:
 Estimated Contract Amount: \$
 * Estimated Local-Traffic AADT: Trucks %
 * Estimated Through-Traffic AADT: Trucks %
 ** Length of Local-Traffic Detour: mi
 ** Length of Through-Traffic Detour: mi

* Use best judgment for breakdown of traffic.
 ** Use official detour for through traffic.

II. I/D CONSIDERATIONS

Contract restrictions (e.g., utility adjustments, R/W acquisitions, permits, environmental constraints, closure times, special fabrication requirements):

Reasons for proposing I/D:

Critical construction elements:

Estimated Completion Date With I/D:
 Estimated I/D Amount: \$ per day
 Proposed I/D Time: Calendar Days

Maximum I/D Adjustments = (I/D Amount) x (I/D Time):

$$\text{\$} \quad \times \quad \text{days} = \text{\$}$$

Figure 22. INDOT worksheet for I/D amount determination

User Vehicle Costs (UVC):	\$0.25 / mi / veh (Autos & Trucks)
User Time Value (UTV):	\$5.00 / h / veh
Local Design Speed:	mph
Through Design Speed:	mph
Traffic Adjustment Factor (TAF):	Suggested Value 0.35 (TAF normal range is 0.30 to 0.45)

NOTE: Use either of the following analyses depending on the type of project (road closure-detoured or through-traffic project). Various computer programs are available such as QUEWZ for estimating queue lengths and user costs that can be used in lieu of the following for freeway work-zone lane closures. Contact the Highway Operations Division's Traffic Control Team for details.

A. User Costs for Closure-Detoured Project

Local Traffic:

$$\text{Vehicle Costs} = (\text{UVC}) (\text{AADT}) (\text{Local-Detour Length})$$

$$(\$0.25) (\quad) (\quad \text{mi}) = \$$$

$$\text{User Costs} = (\text{UTV}) (\text{AADT}) (\text{Local-Detour Length}) (1/\text{Design Speed})$$

$$(\$5.00) (\quad) (\quad \text{mi}) (1/ \quad) = \$$$

$$\text{Local-Road User Costs (LRUC)} = (\text{Vehicle Costs} + \text{User Costs})$$

$$\$ \quad + \$ \quad = \$$$

Through Traffic:

$$\text{Vehicle Costs} = (\text{UVC}) (\text{AADT}) (\text{Through-Detour Length})$$

$$(\$0.25) (\quad) (\quad \text{mi}) = \$$$

$$\text{User Costs} = (\text{UTV}) (\text{AADT}) (\text{Through-Detour Length}) (1/\text{Design Speed})$$

$$(\$5.00) (\quad) (\quad \text{mi}) (1/ \quad) = \$$$

$$\text{Through-Road User Costs (TRUC)} = (\text{Vehicle Costs} + \text{User Costs})$$

$$\$ \quad + \$ \quad = \$$$

$$\text{Site RUC} = \text{LRUC} + \text{TRUC}$$

$$\$ \quad + \$ \quad = \$$$

Figure 22 (continued)

B. Disruption Costs for Through-Traffic Project

NOTE: The following analysis provides delay cost for through traffic only. If the project includes ramp or intersection closures, the analysis from Part A above can be added to the through-traffic disruption costs or other factors commensurate upon the scope of the particular project.

$$\text{Vehicle Costs} = (\text{UVC}) (\text{AADT}) (\text{TAF})$$

$$(\$0.25) (\quad) (\quad) = \$$$

$$\text{User Costs} = (\text{UTV}) (\text{AADT}) (\text{TAF})$$

$$(\$5.00) (\quad) (\quad) = \$$$

$$\text{Traffic Disruption Costs} = (\text{Vehicle Costs} + \text{User Costs})$$

$$\$ \quad + \$ \quad = \$$$

C. General Comments

D. Other Factors to Consider. Is the route on or near one or more of the following?

- | | |
|---|---|
| School: <input type="checkbox"/> Yes <input type="checkbox"/> No | Hazardous-Materials Route: <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Hospital: <input type="checkbox"/> Yes <input type="checkbox"/> No | Special or Seasonal Event: <input type="checkbox"/> Yes <input type="checkbox"/> No |
| Emergency Route: <input type="checkbox"/> Yes <input type="checkbox"/> No | Local Business: <input type="checkbox"/> Yes <input type="checkbox"/> No |

III. SUMMARY

Recommended Maximum I/D Time: Calendar Days
 Recommended I/D Date:
 Recommended Maximum I/D Amount: \$ per Day
 Is I/D amount > 5% of contract amount? Yes No

NOTE: If the I/D amount per day is greater than the Site RUC or Traffic User Costs, I/D is not justified.

IV. APPROVALS

Figure 22 (continued)

A. Non-NHS Project

Prepared By: _____ Date _____

Recommended By: _____ Date _____
Field Construction Engineer, Construction Mgmt.. Div.

If $I/D \leq 5\%$ of contract amount,

Approved By: _____ Date _____
Director, Construction Management Division

If $I/D > 5\%$ of contract amount,

Approved By: _____ Date _____
Chief Highway Engineer

Received By: _____ Date _____
Contracting Office Manager, Contract Administration Division

Figure 22 (continued)

B. NHS Project

Prepared By: _____ Date _____

Recommended By: _____ Date _____
Field Construction Engineer, Construction Mgmt.. Div.

Approved By: _____ Date _____
Chief Highway Engineer

Received By: _____ Date _____
Contracting Office Manager, Contract Administration Division

NHS Exemption: Yes No

If No, this document must be submitted to FHWA for approval.

Approved By: _____ Date _____
Federal Highway Administration

Figure 22 (continued)

6.2.2 Proposed Guidelines for Developing A+B Provisions Standard I/D Provisions

1. INDOT Guidelines for Setting Contract Time

In this study, the guidelines for setting contract times established in other states were reviewed. It was found that the guidelines vary from state to state. However, they all contain similar common major components (NCHRP, 1995) and they all follow the FHWA recommended procedures (FHWA, 2002). The INDOT guidelines for setting contract time (INDOT, 1997) also contain the major components and are consistent with the FHWA recommended procedures. Based on the literature review and comparison with other states' procedures, it is believed that the INDOT guidelines for setting contract time are good and practical and provide a useful procedure for INDOT to follow. No changes are recommended to the INDOT guidelines for setting contract time. Since the production rates have been updated as shown in Chapter 4 of this report, it is recommended that the new production rates be used in setting contract time.

2. A + B Bidding and Standard I/D Provisions

Through this study, some methods were developed to provide tools for INDOT to determine appropriate incentive and disincentive amounts. They include the user cost estimation, daily I/D amount selection, and maximum incentive determination. In addition, the new production rates were validated and Indiana traffic volume distributions were obtained. These research results can be used in developing A+B and I/D provisions.

FHWA Technical Advisory T5080.10 (FHWA, 1989b) titled "Incentive/Disincentive for Early Completion" provided basis for many states' guidelines for A+B and I/D provisions. Based on the FHWA guidance, many states, including Indiana, developed their own guidelines for A+B and I/D provisions. New York State Department of Transportation (NYSDOT) developed its guidelines for time-related contract provision (NYSDOT, 1999). To incorporate the research results from this study into INDOT implementation, the following guidance is proposed for developing A+B provisions and standard I/D provisions. The guidance is based on the current INDOT guidelines with additional information obtained in this study. The guidance is also

based on the FHWA and some other states' guidelines. The major references include FHWA Technical Advisory T5080.10, the NYSDOT guidelines, and the Pennsylvania DOT policies (PENNDOT, 2002).

Guidelines for A+B Bidding Contracts

This bidding method involves time and an associated cost to determine the low bidder. The A+B method evaluates the overall impact the project will have on the travelling public. A+B bidding should be used when there is a need to shorten the overall duration of a project. This method encourages innovation for the contractors to do the best job in the shortest time possible. A+B bidding is an effective way to reduce construction induced congestion and delays by allowing the cost of work and time to be balanced through the open competitive bidding process. Each bid submitted consists of two parts:

- The A portion of the bid is the sum bid for the contract work items, including material, equipment, and manpower.
- The B portion of the bid is the time in calendar days proposed by the bidder to complete the project or a portion of the project, multiplied by a daily road user cost determined by the Department.

The contract is awarded based on the sum of the A portion and the B portion of the bid. The contract amount after award is limited to the A portion of the bid. Part A is determined using the contractor's unit prices and the estimate of quantities determined by the Department. Part B is established by adding together the costs for each of the following:

1. Peak-traffic-volume lane-closure periods = (no. of periods) x (cost/lane/period);
2. Non-peak-traffic-volume lane = (no. of periods) x (cost/ lane/period); plus
3. Contract days = (no. of days) x (cost/day)

The contractor is required to estimate the number of periods that the facility will be closed during peak- and non-peak-traffic-volume hours and the overall number of calendar days required to complete the contract. The cost for each of the above items is determined by the Department and is the same for each bidder. Before adding an A+B bidding special provision to a contract, the designer should coordinate its use with the Highway Operations Division and the district construction engineer.

An A+B contract may include an incentive/disincentive (I/D) provision. A+B bidding with incentive/disincentive provisions has proved to be effective. It motivates the contractor to bid a contract with a compressed schedule and to follow through with the schedule in order to gain the incentive and to avoid the disincentive.

The use of A+B provisions is primarily intended for critical projects or project phases where traffic inconvenience and delays must be held to a minimum. User delay costs or public benefit must be significant enough to warrant construction acceleration.

The following characteristics are associated with projects appropriate for A+B bidding:

1. high traffic volume occurs in an urban area;
2. it completes a gap in the highway facility;
3. it severely disrupts traffic or highway services;
4. it significantly increases road user's costs;
5. it significantly impacts adjacent neighborhoods or businesses;
6. it replaces a major bridge that is out of service; or
7. it includes lengthy detours.

Based on the analysis of INDOT traffic data, the AADT values listed below should be used to identify high traffic volumes.

Type of Highway	High Traffic Value (AADT)
Interstate (Four Lanes)	$\geq 51,000$
Interstate (Six or More Lanes)	$\geq 133,000$
US Routes (Two Lanes)	$\geq 21,050$
US Routes (Four Lanes)	$\geq 28,500$
State Roads	$\geq 12,000$

It is essential that a project's suitability for A+B bidding be identified during the early stages of project development. This allows for full deployment of resources needed to properly design and coordinate the project. During the development of A+B projects, extra effort should be made to

ensure that the design, specifications, schedule, etc., are compatible and appropriate for the project.

The contract must clearly define what constitutes the start and the completion of the B portion work. Both may differ from the start or completion of the project. For example, the B time might not begin until a detour is implemented, a bridge closed, or traffic is otherwise impacted. This allows the contractor time to fabricate and deliver steel, obtain mix design approval, and do other pre-construction planning. However, it is necessary to define in detail what is expected of the contractor. This can be done through the plans and by detailed description in the special provisions. Work to be completed must be clearly stated. Off-road items such as landscaping, sidewalks or other items that could be performed without disrupting traffic should be addressed. If the intent is to get the roadway open to traffic as soon as possible, off-road items may be excluded from the B portion work.

Counting days for the B portion work can begin with the lane closure, event that results in user delay, or with the award notification.

Begin B portion work with lane closure or event that results in user delay: Under this condition, B portion work begins with an event such as closing a bridge or the first lane closure(s) and ends with an event, i.e., when the bridge is reopened or all work requiring lane closures is complete. This is the preferred method of starting the B portion work if the goal is to minimize user delay associated with a certain situation. The contractor should be allowed the flexibility to prepare for the lane closure period and select a start date that will result in the shortest period of time, within the overall time limits of the contract. Bridge replacement projects with an off-site detour are ideally suited for this situation. The counting of B portion workdays should start when the contractor closes the bridge to traffic and end when the bridge is reopened to traffic. This encourages the contractor to take care of all shop drawing submittals, ordering and delivery of materials, and other preparatory work such that the timing of the closure is based on the critical path of the actual construction. If the B portion work starts with the award notice, the contractor may close the bridge earlier than necessary, resulting in additional user delay. One thing to consider in this situation is the amount of time that can be allowed

before starting the B portion work. If the contractor waits too long before starting the work, the time bid may end after the contract completion date or some other milestone date. If the B portion work must be complete by a certain date, then the contractor must be informed in the contract what the consequences are for not completing the work by that date. One option is to indicate in the special note that the disincentive period will begin on a certain date regardless of the time bid. In other words, if the contractor fails to begin the work in time to complete by the milestone or contract completion date, all incentive payments must be forfeited.

Begin B portion work with award notification: In some cases, the goal is to achieve the B portion milestone date as soon as possible, by having the contractor mobilize and begin working immediately. The starting point could then be tied to the notification of contract award.

Begin B portion work with either an event that results in user delay or tied to award notification: This option still gives the contractor the flexibility desirable while also allowing the Department to demand the B portion work begin within a reasonable time period.

Multiple B Phases: Periodically, projects include multiple phases with varying degrees of user delay. Furthermore, projects may not be completed in one season, but the roadway must be fully open for the winter months. For example, assume Phase 1 of a project is "pave westbound" and phase 2 is "pave eastbound", and the project is let early enough to allow the Contractor to complete both phases in one season. If the user delay is the same for each direction and we want both phases completed in one season, separate B portions may not be required. If this same project is let late in the season and both phases are in the same B portion work and cannot be done concurrently, some contractors may bid one season, while others may bid 2 seasons. A contractor that bids one season would have a significantly lower B portion bid because they are not including the winter months within their bid. The one season bid may require late season paving. If there are any significant increases in the B portion work during construction of Phase 1, the contractor would most certainly request an extension of time which would result in the performance of Phase 2 in the second season.

The need for multiple B portions must be determined on a project-specific basis in consideration of the problems and objectives of the situation. All options must be considered when developing the description of the B portion work. A general guide is to tie the B portion work to the user delay. If there is no user delay during the winter, this period should not be included in the B portion work. If the user delay for westbound is different from eastbound, they should be separate B portions. If the roadway is closed or restricted during the winter with a measurable user impact, the winter should be included in the B portion time frame.

Utilities and Railroads: Utility, Railroad or other third party work within the B portion requires additional effort by designers and construction staff in order to minimize potential for delays. If possible, arrangements should be made to have this third party work done prior to the start of B portion work. If this is not possible, special notes must be included in the contract describing the time frames allowed for any Utility, Railroad or other third party agreement. It is essential that these time frames be consistent with the description of B portion work and the Designer's schedule. Conflicts between these third party schedules and the time specified for the B portion work must be avoided. Underground utilities within the B portion phase should be located with the highest possible degree of accuracy if there is contract work that could potentially interfere with these utilities.

Determination of Incentive/Disincentive Amount: To be effective in accomplishing the objectives of I/D provisions, the I/D amount must be sufficient to encourage the contractor to develop innovative ideas, and ensure the profitability of meeting tight schedules. If the incentive payment is not sufficient to cover the contractor's extra costs, then there is no incentive to accelerate production, and the I/D provisions will not produce the intended results. As a general rule, the maximum number of days of incentive for each incentive period should be less than 10% of the number of days estimated by the Engineer rounded to the nearest whole day. The sum of all incentives for a single contract should be less than 5% of the Engineer's estimated contract amount. It should be noted that the 10% of time and 5% of budget are not meant to be the absolute limits to the incentive amounts. Engineering judgment may be used to allow some variations if it is more reasonable to use higher incentive amounts for some projects.

The current INDOT method for I/D amount determination in the Indiana Design Manual (INDOT, 2009) can be used to calculate the I/D amounts. The INDOT calculation sheet is shown below:

INCENTIVE / DISINCENTIVE (I/D) AMOUNT DETERMINATION
English-Units Project

I. PROJECT CHARACTERISTICS

Route Contract No. Project No.

Des. No. District:

National Highway System (NHS) Route? Yes No

Location:

Estimated Start Date of Work:

Estimated Completion Date Without I/D:

Estimated Contract Amount: \$

* Estimated Local-Traffic AADT: Trucks %

* Estimated Through-Traffic AADT: Trucks %

** Length of Local-Traffic Detour: mi

** Length of Through-Traffic Detour: mi

* Use best judgment for breakdown of traffic.

** Use official detour for through traffic.

II. I/D CONSIDERATIONS

Contract restrictions (e.g., utility adjustments, R/W acquisitions, permits, environmental constraints, closure times, special fabrication requirements):

Reasons for proposing I/D:

Critical construction elements:

Estimated Completion Date With I/D:

Estimated I/D Amount: \$ per day

Proposed I/D Time: Calendar Days

Maximum I/D Adjustments = (I/D Amount) x (I/D Time):

\$ x days = \$

User Vehicle Costs (UVC): \$0.25 / mi / veh (Autos & Trucks)

User Time Value (UTV): \$5.00 / h / veh

Local Design Speed: mph

Through Design Speed: mph

Traffic Adjustment Factor (TAF): Suggested Value 0.35
(TAF normal range is 0.30 to 0.45)

NOTE: Use either of the following analyses depending on the type of project (road closure-detoured or through-traffic project). Various computer programs are available such as QUEWZ for estimating queue lengths and user costs that can be used in lieu of the following for freeway work-zone lane closures. Contact the Highway Operations Division's Traffic Control Team for details.

A. User Costs for Closure-Detoured Project

Local Traffic:

Vehicle Costs = (UVC) (AADT) (Local-Detour Length)
(\$0.25) () (mi) = \$

User Costs = (UTV) (AADT) (Local-Detour Length) (1/Design Speed)
(\$5.00) () (mi) (1/) = \$

Local-Road User Costs (LRUC) = (Vehicle Costs + User Costs)
\$ + \$ = \$

Through Traffic:

Vehicle Costs = (UVC) (AADT) (Through-Detour Length)
(\$0.25) () (mi) = \$

User Costs = (UTV) (AADT) (Through-Detour Length) (1/Design Speed)
(\$5.00) () (mi) (1/) = \$

Through-Road User Costs (TRUC) = (Vehicle Costs + User Costs)
\$ + \$ = \$

Site RUC = LRUC + TRUC
\$ + \$ = \$

B. Disruption Costs for Through-Traffic Project

NOTE: The following analysis provides delay cost for through traffic only. If the project includes ramp or intersection closures, the analysis from Part A above can be added to the through-traffic disruption costs or other factors commensurate upon the scope of the particular project.

Vehicle Costs = (UVC) (AADT) (TAF)
(\$0.25) () () = \$

User Costs = (UTV) (AADT) (TAF)
(\$5.00) () () = \$

Traffic Disruption Costs = (Vehicle Costs + User Costs)
\$ + \$ = \$

C. General Comments

D. Other Factors to Consider. Is the route on or near one or more of the following?

School: Yes No Hazardous-Materials Route: Yes No
Hospital: Yes No Special or Seasonal Event: Yes No
Emergency Route: Yes No Local Business: Yes No

III. SUMMARY

Recommended Maximum I/D Time: Calendar Days

Recommended I/D Date:

Recommended Maximum I/D Amount: \$ per Day

Is I/D amount > 5% of contract amount? Yes No

NOTE: If the I/D amount per day is greater than the Site RUC or Traffic User Costs, I/D is not justified.

IV. APPROVALS

A. Non-NHS Project

Prepared By: Date

Recommended By: _____ Date _____
Field Construction Engineer, Construction Mgmt.. Div.

If I/D ≤ 5% of contract amount,

Approved By: _____ Date _____
Director, Construction Management Division

If I/D > 5% of contract amount,

Approved By: _____ Date _____
Chief Highway Engineer

Received By: _____ Date _____
Contracting Office Manager, Contract Administration Division

B. NHS Project

Prepared By: _____ Date _____

Recommended By: _____ Date _____
Field Construction Engineer, Construction Mgmt.. Div.

Approved By: _____ Date _____
Chief Highway Engineer

Received By: _____ Date _____
Contracting Office Manager, Contract Administration Division

NHS Exemption: Yes No

If No, this document must be submitted to FHWA for approval.

Approved By: _____ Date _____
Federal Highway Administration

Alternatively, the methods discussed in the previous chapters can be used to estimate the I/D amounts following the following steps.

Step 1: To estimate user costs, the following information is needed:

- Type of work zone to be installed;
- Estimated average normal speed and work zone speed;
- ADT, hourly traffic volumes (% of ADT), and hourly % of trucks. Average values of hourly % of ADT and hourly % of trucks are given in Table 3 of this report. The average values in Table 3 can be used if actual values are not available.

A computer program was developed for the calculation. The results of the calculation include the average hourly user costs, daily user cost, average user cost per vehicle, and average user cost per hour. An example of the computer program is shown below:

ROAD USER COST CALCULATIONS-Crossover

Project NO: 110	Road No: 165		
Type of Road: 4 lanes divided	Open lane(Cross): 1	Dir-Coffe(Cross): 0.50	
Length Miles: 1.00	Open lane(Cross): 1	Dir-Coffe(Cross): 0.50	
Normal Speed (mph): 70.00	Workzone Speed (mph): 45.00		
S _{car} : 12.56	S _{TRUCK} : 54.16		
R _{car} : 73.2	R _{TRUCK} : 171.85		
R _{car} : 88.81	R _{TRUCK} : 216.48		

EXCESS COST OF SPEED CHANGE CYCLES:	
CPI of Private Transportation, Gasoline (all types),CPI _g :	257.85
CPI of Private Transportation, Motor oil, coolant, and fluids,CPI _o :	247.51
CPI of Private Transportation,Tires,CPI _t :	113.86
CPI of Private Transportation,Motor vehicle maintenance and repair,CPI _m :	228.73
CPI of Private Transportation,New vehicles,CPI _v :	136.28
PPI of #2 Diesel Fuel ,PPI _f :	286.70
PPI of Motor gasoline, including finished base stocks and blending agents,PPI _g :	277.00
PPI of Truck and bus pneumatic tires,PPI _t :	115.00
PPI of Motor vehicles,PPI _v :	135.00
CPI of Construction year based on 1982-84=100	211.00
PPI of Construction year based on 1982=100	172.20

Hour	% Vehicle	% TRUCK	User Cost
0-1	1.7	53.1	\$535
1-2	1.4	39.3	\$418
2-3	1.3	63.7	\$382
3-4	1.3	64.3	\$411
4-5	1.4	60.3	\$458
5-6	2.3	42.1	\$696
6-7	3.3	37.1	\$1,014
7-8	4.4	29.0	\$1,360
8-9	4.6	28.8	\$1,428
9-10	5.1	28.8	\$1,705
10-11	5.5	27.3	\$1,714
11-12	6.0	25.7	\$2,627
12-13	6.1	25.2	\$1,890
13-14	6.1	24.4	\$1,893
14-15	6.5	24.4	\$2,069
15-16	6.6	23.7	\$2,152
16-17	6.6	23.1	\$2,174
17-18	6.4	22.3	\$2,140
18-19	5.6	24.8	\$1,841
19-20	4.9	27.0	\$1,574
20-21	4.2	30.2	\$1,306
21-22	3.6	33.3	\$1,119
22-23	2.9	39.6	\$879
23-24	2.3	45.2	\$710
ADT	47585		
Total User Cost Per Day			\$32,496
Average User Cost Per Vehicle			\$0.58
Average User Cost Per Hour			\$1,354

DO NOT MAKE ANY CHANGES HERE

Step 2: With the calculate daily user cost, the daily incentive can then be determined as discussed in Chapter 5.1 using the following inequality to select an appropriate value of p (the portion of the user cost savings to be shared with the contractor).

$$(A/X) + B \leq R \leq pC$$

where:

A = one-time cost to the contractor to expedite;

B = the daily cost to the contractor to expedite;

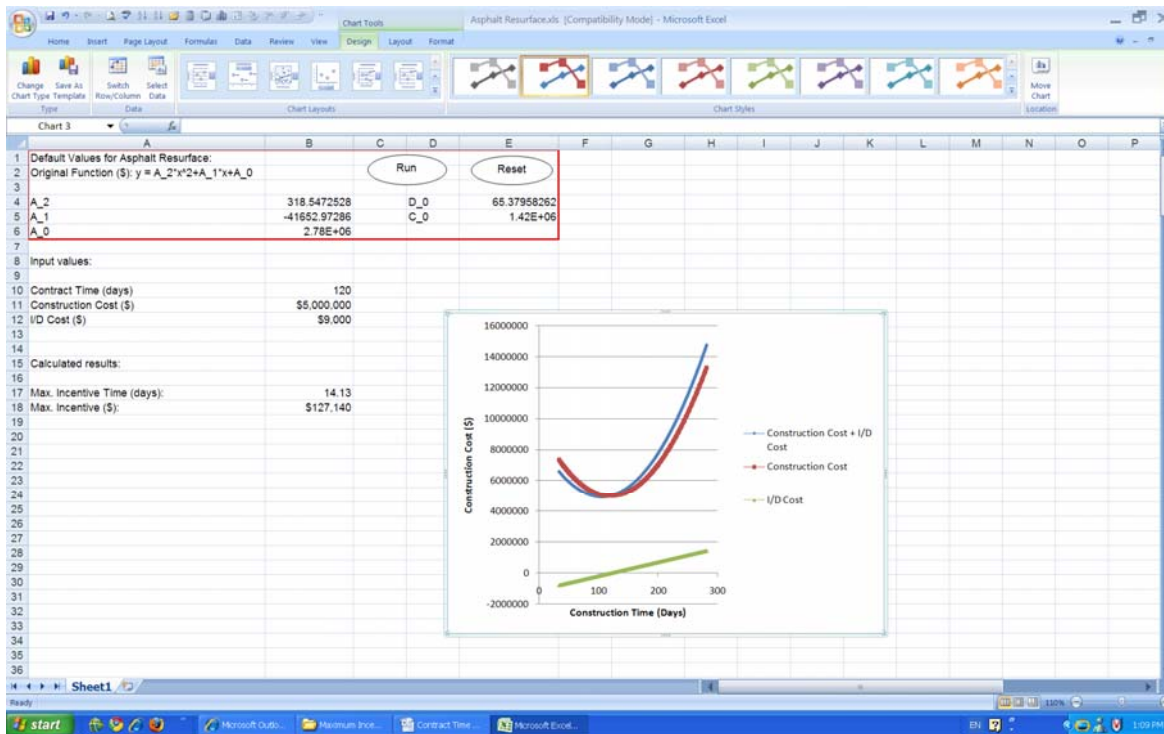
X = the number of days the contract to be expedited;

p = the portion of the user cost savings to be shared with the contractor; $0 < p \leq 1$.

C = the daily user cost.

See the example of p value determination shown in Chapter 5.

Step 3: With the I/D value determined in Step 2, which is pC (the value of p in Step 2 times the daily user cost in Step 1), and the estimated contract time, the computer program developed in Chapter 5.3 is used to determine the maximum incentive time and incentive money. An example of the computer program calculation results is shown below:



The results from this computer program will then be compared with the 10% of contract time and 5% of total contract cost. Engineering judgment may be required to determine the final amounts of the maximum incentive.

B Portion Work Time Determination: When determining the maximum duration for the B portion time period, the Designer must consider to what extent, and at what cost, construction can be compressed from a normal construction schedule. Normal construction time is generally based on a highly qualified contractor working five days a week, eight hours a day, while an accelerated time should be based on the performance of the same contractor working extended or extra shifts with additional workers for six or seven days a week. However, the use of a continuous seven-day work week is cautioned against, because extended periods of work without days off may result in reduced efficiency and morale, and high turnover rates for both contractor and inspection personnel. The maximum duration for the B portion time period should be based on an accelerated but achievable work schedule. If the completion date is impossible to meet, the contractor will not even try to earn the incentive. In fact, unreasonable completion dates may discourage potential bidders from bidding. To accurately determine the B portion time period,

Designers should develop a schedule, ideally using the critical path or some other quantitative method. This will ensure that the maximum duration specified is achievable, and that any other time related contract provisions are incorporated and consistent, i.e., utility schedule, railroad involvement, seasonal limitations, work restrictions, etc. The season of the year in which the project will be constructed should also be considered in determining the B portion time.

Guidelines for Standard I/D Provisions

Incentive/disincentive is used to minimize the time that a facility may be affected by construction. The contractor is provided additional funds if the project is completed early, or is assessed damages if the project is not completed on time. Due to administrative concerns of implementing this concept, limit incentive/disincentive to a project that has one or more of the characteristics as follows:

1. high traffic volume occurs in an urban area;
2. it completes a gap in the highway facility;
3. it severely disrupts traffic or highway services;
4. it significantly increases road user's costs;
5. it significantly impacts adjacent neighborhoods or businesses;
6. it replaces a major bridge that is out of service; or
7. it includes lengthy detours.

Based on the analysis of INDOT traffic data, the AADT values listed below should be used to identify high traffic volumes.

Type of Highway	High Traffic Value (AADT)
Interstate (Four Lanes)	$\geq 51,000$
Interstate (Six or More Lanes)	$\geq 133,000$
US Routes (Two Lanes)	$\geq 21,050$
US Routes (Four Lanes)	$\geq 28,500$
State Roads	$\geq 12,000$

The major differences between A+B and standard I/D contracts is that with Standard I/D provisions, INDOT determines the maximum duration to complete a project or project phase. When contractors prepare their bids, they check whether they can complete the work in the specified time frames, and bid the cost to complete within the specified time frame. Using A+B bidding, INDOT also determines the maximum duration to complete a project or project phase. However, when contractors prepare their bids, they determine the time it will take to complete the project or project phase. They balance the cost of the project and the cost of time to get the project.

Determination of Incentive/Disincentive Amount: To be effective in accomplishing the objectives of I/D provisions, the I/D amount must be sufficient to encourage the contractor to develop innovative ideas, and ensure the profitability of meeting tight schedules. If the incentive payment is not sufficient to cover the contractor's extra costs, then there is no incentive to accelerate production, and the I/D provisions will not produce the intended results. As a general rule, the maximum number of days of incentive for each incentive period should be less than 30% of the number of days estimated by the Engineer rounded to the nearest whole day. The sum of all incentives for a single contract should be less than 5% of the Engineer's estimated contract amount. It should be noted that the 30% of time and 5% of budget are not meant to be the absolute limits to the incentive amounts. Engineering judgment may be used to allow some variations if it is more reasonable to use higher incentive amounts for some projects.

The current INDOT method for I/D amount determination in the Indiana Design Manual (INDOT, 2009) can be used to calculate the I/D amounts. The INDOT calculation sheet is shown below:

INCENTIVE / DISINCENTIVE (I/D) AMOUNT DETERMINATION
English-Units Project

I. PROJECT CHARACTERISTICS

Route Contract No. Project No.
Des. No. District:
National Highway System (NHS) Route? Yes No
Location:
Estimated Start Date of Work:
Estimated Completion Date Without I/D:
Estimated Contract Amount: \$
* Estimated Local-Traffic AADT: Trucks %
* Estimated Through-Traffic AADT: Trucks %
** Length of Local-Traffic Detour: mi
** Length of Through-Traffic Detour: mi

* Use best judgment for breakdown of traffic.

** Use official detour for through traffic.

II. I/D CONSIDERATIONS

Contract restrictions (e.g., utility adjustments, R/W acquisitions, permits, environmental constraints, closure times, special fabrication requirements):

Reasons for proposing I/D:

Critical construction elements:

Estimated Completion Date With I/D:

Estimated I/D Amount: \$ per day

Proposed I/D Time: Calendar Days

Maximum I/D Adjustments = (I/D Amount) x (I/D Time):

\$ x days = \$

User Vehicle Costs (UVC): \$0.25 / mi / veh (Autos & Trucks)

User Time Value (UTV): \$5.00 / h / veh

Local Design Speed: mph

User Costs = (UTV) (AADT) (TAF)
(\$5.00) () () = \$

Traffic Disruption Costs = (Vehicle Costs + User Costs)
\$ + \$ = \$

C. General Comments

D. Other Factors to Consider. Is the route on or near one or more of the following?

School: Yes No Hazardous-Materials Route: Yes No
Hospital: Yes No Special or Seasonal Event: Yes No
Emergency Route: Yes No Local Business: Yes No

III. SUMMARY

Recommended Maximum I/D Time: Calendar Days

Recommended I/D Date:

Recommended Maximum I/D Amount: \$ per Day

Is I/D amount > 5% of contract amount? Yes No

NOTE: If the I/D amount per day is greater than the Site RUC or Traffic User Costs, I/D is not justified.

IV. APPROVALS

A. Non-NHS Project

Prepared By: Date

Recommended By: _____ Date _____
Field Construction Engineer, Construction Mgmt.. Div.

If I/D ≤ 5% of contract amount,

Approved By: _____ Date _____
Director, Construction Management Division

If I/D > 5% of contract amount,

Approved By: _____ Date _____
Chief Highway Engineer

Received By: _____ Date _____
Contracting Office Manager, Contract Administration Division

B. NHS Project

Prepared By: _____ Date _____

Recommended By: _____ Date _____
Field Construction Engineer, Construction Mgmt.. Div.

Approved By: _____ Date _____
Chief Highway Engineer

Received By: _____ Date _____
Contracting Office Manager, Contract Administration Division

NHS Exemption: Yes No

If No, this document must be submitted to FHWA for approval.

Approved By: _____ Date _____
Federal Highway Administration

Alternatively, the methods discussed in the previous chapters can be used to estimate the I/D amounts following the following steps.

Step 1: To estimate user costs, the following information is needed:

- Type of work zone to be installed;
- Estimated average normal speed and work zone speed;
- ADT, hourly traffic volumes (% of ADT), and hourly % of trucks. Average values of hourly % of ADT and hourly % of trucks are given in Table 3 of this report. The average values in Table 3 can be used if actual values are not available.

A computer program was developed for the calculation. The results of the calculation include the average hourly user costs, daily user cost, average user cost per vehicle, and average user cost per hour. An example of the computer program is shown below:

ROAD USER COST CALCULATIONS-Crossover

Project NO: 110	Road No: 165		
Type of Road: 4 lanes divided	Open lane(Cross): 1	Dir-Coffe(Cross): 0.50	
Length Miles: 1.00	Open lane(Cross): 1	Dir-Coffe(Cross): 0.50	
Normal Speed (mph): 70.00	Workzone Speed (mph): 45.00		
S _{car} : 12.56	S _{TRUCK} : 54.16		
R _{car} : 73.2	R _{TRUCK} : 171.85		
R _{car} : 88.81	R _{TRUCK} : 216.48		

EXCESS COST OF SPEED CHANGE CYCLES:	
CPI of Private Transportation, Gasoline (all types),CPI _g :	267.85
CPI of Private Transportation, Motor oil, coolant, and fluids,CPI _o :	247.51
CPI of Private Transportation,Tires,CPI _t :	113.86
CPI of Private Transportation,Motor vehicle maintenance and repair,CPI _m :	228.73
CPI of Private Transportation,New vehicles,CPI _v :	136.28
PPI of #2 Diesel Fuel ,PPI _d :	286.70
PPI of Motor gasoline, including finished base stocks and blending agents,PPI _g :	277.00
PPI of Truck and bus pneumatic tires,PPI _t :	115.00
PPI of Motor vehicles,PPI _v :	135.00
CPI of Construction year based on 1982-84=100	211.00
PPI of Construction year based on 1982=100	172.20

Hour	% Vehicle	% TRUCK	User Cost
0->1	1.7	53.1	\$535
1->2	1.4	39.3	\$418
2->3	1.3	63.7	\$382
3->4	1.3	64.3	\$411
4->5	1.4	60.3	\$458
5->6	2.3	42.1	\$696
6->7	3.3	37.1	\$1,014
7->8	4.4	29.0	\$1,360
8->9	4.6	28.8	\$1,428
9->10	5.1	28.8	\$1,705
10->11	5.5	27.3	\$1,714
11->12	6.0	25.7	\$2,627
12->13	6.1	25.2	\$1,890
13->14	6.1	24.4	\$1,893
14->15	6.5	24.4	\$2,069
15->16	6.6	23.7	\$2,152
16->17	6.6	23.1	\$2,174
17->18	6.4	22.3	\$2,140
18->19	5.6	24.8	\$1,841
19->20	4.9	27.0	\$1,574
20->21	4.2	30.2	\$1,306
21->22	3.6	33.3	\$1,119
22->23	2.9	39.6	\$879
23->24	2.3	45.2	\$710
ADT	47585		
Total User Cost Per Day			\$32,496
Average User Cost Per Vehicle			\$0.58
Average User Cost Per Hour			\$1,354

DO NOT MAKE ANY CHANGES HERE

Step 2: With the calculate daily user cost, the daily incentive can then be determined as discussed in Chapter 5.1 using the following inequality to select an appropriate value of p (the portion of the user cost savings to be shared with the contractor).

$$(A/X) + B \leq R \leq pC$$

where:

A = one-time cost to the contractor to expedite;

B = the daily cost to the contractor to expedite;

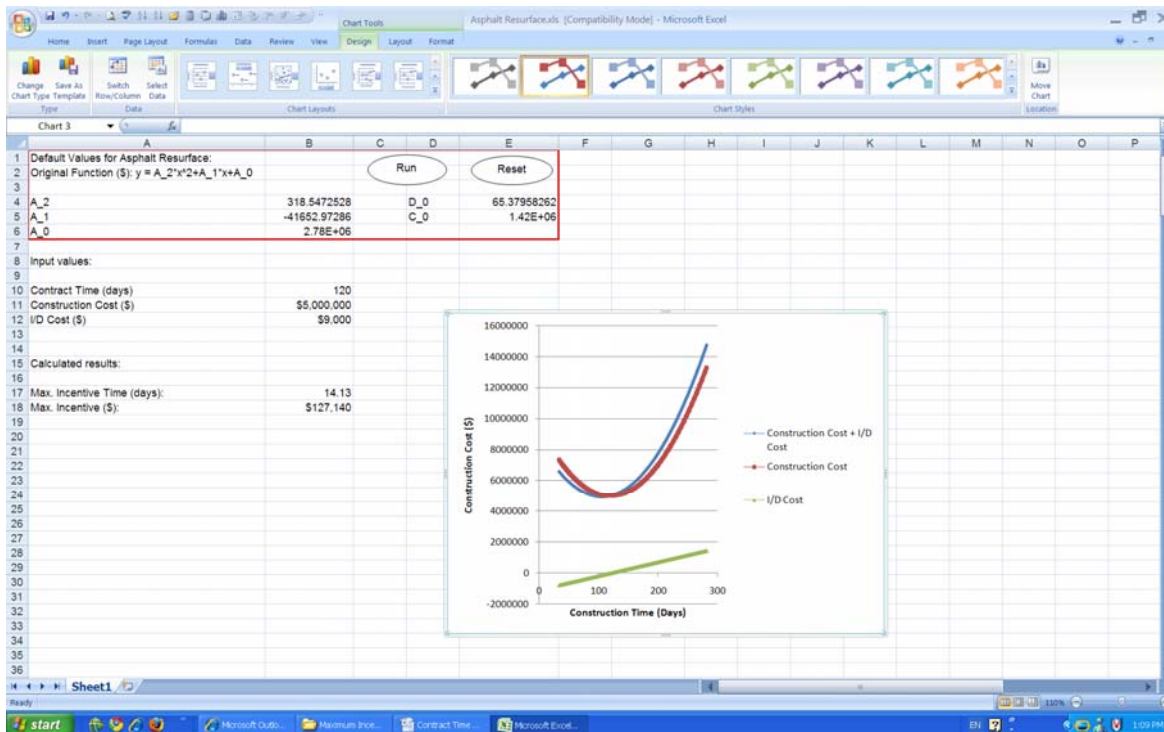
X = the number of days the contract to be expedited;

p = the portion of the user cost savings to be shared with the contractor; $0 < p \leq 1$.

C = the daily user cost.

See the example of p value determination shown in Chapter 5.

Step 3: With the I/D value determined in Step 2, which is pC (the value of p in Step 2 times the daily user cost in Step 1), and the estimated contract time, the computer program developed in Chapter 5.3 is used to determine the maximum incentive time and incentive money. An example of the computer program calculation results is shown below:



The results from this computer program will then be compared with the 30% of contract time and 5% of total contract cost. Engineering judgment may be required to determine the final amounts of the maximum incentive.

I/D Phase Time Determination: When determining the maximum duration for the I/D time period, the Designer must consider to what extent, and at what cost, construction can be compressed from a normal construction schedule. Normal construction time is generally based on a highly qualified contractor working five days a week, eight hours a day, while an accelerated time should be based on the performance of the same contractor working extended or extra shifts with additional workers for six or seven days a week. However, the use of a continuous seven-day workweek is cautioned against, because extended periods of work without days off may result in reduced efficiency and morale, and high turnover rates for both Contractor and inspection personnel. The maximum duration for I/D contracts should be based on an accelerated but achievable work schedule. If the completion date is impossible to meet, the contractor will not even try to earn the incentive. Unreasonable completion dates may discourage potential bidders from bidding. To accurately determine the I/D time period,

Designers should develop a schedule, ideally using the critical path or some other quantitative method. This will ensure that the maximum duration specified is achievable, and that any other time related contract provisions are incorporated and consistent, i.e., utility schedule, railroad involvement, seasonal limitations, work restrictions, etc. The season of the year in which the project will be constructed should also be considered in determining the I/D time period.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

A user cost model was developed to compute the excess user costs caused by work zones. The user cost model was incorporated into a Microsoft Excel based computer program. The model can be used to estimate daily user costs at highway work zones based on the work zone layouts and traffic volumes passing through the work zones. The required input of the user cost calculation includes hourly traffic volumes, vehicle speeds, and percents of trucks. Through traffic data analysis, the average hourly traffic information was determined for different types of highways using WIM recorded traffic data. The average traffic information can be used as the input for the user cost model if detailed traffic data are not available.

The highway construction production rates in Indiana were calculated in a previous study. These production rates were validated by an experienced highway engineer. The validated production rates may be used in setting contract time in place of the old production rates.

The vast amount of AADT data in Indiana was analyzed. The AADT frequency distribution and cumulated frequency were obtained. The results of the AADT analysis provide a basis for defining what “high traffic volumes” should be in Indiana for various types of highways.

Based on the estimated user costs, the portion for a contractor to share the savings in user costs can be determined by considering the extra costs to the contractor to expedite the construction. Thus, the daily I/D amount can be obtained.

The cost-time relationships were established for various types of highway construction projects. Using the cost-time relationship curves, the maximum incentive days and the maximum incentive money amount can be determined based on the estimated contract time, construction cost, and the daily I/D value. A computer program was developed to do the calculations.

With the above mentioned study results, guidelines for A+B bidding and I/D determination were proposed. The guidelines outline the key items and steps for developing appropriate A+D bidding and I/D contract provisions.

The study results from this study should be implemented to improve INODT's practices of setting contract time and determining appropriate I/D values. The implementation should include the following items:

1. Use the updated production rates for setting work days for highway construction projects. The new production rates include mean production rates and baseline production rates. The new production rates also provide production rates in urban as well as in rural areas, which will be useful for setting more accurate work days.
2. Use the developed user cost software for estimating user costs of highway construction projects. The traffic information at the 47 WIM stations is provided for the implementation. In addition, the average hourly ADT percentages and truck percentages are provided as default values for interstate highways, US routes, and state roads. These average percentages can be used with ADT values to compute user costs caused by work zones.
3. Use the developed software for determination of maximum incentive days and maximum incentive money. The results of this task will provide INODT personnel a basis of decision making for A+B and/or I/D contracts. The recommended "high traffic volume" AADT values should be used in selecting candidate projects for A+B and/or I/D contracts.
4. To facilitate implementation, the new production rates and the developed computer programs should be placed on INDOT Intranet so that all INDOT agencies can use the same production rates and a uniform set of computer programs.
5. The guidelines for A+B bidding and I/D provisions should be considered for INDOT to improve the current guidelines.

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