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Work Zone User Costs and Incentive Values of Highway Construction Projects

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Abstract
During highway repair or rehabilitation period, highway work zones cause additional highway user costs and affect highway safety and environment. In order to minimize the negative effects of construction projects, the state highway agencies have been using incentive/disincentive clauses in contracts to encourage early completion of highway projects. Incentive clauses are used to reward the contractors for 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. The excess user costs of traffic delays caused by the presence of work zones are essential for assessment of the impact of the work zones on public. User costs at highway work zones are increasingly used by highway agencies in determining the contract times of highway construction projects. This paper analyzes the user costs at freeway work zones based on traffic data recorded by weigh-in-motion devices in Indiana. With a high traffic volume, user costs caused by a work zone can be significant; it is therefore desirable to minimize the user costs by expediting construction process. 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.

Keywords
Work zone; user cost; traffic delay; incentive/disincentive; contract time

1. Introduction

The excess user costs of traffic delays caused by the presence of work zones are essential for assessment of the impact of the work zones on public. The excess user costs include the traffic delay costs and the additional vehicle operating costs resulted from the speed changes at work zones. User costs at highway work zones are increasingly used by highway agencies in determining the contract times of highway construction projects. The estimated user costs provide highway engineers and construction managers with useful information for effective highway construction planning. The user cost information is especially useful for highway agencies to determine contract times and incentive and disincentive monetary values for highway construction projects.

2. Excess User Costs at Work Zones

Two types of work zones on four-lane divided highways are commonly utilized in Indiana as shown in Figures 1 and 2. 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.

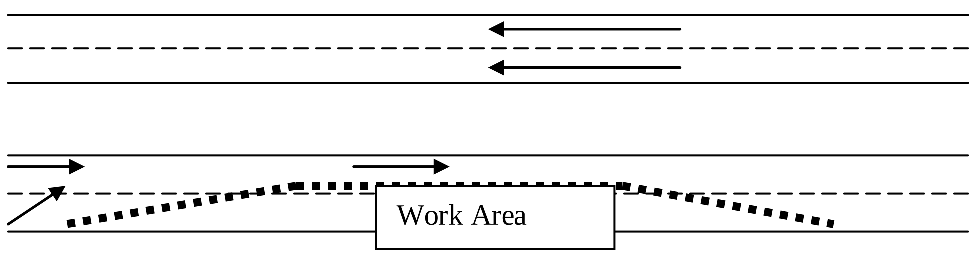

Figure 1: Partial closure work zone.

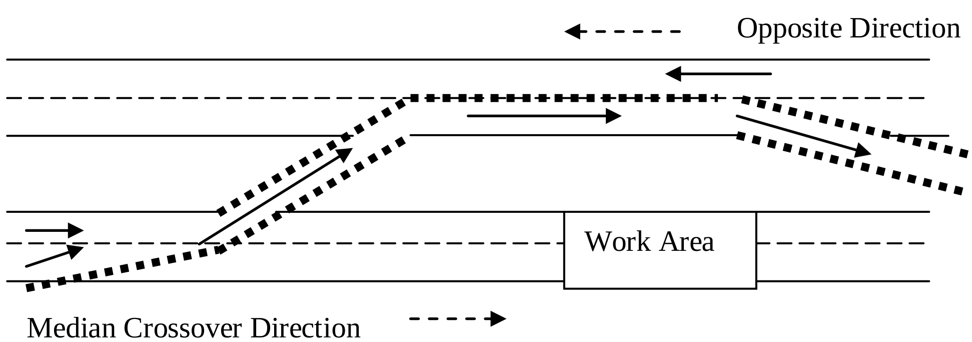

Figure 2: Crossover work zone

The excess user costs at work zones 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 that were developed in the previous study on work zones (Jiang, 1999). The excess user costs are listed below but are not discussed in detail in this paper because of length limitations.

- *Deceleration Delay Cost:* when approaching a work zone on a freeway, a vehicle gradually reduces its speed from the freeway speed to the work zone speed over a deceleration distance.
- *Reduced Speed Delay Cost:* the traffic delay caused by the reduced speed at a work zone.
- *Acceleration Delay Cost:* after exiting a work zone, a vehicle accelerates from the work zone speed to the freeway speed.
- *Vehicle Queue Delay Cost:* the traffic delay when vehicle queues are formed at work zone.

- *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.
- *Excess Running Cost of Vehicles at Reduced Speed through Work Zone:* Vehicles travel through work zones at lower than normal freeway speeds. The differences in travel speeds would result in different vehicle running costs.

The traffic data recorded by the weigh-in-motion (WIM) devices were used to calculate the user costs at work zones. The 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. 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. 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.

To demonstrate and analyze the work zone user costs at a freeway work zone, the traffic data recorded at the I-65 WIM station were utilized. The formulas 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 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. 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 3. The curves in Figure 3 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.

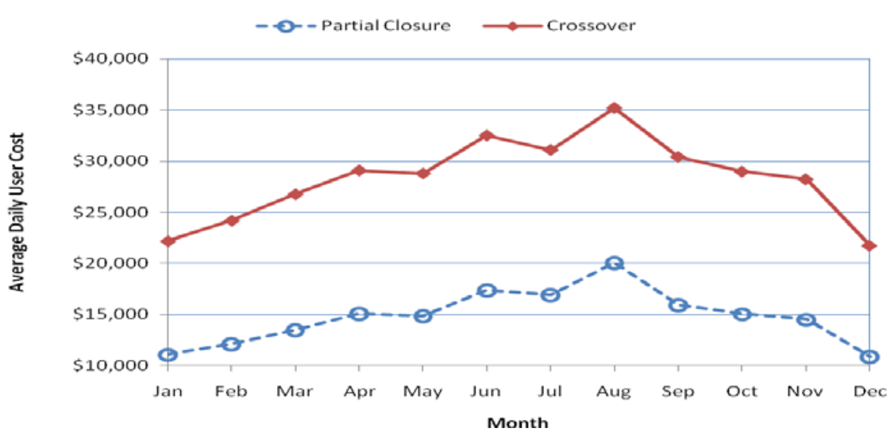

Figure 3: Average daily user costs at partial closure and crossover work zones.

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 July and August are plotted in Figure 4. The curves in Figure 4 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 in August was in its maximum at 15:00 and the user cost reached its peak point at 18:00. This can be attributed to the fact that as the traffic volume increased to the highest level at 15:00 the traffic started to become congested and a vehicle queue started to form. As the vehicle queue grew longer, the user cost increased until at 18:00 when the traffic volume had decreased to a certain level and the vehicle queue had cleared from the work zone.

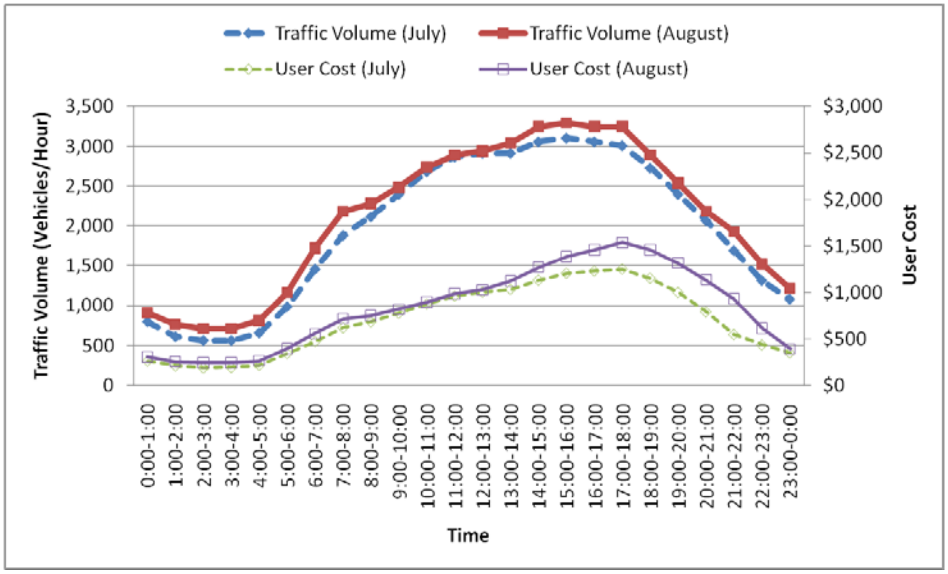

Figure 4: Hourly user costs and traffic volumes at the partial closure work zone

3. Cost-Time Relationship and Incentive Values

The main purpose of using incentive/disincentive (ID) 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 (1989) recommended that the maximum incentive value do not exceed 5% of the total construction cost of the project.

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 I/D 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 5. As can be seen in Figure 5, 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. The construction cost in Figure 5 does not include the excess costs to the roadway users and highway agency.

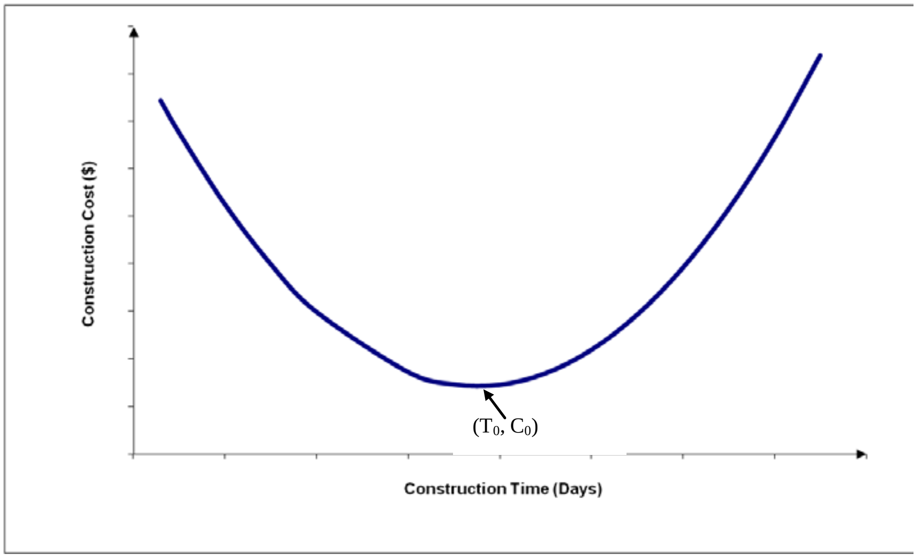

Figure 5: Cost-time relationship of highway construction project

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 can 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 6. 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 6 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.

4. Cost-Time Equations of Highway Construction Projects

In order to develop the cost-time relationship equations 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. The construction data include highway construction projects completed in 2006, 2007, and 2008. The basic concept of statistical regression with one independent variable is that the regression curve represents the mean values of the dependent variable (Neter, Wasserman, & Kutner, 1985). Therefore, each 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 6. 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:

$dy/dx = 2ax+b$

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

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

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

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 7 presents an example of curve shifting. As illustrated in Figure 7, the project curve is obtained by sifting the general curve a horizontal distance of $g=T_0-T_1$ and a vertical distance of $h=C_0-C_1$. The general curve and the project curve have the same shape with different lowest points. 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. Once the cost-time curve is obtained by shifting, the maximum days for incentive and maximum incentive can be determined with user cost information as illustrated in Figure 6. The curve shifting and the maximum incentive determination processes were incorporated into an Excel based computer program. With this program, a user only needs to input estimated contract time, construction cost, and user cost. The output is instantly calculated, including maximum incentive days and maximum incentive money amount.

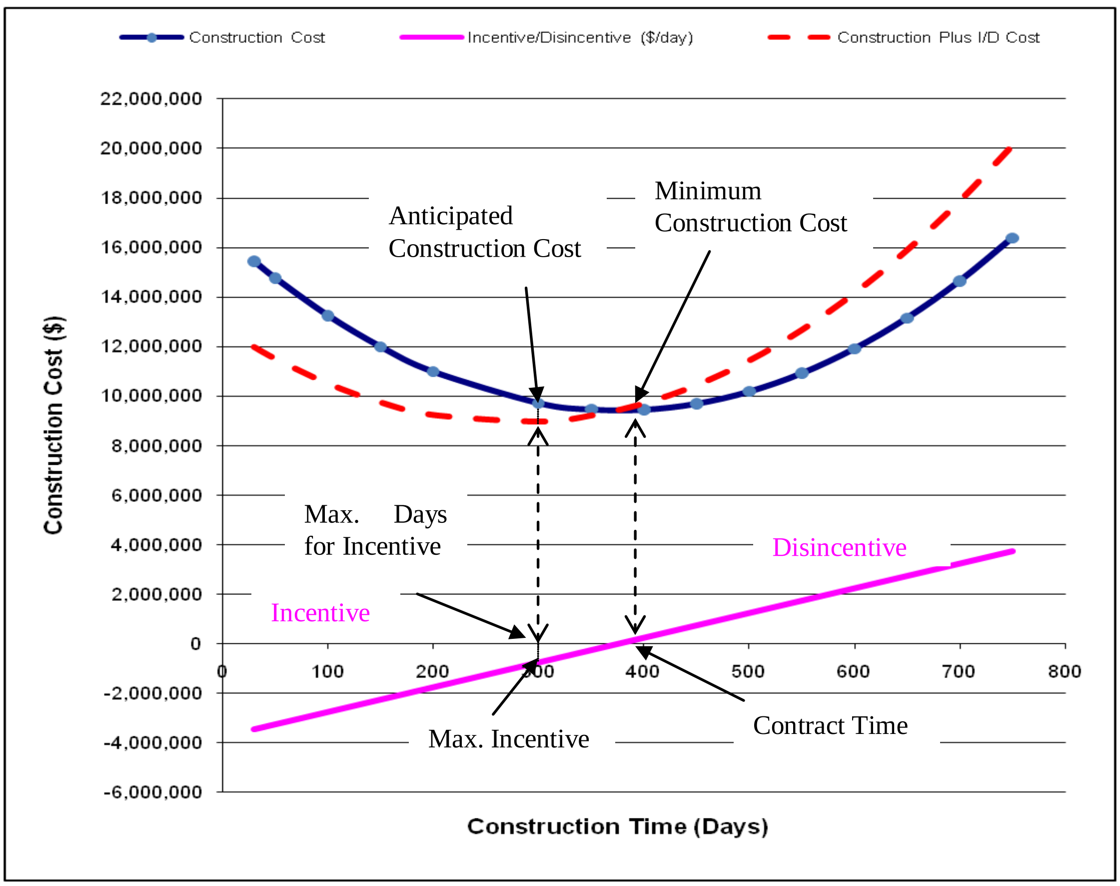

Figure 6: Determination of maximum incentive days and maximum incentive money amount

5. Determination of Contract Time and Incentive/Disincentive Values

To demonstrate the determination of contract time and I/D values, it was assumed that an asphalt resurface project was planned on I-65 near the WIM site with a total construction cost of $500,000 and an estimated contract time of 25 days. For asphalt resurface projects in Indiana, the equation of the general curve is $y = 318.55x^2 - 41{,}652.97x + 2{,}784{,}769.51$. The resurface project was to be constructed in August. As shown in Table 1, the estimated daily user cost was $20,044. If the whole user cost is used as the daily I/D amount, the incentive or disincentive may 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.

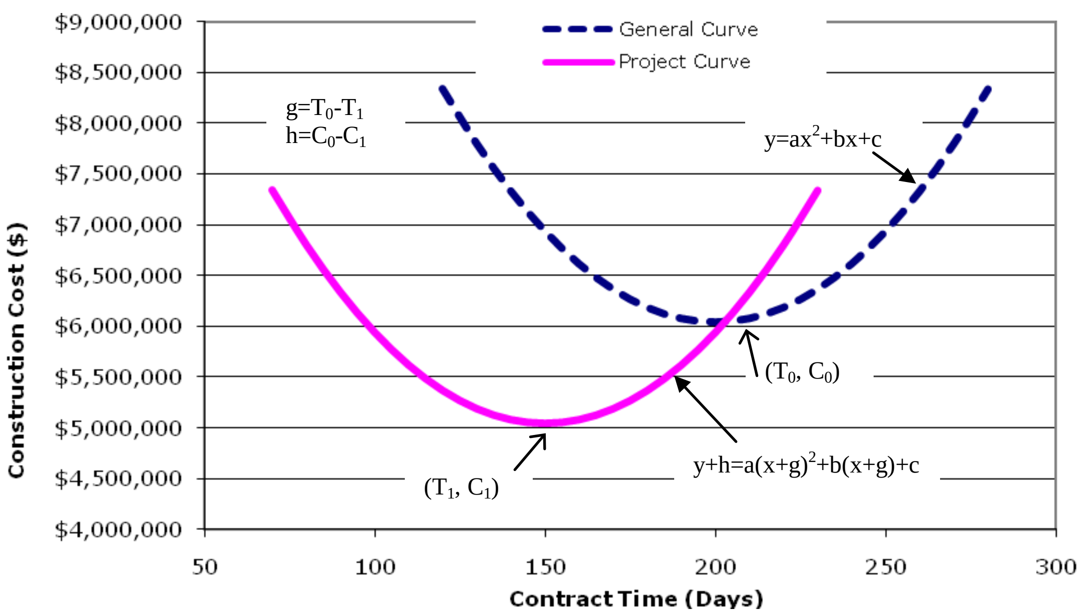

Figure 7: Shifting from general curve to project curve

To examine the effects of user costs on incentive/disincentive values, the maximum incentive values were computed with the Excel based program with different daily I/D values. The maximum incentive days and maximum amount of incentive money were computed with 20%, 25%, 30%, 35%, and 40% of the daily user cost ($20,044) as the daily I/D amounts. It should be pointed out that these percentages were chosen arbitrarily for demonstration purpose. One may choose any other portions of the daily user cost to analyze the effect of user cost to daily I/D amounts. The computed maximum incentive days and incentive money are presented in Table 4. Although only the incentive values are presented in Table 1, it should be pointed out that the disincentive values were assumed to be the same as the incentive values in case the project was completed behind schedule. As shown in the table, the maximum incentive values were directly affected by the percent of the daily user cost used as the I/D amount. As the daily I/D amount increased, the maximum incentive days also increased. This is intuitively correct as a greater I/D value will motivate a contractor to speed up construction so that they can obtain a larger reward or avoid a larger penalty. From a highway agency's point of review, the highway agency has to pay more in order to encourage a contractor to complete the construction project as early as possible.

Table 1: Maximum incentive values with different I/D amounts

Portion of Daily User Cost	20%	25%	30%	35%	40%
I/D Amount per day	$4,009	$5,011	$6,013	$7,015	$8,018
Max Incentive Days	6.29	7.87	9.44	11.01	12.59
Max Incentive	$25,227	$39,413	$56,752	$77,242	$100,909

For any given highway construction project, the highway agency can use the method shown in this example to determine the I/D value as an appropriate portion of daily user cost. The maximum incentive values can serve as a basis for a highway agency to decide a reasonable amount of money to be used to motivate the contractor to reduce the construction duration for a certain number of days.

6. Conclusions

The excess user costs of traffic delays caused by the presence of work zones are essential for assessment of the impact of the work zones on public. WIM data provides detailed information on traffic flows for calculating user costs at work zones. 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. This paper presents a method for estimating user costs at highway work zones based on the traffic data recorded by WIM devices in Indiana. The estimated user costs provide highway engineers and construction managers with useful information for effective highway construction planning. The user cost information is especially useful for highway agencies to determine contract times and incentive and disincentive monetary values for highway construction projects. For any highway construction project, there exists a construction time that would minimize the construction cost with given manpower and equipment. If the construction is shortened or prolonged from this construction time, the construction cost will increase. It is demonstrated that reasonable incentive and disincentive values can be determined by including a portion of the work zone user costs in the relationship between construction time and construction costs.

7. References

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