Model for Analysis of Factors Affecting Construction Schedule in Highway Work Zones

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Abstract: In highway construction, it is not only important to understand the factors that affect the schedule but also to evaluate their probable severity and impact on project duration. However, there is currently no standard or accepted model existing in the industry that can be used for this purpose. This paper presents a model that identifies various factors which have a potential to influence and impact the construction schedule in highway work zones. Also, a stochastic analysis of those factors is conducted by the model to determine probable changes, i.e., reduction or escalation, in the original estimated schedule for a given project. The analysis offers a revised schedule that is bound to be more meaningful and close to the expected value. The state Department of Transportation cannot only use the results to improve project scheduling but also improve the user cost calculations and decisions regarding contract types and requirements, e.g., liquidated damages, penalties, and incentives/disincentives.

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Introduction

There are three parties to a highway work zone project in traditional contract delivery methods: (1) The state Department of Transportation (DOT); (2) contractor; and (3) the user community. For a project to be successful, it is important that the concerns of all involved reflect in the construction schedule. However, there is often a lack of coordination between the state DOT and the constructor during the early planning stages of highway construction projects that leads to some missing links between construction planning control systems and those of traffic management. In most cases, project scheduling is done by DOT engineers who lack the necessary experience in the construction of such facilities. Furthermore, the contractors cannot participate in the process since that would prevent them from bidding on the project. As a result, the proposed project scheduling might not be the most optimal or efficient scenario (Goulias et al. 2002). On the other hand, efficient scheduling and traffic control through a work zone may greatly reduce the total cost, including user and agency costs (Najafi and Soares 2001). Since the user and agency costs such as travel time cost and accident costs are significantly affected by the timing of the work zone activities, it is highly desirable to optimize work zone scheduling so as to minimize the total cost (Chien et al. 2002).

Studies relating to scheduling of renovation and maintenance processes have been done in the past. *The Highway Capacity Manual* (TRB 1985) provides procedures for determining the capacity of work zones. From the traffic maintenance perspective, studies have been conducted to provide recommendations on estimating capacity of short-term lane closures (Krammes and Marsden 1987), estimating the effect of the intensity and location of construction and maintenance activities on mean speeds in work zones (Nemeth and Rathi 1985), estimating road user cost including delay cost and vehicle operating cost (Memmott and Dudek 1982), estimating queue lengths, optimizing work zone lengths, and optimizing work zone traffic control design and practice (Chien et al. 2002). Furthermore, Mahmassani and Jayakrishnan (1988) have looked at a dynamic analysis of lane closure strategies in highway repair or reconstruction activities.

From the contracting perspective, tremendous progress has been made in the last 2 decades with respect to implementation of innovative contracting techniques. In 1992, the Transportation Research Board (TRB) had recommended to the Federal Highway Administration (FHwA) to start experimenting with innovative techniques that will reduce construction time. After criticism from many public officials that highway construction takes too much time, many state DOTs are increasingly using daily road user cost (DRUC) estimates in the contract bidding process. They are also implementing several innovative contracting procedures like lane rentals, cost-plus-time (A+B) bidding, and incentive-disincentive methods extensively to motivate the highway contractors to expedite construction schedules.

In spite of all the progress made in this direction, there is still scope for improving the estimation process for the total duration of highway projects. It is evident that there is currently no standard model existing in the industry that can be used to calculate probable schedule changes associated with highway road construction. This paper addresses this need by presenting various

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factors that have a potential to impact the construction schedule in highway work zones. A model is also proposed for stochastic analysis of those factors to determine probable changes, i.e., reduction or escalation, in the original estimated schedule for a given project. The main advantage of the proposed model is that the analysis offers a revised schedule that is bound to be more meaningful and close to the expected value. The state DOTs cannot only use the results to improve project scheduling but also improve the user cost calculations and decisions regarding contract types and requirements, e.g., liquidated damages, penalties, and incentives/disincentives. From the same perspective, the model introduced in this paper is also beneficial to the contractors simply because they can get an idea about the criticality of factors that are likely to affect the schedule of a particular project and plan ahead to avoid delays.

Decision Framework of Model

The objective of this section is to provide initial information on the structure of the model for analysis of factors affecting construction schedule in highway work zones. The subsequent sections of the paper will cover the different levels of the model in detail and illustrate the usage of the final product with a hypothetical example.

The decision framework of the model is divided into four levels as shown in Fig. 1. Level 1 includes criteria identification for three different entities, namely the state DOT, road user, and the contractor. Every construction project is unique and involves many different factors that influence and impact the schedule considerably. The fact that these factors and their impact are not the same for all projects calls for a detailed subjective assessment of these factors for each and every project. In this regard, the first phase of this research included a comprehensive literature review to identify all the factors that could have a potential influence on the construction schedule for any given project. Furthermore, expert interviews were conducted to clarify the impact of identified factors. During application of the model, the critical factors that have a high potential to impact the project under consideration are identified by the analyst out of the set of factors provided by the model and their probable impact on the project schedule is determined. It is important to consider the probability of occurrence of these factors for each individual project simply because it is possible that a particular high-impact factor could be either absent or insignificant in that particular project. While careful attention has been given to identify relevant factors, the model allows users to make additions to the factors specific to the project.

Level 2 of the model involves identification of the type of impact of each relevant factor; whether it contributes to a reduction or an escalation in the schedule according to the user of the model. At this stage, all the factors in the hierarchy are categorized into one of these two groups by the user. Followed by this step is the analytic hierarchy process (AHP) evaluation of reduction criteria and escalation criteria separately. The AHP allows subjective and objective evaluation of the criteria and establishes the priorities among factors in the hierarchical setup according to the user input. After establishing priorities, the model requires the management or user to enter threshold values for separating those factors that are critical in terms of affecting the schedule from others that are insignificant. This step is important because it reduces the number of factors used for further analysis in the model.

Level 3 of the model involves impact evaluation for the selected criteria. For different projects under consideration, the chance of occurrence and the severity of impact of any given factor might vary substantially. In order to quantify these two variables for each factor under consideration, the user is required to enter the minimum, most likely, and the maximum values for these variables. The values provided by the user establish the triangular distributions required for further analysis in the following level. After all the assumptions have been setup for the variables in the model by the user, a Monte Carlo simulation is run using Crystal Ball in Level 4. The simulation produces a probabilistic distribution and a mean value for the total probable reduction and total probable escalation. The difference of these two values gives the net estimated change in schedule.

The model proposed in this paper was validated using case studies from the Indiana Department of Transportation (INDOT). Two case studies of completed projects were performed in order to validate the model. The third case study was that of a project in the planning stages in order to test the applicability of the model as a forecast tool for predicting schedule changes. Due to editorial constraints, this paper only focuses on the function and development of the model through a hypothetical example and relevant results from case studies conducted during this research. However, the details about the case studies are the subject of another journal paper which is currently under review for publication.

Level 1: Criteria Identification

A comprehensive study was conducted to identify all the relevant factors that could have a probable impact on the construction schedule. The studies conducted in the past on the subject matter were reviewed and experts were contacted for additional information. Upon completion of this step, the factors were categorized into a hierarchy in order to facilitate further evaluation. As shown in Fig. 2, the critical factors were categorized into three main groups including DOT criteria, user criteria, and contractor criteria. Each main group was further divided into different subcategories which included the appropriate critical factors.

Factors Affecting DOT's Schedule Requirements

The first main category in the hierarchy, DOT criteria, includes five subcategories, e.g., political, legal, financial, traffic, and project. Construction schedule, budget, and contractual agreements could be impacted by special interests stemming from political corners, additional funds made available by a political institution/individual, and imminent elections or political events. Therefore, the category of political criteria included interest groups, additional funds available, and elections/political events. Similarly, several legal factors such as state-specific local ordinances and restrictions are likely to control construction activity and impose very rigorous schedule changes. For example, such a restriction could include any operating hour limitations that have been placed on the project through local, state, and federal agencies as well as contract restrictions. Also, in certain cases, archeological issues are a point of concern especially while dealing with subsurface utility work (Forkenbrock et al. 1990).

The costs that are incurred by the agency over and above the budget in order to perform supervision and quality control and the cost of work zone accidents were also identified as important financial factors that need to be considered in terms of their impact on the construction schedule (Hancher and Taylor 2001).

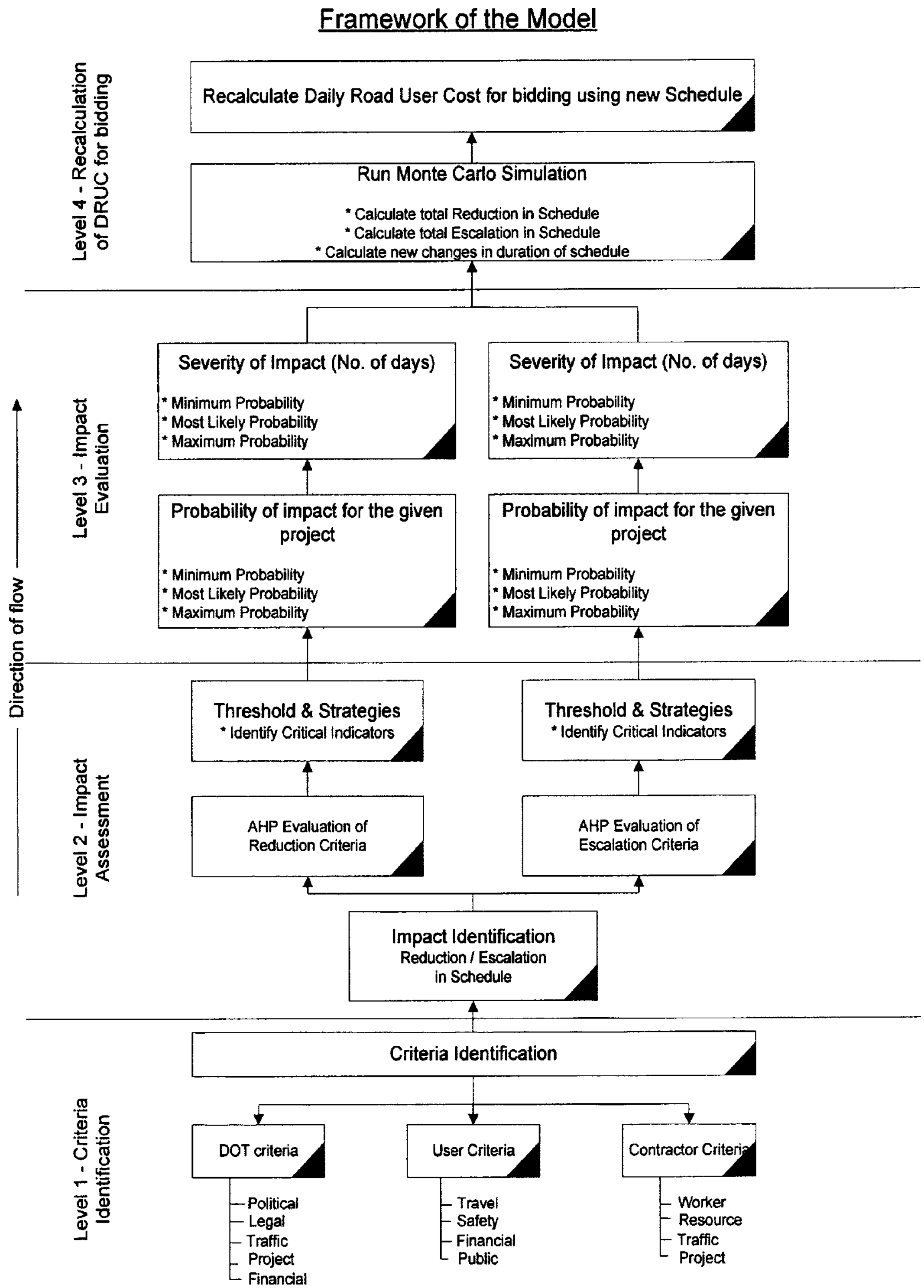

Fig. 1. Framework of model

Traffic parameters and safety issues involving road users and construction workers constitute a large portion of the claims that a state DOT has to handle (Blincoe 1996). Minimization of freeway-incident delays through optimization of the construction schedule is one of the main challenges in front of the DOT. Also, the DOT has to plan beforehand for traffic redistribution in case it anticipates complete closure of the freeway. Hence, traffic safety, maintenance, and redistribution are three primary concerns of state DOTs in this category (Curry and Anderson 1972).

From a project characteristics point of view, the type of contract will usually determine the level of motivation for a contractor to complete construction ahead of schedule and help the state DOT in establishing appropriate rates for incentives, disincentives, and lane rental charges. Also, if there is a warranty provision on the contract, it could lead to other possible issues affecting the schedule. Furthermore, highway characteristics, including type of highway and length of work zone, are important for the DOT in planning the construction activity. Also, in some

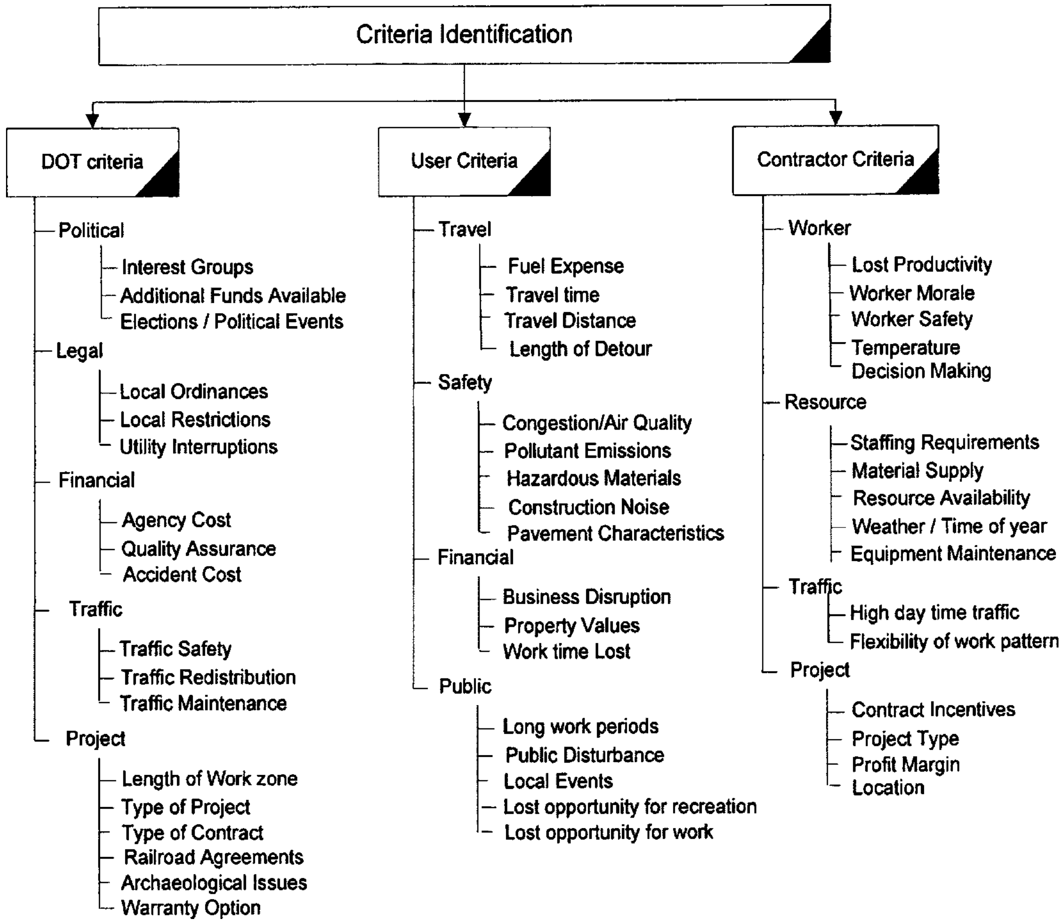

Fig. 2. Categorization of factors into criteria and subcriteria

cases, railroad agreements could come in the way of construction activity. Furthermore, prolonged construction could drastically impact the property values in and around the work zone areas (Anderson et al. 1992).

Factors Affecting Road Users and Neighborhood Businesses

The second main category in the hierarchy, user criteria, includes four subcategories, e.g., travel, safety, financial, and public. One of the most important travel characteristics for road users is the time spent in traffic which contributes to monetary losses. Most of the construction zones have restricted speed limits which lead to extensive queuing during peak hours resulting in increased travel time for the commuters. In certain cases, some roads are completely closed due to construction which is not only for the safety of motorists, but also because it is not feasible for the large construction machinery to move for every vehicle that wants to pass. Most often the detours are through rural highways where the speed limits are lower. Motorists are averse toward lengthy detours that can significantly increase travel time. Also, fuel expense is incorporated into the formula for calculating DRUC (Shepard and Cottrell 1985).

As far as road user safety is concerned, construction deteriorates air quality considerably in and around the construction zone. When dealing with air quality issues in construction zones, it is not only important to look into air quality impacts on construction workers from road traffic but also at the impact of deteriorated air quality from construction on neighborhood and road users (Cohen 1995). Neighborhood businesses also suffer from construction equipment emissions. Construction noise and hazardous materials are other serious health hazards to surrounding areas. High levels of noise can lead to hearing impairments or tinitis (Mahmassani and Jayakrishnan 1988).

In today's highway construction industry, the focus has shifted from building new transportation facilities to resurfacing, rehabilitating, and restoring those already in existence. Typically, these projects are undertaken in heavily urbanized areas, causing extreme traffic congestion during the construction period. From a financial perspective, this slowdown of traffic flow poses severe negative impacts on the business community. Loss of existing clients due to detours and traffic disruptions, loss of potential clients, loss of work time, and potential decrease in property values could affect the business community around the neighborhood at large (Grenzeback and Warner 1994).

Certain issues like lost opportunity for work, public disturbance, long work periods, and local events for road users are hard to quantify but they are important factors to be considered in road construction scheduling. Therefore, these factors were captured under the public subcategory in the hierarchy.

Factors Affecting Contractor's Performance

The third main category in the hierarchy, contractor criteria, included four subcategories, e.g., worker, resource, traffic, and project. Since the contractors are required to work around the traffic conditions at the work zone, often requiring night shifts, worker considerations like safety, morale, and productivity are important considerations (Blincoe 1996).

Resource concerns to the contractor include contingency plans for equipment repair and maintenance as well as resource availability. Also, selecting personnel to work, especially for night construction, based upon employee satisfaction, family disruptions, and supervisory problems could be another big concern. Location of the project and material supply become critical in this regard and the ability of on site field personnel to make good decisions becomes critical as well. The traffic characteristics at the job site are also important for contractors. High daytime traffic may adversely affect the construction processes at the job site, while flexible work patterns help contractors increase job site productivity. Also, scheduling construction in order to avoid claims is important but difficult. However, the extent of claims can definitely be reduced if the probable factors leading to these claims are investigated while scheduling the operation (Curry and Anderson 1972).

From a project characteristics perspective, type of contract, profit margin, and incentives can either act as a motivation or deterrent for contractors. Use of incentive/disincentive (I/D) clause probably causes construction bids to rise as it transfers some risk from the state DOT to the contractors. Many contractors will perceive that they must adjust their project management practices in order to bring under their control all of the factors for which the I/D clause holds them newly responsible. The contractors either do not submit bids if they feel that the risk is inclined excessively toward them or they quote a slightly higher price to assure a higher return in exchange for the higher risk (Goulias et al. 2002).

Level 2: Impact Assessment

Level 2 of the model includes the identification of the types and relative weights of the factors impacting the schedule for a given project (Fig. 1). Every factor impacting the construction schedule could either cause a net reduction or escalation in the schedule. Level 2 of the model is very project specific and depends on the subjective judgment of individuals involved in the project. For any given project, the user needs to decide on the potential net impact of each factor under consideration on the project schedule, e.g., reduction or escalation. In certain cases, when it is difficult to judge whether a particular factor could lead to reduction or escalation in a particular project, similar projects from the past can be used as reference. Furthermore, if the user feels that a particular factor is totally irrelevant for the project under consideration, that factor can be removed from the hierarchy.

Also, a hypothetical example will be illustrated from this point onward along with the detailed explanation of the model in order to show the functionality of the model and to test it. The project considered in the example could be that of a highway construction in a busy urban area where there is a lot of pressure from interest groups to finish the project ahead of schedule. Some of the assumptions made in this hypothetical example include lengthy detours, imminent political/local events, utility interruptions, high daytime traffic, business disruptions, construction noise, and handsome contract incentives as critical factors affecting the schedule. It is important to note that the evaluations and values used in calculations might not necessarily be commensurate with actual user input values for any given project of this kind.

Table 1. Example Identification of Type of Impact—DOT Attributes

Number	DOT subcriteria	Description of attribute	Type of impact (user input)
1	Political parameters	Interest Groups	Reduction
2		Additional Funds Available	Reduction
3		Elections/political events	Reduction
4	Legal parameters	Local ordinances	Escalation
5		Local restrictions	Escalation
6		Utility interruptions	Escalation
7	Traffic parameters	Traffic safety	Escalation
8		Traffic redistribution	Escalation
9		Traffic maintenance	Escalation
10	Project parameters	Length of work zone	Reduction
11		Type of highway	Reduction
12		Railroad agreements	Escalation
13		Archeological issues	Escalation
14		Type of Contract	Reduction
15		Warranty option	Escalation
16	Financial parameters	Agency costs	Reduction
17		Quality assurance	Reduction
18		Accident cost	Reduction

As discussed earlier, the user is first expected to identify the type of impact each relevant factor is likely to have on the project schedule. Table 1 is a summary of the type of impact identified by the user for the DOT criteria. The fifth column in the table actually shows the user input. The type of impact of each relevant factor is also identified for the other two criteria, namely road user and contractor criteria. In the hypothetical example discussed here, the user suggested that interest groups, additional funds available, and imminent political events demanded a reduction in schedule while other factors like utility interruptions, traffic issues, and local restrictions demanded an escalation in schedule. The input was obtained from experts in the DOT and hence it is reasonable to assume that the entire analysis is inclined toward the DOT's point of view.

After all the necessary and relevant factors have been grouped into two major categories, namely factors leading to schedule reduction and factors leading to schedule escalation, the AHP evaluation is performed by the user separately on reduction and escalation factors in order to establish the relative weights for each factor under consideration. This analysis is important because all the indicators in a particular level might not have the same degree of significance with respect to their potential impact on schedule.

The AHP is a systematic way of evaluating this degree of significance in the hierarchy of criteria and subcriteria. In the AHP process, the hierarchy of criteria is systematically evaluated by using a series of matrix computations to determine the decision-maker's preference order among the various criteria. In the AHP analysis, the comparison matrix at the criteria level is established by doing a pairwise comparison of the various criteria based on a predetermined relative scale (Saaty 1980). The diagonal entries of the comparison matrix are equal to 1.0 because the elements being compared are the same (i.e., X compared to X, Y compared to Y, etc.). The entries in the lower triangular matrix, on the other hand, are reciprocals of the entries in the upper triangular matrix. The comparison matrix thus established is evaluated to determine the eigenvector corresponding to the

Table 2. AHP Evaluation and Threshold for Reduction Factors

Number	Criteria	Weights	Subcriteria	Weights	Description of attribute	Weight from AHP	Weighted assessment (%)
1	Department of Transportation	0.3	Political parameters	0.35	Interest groups	0.25	2.63
2				0.35	Additional funds available	0.35	3.68
3				0.35	Elections/political events	0.4	4.20
4		0.3	Project parameters	0.3	Length of work zone	0.25	2.25
5				0.3	Type of highway	0.15	1.35
6				0.3	Type of contract	0.6	5.40
7		0.3	Financial parameters	0.35	Agency costs	0.35	3.68
8				0.35	Quality assurance	0.25	2.63
9				0.35	Accident cost	0.4	4.20
10	Daily road user	0.4	Travel parameters	0.1	Fuel expense	1	4.00
11		0.4	Safety parameters	0.4	Congestion/air quality	0.2	3.20
12				0.4	Pollutant emissions	0.25	4.00
13				0.4	Hazardous materials	0.1	1.60
14				0.4	Construction noise	0.35	5.60
15				0.4	Pavement characteristics	0.1	1.60
16		0.4	Financial parameters	0.4	Business disruption	0.6	9.60
17				0.4	Property values	0.15	2.40
18				0.4	Work time lost	0.25	4.00
19		0.4	Public parameters	0.1	Long work periods	1	4.00
20	Contractor	0.3	Worker parameters	0.45	Lost productivity	0.25	3.38
21				0.45	Worker morale	0.25	3.38
22				0.45	Worker safety	0.5	6.75
23		0.3	Resource parameters	0.25	Staffing requirements	0.2	1.50
24				0.25	Material supply	0.35	2.63
25				0.25	Resource availability	0.3	2.25
26				0.25	Weather / time of year	0.15	1.13
27		0.3	Project parameters	0.3	Contract incentives	0.45	4.05
28				0.3	Project type	0.2	1.80
29				0.3	Profit margin	0.35	3.15

Note: Threshold=2.7%.

maximum eigenvalue of the matrix. The entries of the eigenvector thus determined represent the priority among the various criteria. A similar analysis is performed at the subcriteria level of the hierarchy and the alternative level (if any). The priority vector for the subcriteria is multiplied with the weight (or priority) of the corresponding criterion in the previous level of the hierarchy. Similar analysis is done at all levels of the hierarchy, thus propagating the weight of a criterion all the way down to the last level in the hierarchy.

The results of the AHP analysis of reduction criteria for the hypothetical project are shown in Table 2. These results indicate that road user criteria are more important than DOT and contractor criteria for this particular project as shown in the third column of the table. Also, at the subcriteria and attributes level, weights were established similarly. The eighth column shows the weighted assessment for all the attributes. It should be noted that all the entries in this column will add up to 1 (or 100% if calculated in percentages) satisfying the rules of the AHP.

Finally, in order to limit the number of criteria for further analysis, the model expects the user to enter threshold values in this level. This step is important because it separates the most critical factors from the other insignificant ones. The level of threshold used to establish criticality of factors is purely a management decision and can vary with each project. The threshold value is decided from the weighted assessment of all the factors at the final level of the hierarchy which makes sure that the entire hierarchy of factors is considered before criticality is established. Also, the threshold values for reduction and escalation factors can be different. In the example discussed here, a hypothetical threshold value of 2.7% is considered based on which 17 out of 29 reduction factors were identified to be critical (Table 2).

Level 3: Impact Evaluation

Once the factors impacting the schedule for a given project are categorized and their relative weights are established, this level of the model seeks user input in order to establish the probability of occurrence and severity of impact of each critical factor (Fig. 1).

The use of probabilistic durations for construction activity is not uncommon and dates back to the late 1950s and the development of the program evaluation and review technique (PERT). In the PERT method, a beta distribution is used to model activity duration time. Reasons for this choice of distribution are mainly due to the characteristics of construction cost and schedule data, i.e., construction data are usually distributed asymmetrically, have confined ends, and unimodal (has only one most likely value). MacCrimmon and Ryavec (1964) have suggested that the use of the triangular distribution is no less accurate than the beta

Table 3. Assessment of Minimum, Most Likely, and Maximum Values for Critical Reduction Factors

Critical indicator	Type of impact on schedule (reduction/escalation)	Probability (chance of occurrence) Minimum (5th percentile) (%)	Most likely (%)	Maximum (95th percentile) (%)	Severity (number of days of impact) Minimum (5th percentile)	Most likely	Maximum (95th percentile)	Most likely reduction
Additional funds available	Reduction	5	10	15	30	45.00	60	4.50
Elections/political events	Reduction	20	30	35	15	30.00	45	9.00
Type of contract	Reduction	30	50	60	20	22.00	30	11.00
Agency costs	Reduction	10	20	50	20	25.00	30	5.00
Accident cost	Reduction	20	30	40	10	15.00	20	4.50
Fuel expense	Reduction	5	6	10	10	12.00	20	0.72
Congestion/air quality	Reduction	10	15	20	15	20.00	30	3.00
Pollutant emissions	Reduction	10	15	20	20	35.00	45	3.50
Construction noise	Reduction	30	50	60	20	25.00	30	12.50
Business disruption	Reduction	50	60	75	60	70.00	90	42.00
Work time lost	Reduction	20	25	30	20	25.00	30	6.25
Long work periods	Reduction	10	15	30	5	7.00	10	1.05
Lost productivity	Reduction	10	15	20	20	25.00	30	3.75
Worker morale	Reduction	10	15	30	30	40.00	45	6.00
Worker safety	Reduction	5	7	10	15	21.00	25	1.05
Contract incentives	Reduction	60	75	80	10	20.00	25	15.00
Profit margin	Reduction	20	25	40	10	15.00	30	3.75
							Total	132.57

distribution. The benefit is of course the simplicity of the triangular distribution. Moder et al. (1983) suggested that in probabilistic scheduling, it would be preferable to estimate the most likely value, the 5th percentile and the 95th percentile values of the distribution as it would be extremely difficult to estimate the 0th and 100th percentile points of the distribution.

This research follows the suggestion of Moder et al. (1983) and uses a triangular distribution to model the impact of critical factors on total construction duration. The main advantage in using the triangular distribution is that, unlike other distributions, collection of data is very straightforward and manageable. Not all factors impact the schedule the same way. Hence, it is important to identify the severity of impact of each factor. Also, not all factors are always present in any given project. Therefore, the probability or chance of occurrence of each factor in a given project has to be modeled using the triangular distribution.

Hence, in this level of the model, the 5th percentile (minimum), most likely, and 95th percentile (maximum) values are specified for the probability of impact (chance of occurrence of that particular factor) as well as the severity of impact (number of days by which the factor can impact the schedule) of the factors that were short listed in the previous step. This approach is reasonable because the required information can be obtained from experts with experience in construction scheduling and execution including DOT engineers/project managers and contractors/construction managers participating in the process. Additional information can also be obtained through interviews with officials in charge of project management which will establish justifications for the values of probabilities used to indicate level of criticality of impacting factors.

Table 3 shows the user input values for the critical reduction factors for the hypothetical project. For example, the user input a value of 75% as the most likely value for occurrence of contract incentives, which is the highest among all the critical reduction factors. On the other hand, worker safety got a value of 5% which is the lowest. In the severity of impact section, based on the user input, additional funds available were likely to have the maximum impact on the schedule (45 days is the most likely value), while long work periods would have the least impact (7 days is the most likely value). This step was repeated for all the critical escalation factors as well and the most likely outcome for the total impact of each factor was finally obtained in units of number of days as shown in Table 4. The values indicated under the columns "Most likely reduction and most likely escalation" in Tables 3 and 4 reflect the product of most likely values for probability and severity and do not take into consideration the entire range of these values. The entire range, however, would be considered under simulation as explained in the following section.

Level 4: Simulation

Without the aid of simulation, a spreadsheet model will only reveal a single outcome, generally the most likely or average scenario. Spreadsheet risk analysis uses both a spreadsheet model and simulation to automatically analyze the effect of varying inputs on outputs of the modeled system. One type of spreadsheet simulation is Monte Carlo simulation, which randomly generates values for uncertain variables over and over to simulate a model. This study proposes using Monte Carlo simulation in order to simulate the model and generate values for both the probability of occurrence and severity of impact of the critical factors (Fig. 1).

The probability of occurrence is in terms of percentage and the severity of impact is in terms of number of days. These two values can be combined together in order to calculate the probable impact on schedule in terms of number of days. The product of the two variables (probability of occurrence and severity of impact) for a particular critical reduction factor will give the probable impact in terms of number of days that the critical

Table 4. Assessment of Minimum, Most Likely, and Maximum Values for Critical Escalation Factors

Critical indicator	Type of impact on schedule (reduction/escalation)	Probability (chance of occurrence) Minimum (5th percentile) (%)	Most likely (%)	Maximum (95th percentile) (%)	Severity (number of days of impact) Minimum (5th percentile)	Most likely	Maximum (95th percentile)	Most likely escalation
Local restrictions	Escalation	5	10	30	15	30.00	35	3.00
Utility interruptions	Escalation	15	60	80	20	30.00	45	18.00
Traffic safety	Escalation	20	25	30	10	15.00	20	3.75
Traffic redistribution	Escalation	10	15	40	25	30.00	60	4.50
Traffic maintenance	Escalation	10	20	40	10	15.00	30	3.00
Travel time	Escalation	15	25	30	5	10.00	15	2.50
Travel distance	Escalation	15	20	40	20	25.00	35	5.00
Length of detour	Escalation	10	12	20	21	25.00	35	3.00
Public disturbance	Escalation	20	30	50	30	40.00	60	12.00
Local events	Escalation	25	50	60	21	30.00	42	15.00
Lost opportunity for work	Escalation	15	25	55	15	30.00	45	7.50
Temperature	Escalation	5	10	20	7	10.00	14	1.00
Decision making	Escalation	10	15	20	7	10.00	21	1.50
Equipment maintenance	Escalation	15	25	40	10	14.00	30	3.50
High day time traffic	Escalation	10	20	45	10	25.00	45	5.00
Flexibility of work pattern	Escalation	15	30	60	7	14.00	28	4.20
							Total	92.45

reduction factor is likely to have on the schedule. The sum of all these impacts for all the reduction factors will give the total probable reduction in schedule. Similarly, total probable escalation is calculated from the combined impact of all the critical escalation factors. Finally, the total estimated change in schedule is calculated as the difference between total probable escalation and total probable reduction.

In the final stage of the hypothetical example, Monte Carlo simulation was run using Crystal Ball (an add-in forecasting tool for MS Excel) in order to get a mean value for the estimated total change in schedule. The results of the simulation are summarized in Table 5 that were modified from the self-generated report in Crystal Ball. At the end of 1,000 trials, the total probable escalation was calculated as 107.15 days, while the total probable reduction was calculated as 139.52 days. Therefore, the net change in schedule was estimated as −32.37 days. The negative sign indicates probable reduction in schedule. Hence, this value indicates that there will be a probable reduction in schedule by approximately 33 days. Since this value was generated with a confidence level of 95%, it could vary a little bit from the estimated mean value. Also, the entire range was from −71.89 to 1.66 days. It is clear from the range of the distribution that the reduction factors had more impact on the schedule than the escalation factors and hence the project was inclined more toward a schedule reduction than a schedule escalation.

Crystal Ball reports can also be used to obtain graphical information about all the factors that were used in the simulation. In this hypothetical example, it became evident from the additional reports that additional funds available will have the maximum impact on the schedule followed by congestion/air quality, equipment maintenance, long work periods, lost opportunity for work, traffic maintenance, local restrictions, and worker safety. This information is useful because it could be a means of checking whether the user was able to convert his or her ideas into justifiable inputs for the model, the way he or she intended.

Case Studies

In order to validate the model and assess its efficiency, case studies were performed on three Indiana DOT projects. Due to editorial constraints, the subsequent sections provide only brief information about the case studies while another paper by the

Table 5. Total Estimated Change in Schedule—Summary and Statistics

Statistic	Hypothetical example	Case Study 1	Case Study 2	Case Study 3
Trials	1,000	1,000	1,000	1,000
Total probable escalation	107.15	100.16	136.64	111.86
Total probable reduction	139.52	71.13	33.89	24.61
Net change in schedule	−32.37	+29.03	+102.75	+87.25
Range	[−71.89, 1.66]	[17.10, 46.78]	[62.34,146.75]	[53.30, 126.69]
Standard deviation	12.65	4.41	12.65	14.07
Mean standard error	0.57	0.14	0.46	0.44
Actual change in schedule	Not applicable	+30	+110	To be observed

writers presents the findings of the case studies in detail.

The first case study included the analysis of schedule changes of a road construction project in Lafayette, Ind. The second case study included the analysis of the interchange project on US-421 at I-465 in Indiana. Both of these projects were completed and the actual delays in schedule were known. However, the case studies were important to verify the output of the model with the actual results. Finally, the third case study aimed at the prediction and analysis of potential schedule changes in a road rehabilitation project that was going to be let by INDOT in March 2004 on US-421. The contract included conversion of a two-lane highway into a four-lane concrete section.

The results of the first two case studies on completed projects turned out to be very close to the actual changes in the schedule and validated the use of the model on DOT projects (Table 5). On the other hand, the third case study provided a framework where the user could get a detailed look into the critical problem areas that are likely to impact the schedule and take appropriate action.

Conclusions and Recommendations

The purpose of this paper was to present "The model for analysis of schedule changes in highway construction." In order to establish the model, the critical factors that have a potential to affect road construction were identified and stochastically analyzed in terms of their probable impact on construction duration. Also, hypothetical data for a highway construction project was used in order to understand the functionality of the model. User inputs were entered and the calculations were performed using the AHP. Later, Monte Carlo simulation was run in order to calculate the probable estimated change in total construction duration of the hypothetical project.

The model presented in this paper has perceived benefits for both the DOT and the highway contractors simply by virtue of the forecasting ability incorporated into the model using probabilistic analysis and simulation. This research can also be considered as the first step in achieving another objective. Not only can schedule changes be analyzed in detail, but a multifaceted analysis can be performed to forecast cost changes and its implications on schedule and vice versa. In other words, a cost-schedule optimization model can be developed along similar lines to get the optimized cost and schedule for any given project.

The fact that the model currently functions as a single-user model may be a point of concern. However, the subjectivity involved in a single-user decision can be overcome by incorporating a group decision model that will weight the inputs of group members based on their respective experience and knowledge. This approach will set up a better framework for analysis by virtue of being a multiuser decision tool. From the DOT's perspective, this model can be a part of a standardized model that could be used to calculate DRUCs in a more meaningful way, including all the indirect costs.

This model is currently geared toward a DOT's perspective of analyzing schedule changes in order to use it meaningfully in bidding and other areas. However, the model can be customized for contractors as well and assist them in getting information about probable schedule changes before they submit their bids. In other words, there could be different versions of the model, tailored to suit the demands of the owner, contractor, or even the public in some cases. The model is currently applicable for road construction projects. However, similar models can also be developed in other areas of construction including the building construction industry, bridge construction industry, or other heavy civil construction industries. Such models will provide a more meaningful analysis taking into account the contractual nuances relating to specific types of construction projects.

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