A Fuzzy Modeling Approach to Weather Delays Analysis in Construction Projects

M. H. Sebt[1], H. Rajaei[2], M. M. Pakseresht[3]

[1]Associate Professor of Civil and Environmental Engineering Dept., and Head of Construction Engineering and Management Program, Amirkabir University of Technology (Tehran-Polytechnic), sebt@aut.ac.ir

[2]Assistant Professor of Civil and Environmental Engineering Dept., Amirkabir University of Technology (Tehran-Polytechnic),rajaieh@aut.ac.ir

[3]Graduated Assistant of Construction Engineering & management, Amirkabir University of Technology (Tehran-Polytechnic), m_packseresht@yahoo.com

Abstract: *Project participants are becoming more aware of the high costs and risks associated with delay claims and their litigation. Among delays, weather delay has an important role in projects performed in severe environmental conditions. This research is the extension of delay analysis techniques by approving analysis of weather delays using fuzzy logic. At the presented technique, first using a fuzzy logic model calculated the delay that occurred during the activity execution after weather event; then by the selected delay analysis method (Time impact analysis) and using the risk of the contractor during the contract approval together with the effect of previous delay in changing the duration of activities, analyzed weather delays in construction project. A local general contractor and governmental firms involved in a highway construction project practiced by offering their experienced and knowledge in delay analysis procedures to provide data for development and testing of the model specified for rain events. The results indicated that the presented model is in accordance with practical experiences in weather delay duration except in some circumstances that can be divided into the separated parts. It also advances the use of fuzzy logic in delay analysis procedures and becomes it more systematic special for weather delays.*

Keywords: *Fuzzy logic, Weather delay, Time impact analysis*

Introduction

Weather can have a dramatic effect on a construction project. But among the construction projects, Due to the constant exposure to the environment, highway construction is greatly affected by weather. Conditions such as air temperature, precipitation and wind velocity cause the majority of difficulties and delays in highway construction.

In fact weather events are regarded as major uncertainty factor that have adverse impacts on productivity and duration of construction projects. In practice, given a location, type, start date, and original duration of activity, a common approach for construction schedulers to assess the effect of weather event is by adding a certain percentage of time to task. However, this method depends mainly on the experience and subjective judgment of schedulers, who may unfamiliar with the rainfall pattern and its impact on the productivity of operations, and thus, oftentimes produces inaccurate results.

In construction contract, the contractor legally is required to consider all foreseeable delays to the critical path, but due to the wide range of inaccuracies in predicting weather delay durations, legal precedence in delay analysis methods does not require that the method for considering foreseeable weather be defined. In addition, it is advised to the owner that analyzes the additional requested activity duration of contractor affected by weather as soon as possible to avoid potential claims and speeds execution of the project. In these situations, owners always extend uniformly duration of the project, whereas the contractor claims to cover his faults in other activities.

The method presented in this paper describes a fuzzy logic model to deal with these problems.

Use of fuzzy logic in determining the effect of weather events

Weather events have various effects on the duration of activities according to the location of construction site, types of construction work, materials used in construction operation, start and finish date of each construction activity and so on. Since these factors are often associated with many uncertainties resulting in varied impacts on productivity and duration construction jobs, they are assessed subjectively using fuzzy sets based method. For example in outdoor activities, the exposure level of an activity is regularly expressed linguistically as very small, small, medium, large, and very large. The fuzzy set based method has been introduced to cope with uncertainties that cannot be quantified due to their qualitative and subjective nature. Ayyoub and Haldar (1984) pioneered the use of fuzzy sets operations to evaluate the effect of weather and labor skill on predicting the duration of activity. The difference between their method and the presented method in this paper is that the effects of weather conditions become more specific to evaluate its effect on delay analysis method.

Estimation of delay duration

As describe before, to evaluate the effect of weather events on changing the duration of activities, it is important to select the parameters that show the sensitivity of selected activity to the specified weather condition. It is mentioned that these parameters are different due to the condition of the projects and provisions of schedulers. For this reason and because of some restrictions in fuzzy modeling, one should select parameters that have the greatest impact on changing the duration of a specified activity; For illustration purposes, consider rain as common weather event and excavation activity as the most sensitive activity in highway construction projects. In the excavation activity, main parameters that affect the total duration of activity are:

- Activity duration (without the effect of weather condition)
- Location of activity on the project
- Soil properties (soil drainage)

Activity duration was used to take into account the time exposure of the work during rain condition (Smith and Hancher 1989). An excavation activity with short duration is more sensitive to rain condition than a long duration activity.

The activity location would indicate the rain condition that can affect the duration of activity; nevertheless, this factor would be included if the activity is completely or partially exposed to rainy condition.

Another important factor affecting excavation activities is soil type that always considered as soil drainage properties.

Since each parameter can be divided into specific states for evaluation, for each

Table 1 Linguistic representation of factors affecting selected excavation activity [1]

Factor (1)	State (2)	Frequency Potential (3)	Adverse Consequences (4)
	Long	Large	Medium
Duration	Medium	Medium	Large
	Short	Small	Very Large
	Open	Large	Very Large
Exposure	Partial	Medium	Medium
	Protected	Very Small	Very Small
	Well	Very Small	Very Small
Soil Drainage	Average	Medium	Medium
	Poor	Very Large	Large

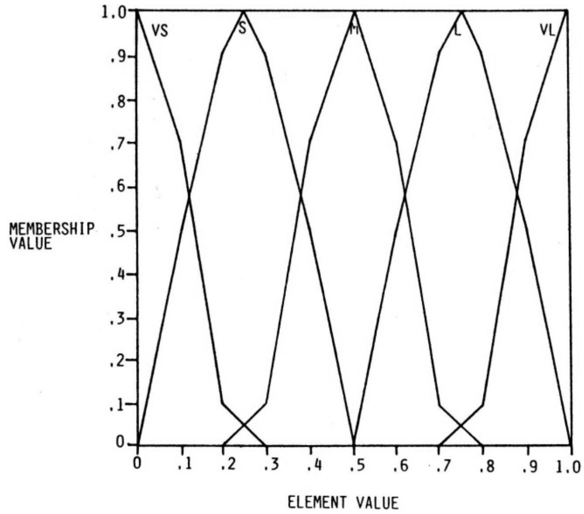
sensitive parameter, the user determines the frequency of occurrence with which the parameter will likely affect the duration of activity, in linguistic terms, based on his or her experience and judgment related to activity and selected parameter.

Finally, the user determines the adverse consequences on the duration of activity, once again in a linguistic form. Adverse consequences are assessed subjectively by the user based on his or her perception with respect to the selected weather event. It is mentioned that linguistic terms are relative to the user' context and depend on the nature of project and of the activity. For example a 'very large' delay may mean a delay of 2 days on a 3 day activity, or a delay of 2 weeks on a month long activity; Allowing the user to use linguistic terms that are relative to his or her context provides the model with flexibility to be used in any given context. The information used to estimate the effect of rainy condition to predict delay duration is consolidated into Table 1.

It is noted that same parameters can be used into several activities even if they occurred in a parallel time. Also for the specified activity, which occurred several times in project life, one cannot use similar adverse consequences and have to choose them in accordance with time conditions that affect in the selected activity.

Next, for each activity parameter, the user translates the linguistic terms of the corresponding frequency of occurrence and adverse consequences into fuzzy sets by assigning membership values, ranging from 0.0 to 1.0, to each element of the set [0, 1] that defines the linguistic term. Each linguistic term is defined on a scale from 0 to 1, with 0 being the lowest value (e.g., very low, very poor, very small), and 1 being the highest value (e.g., very high, very good, very large). The user is free to determine the membership values associated with each linguistic term, based on his or her assessment of what is considered "small," "medium," "large," very large, etc. Alternatively, a number of standard membership functions [similar to those used by Ayyub and Haldar (1984)] for the linguistic terms used into the model, are shown in Fig. 1

Then the fuzzy model combines the frequency of occurrence and the adverse consequences, for each activity parameter. The model calculates a fuzzy combinational relation matrix R(F, C), which is a Cartesian



VS=Very Small, S=Small, M= Medium, L=Large, VL=Very Large

Fig. 1 Graphical presentation of membership functions used in the model

Table 2 Combinational relation matrix of the activity parameter "long duration"

R1=F1xC1=

Frequency of Occurrence \ Consequences	0.3	0.4	0.5	0.6	0.7
0.6	0.1	0.5	0.5	0.5	0.1
0.7	0.1	0.7	0.9	0.7	0.1
0.8	0.1	0.7	0.9	0.7	0.1
0.9	0.1	0.5	0.5	0.5	0.1

product F×C, between the fuzzy subset F, representing the frequency of occurrence and the fuzzy subset C, representing the adverse consequences. The elements of R(F, C) are computed as follows:

$$\boldsymbol{\mu_R(x_i, y_j) = \mu_{F\times C}(x_i, y_j) = \min(\mu_F(x_i), \mu_C(y_j))} \quad (1)$$

where $\mu_R(x_i\ ,\ y_j)$ = membership value of element $(x_i\ ,\ y_j)$ in fuzzy relation R; min = minimum value; $\mu_R(x_i)$ membership value of element x_i in fuzzy set F; $\mu_C(y_j)$ membership value of element y_j in fuzzy set C; x_i element of universe X; and y_j element of universe Y.

Table 2. shows the fuzzy combinational relation R(F, C) = F×C, between the frequency of occurrence and the adverse consequences obtained for the activity parameter "long duration". Elements not shown have a membership value of zero in fuzzy combinational relation R(F, C).

After calculation of the combinational relation matrix corresponding to all linguistic state of the specified parameter, the fuzzy logic model performs the union matrix of all combinational relation matrices; in the example, using total 3 combinational relation

Table 3 Union Matrix T for Activity Excavation

T =

Frequency of Occurance \ Consequences	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
0.4	0.0	0.0	0.0	0.1	0.7	0.7	0.7	0.1	0.0	0.0	0.0
0.5	0.0	0.0	0.0	0.1	0.7	1.0	0.7	0.1	0.0	0.0	0.0
0.6	0.0	0.0	0.0	0.1	0.7	0.7	0.7	0.1	0.1	0.5	0.5
0.7	0.0	0.0	0.0	0.1	0.7	0.9	0.7	0.1	0.1	0.7	0.9
0.8	0.0	0.0	0.0	0.1	0.7	0.9	0.7	0.1	0.1	0.7	0.9
0.9	0.0	0.0	0.0	0.1	0.5	0.5	0.5	0.1	0.1	0.5	0.5
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4 Membership Functions for Adverse Consequences and Delay Duration for Activity Excavation

Elements of linguistic variable	Adverse Consequences		
	Large	Medium	Small
0.0	0	0	0
0.1	0	0	0.5
0.2	0	0	0.9
0.3	0	0.1	0.9
0.4	0	0.7	0.5
0.5	0.5	1	0
0.6	0.9	0.7	0
0.7	0.9	0.1	0
0.8	0.5	0	0
0.9	0	0	0
1.0	0	0	0
Elements of linguistic variable	**Delay Duration in Weeks**		
	Very large	large	Very Small
0	0	0	0.7
1	0.2	0.8	0.9
2	0.8	0.9	0.2
3	0.9	0.3	0

matrices R(F, C), the union T, is computed as follows:

$$T = (F_1 \times C_1) \cup (F_2 \times C_2) \cup (F_3 \times C_3)$$
$$= \mathbf{Max}\,[(F_1,C_1),(F_2,C_2),(F_3,C_3)] \qquad (2)$$

Table 3. shows the union matrix obtained for activity excavation.

Next, the user assesses the relationship between the adverse consequences and the delay duration for the activity in question, using his or her linguistic assessment of the length of the delay for each level of adverse consequences. For example, for a given activity, if the adverse consequences are Large, then the delay duration is Very Large; if the adverse consequences are Medium, then the delay duration is Large; if the adverse consequences are small, then the delay duration is Very Small. The user translates these linguistic terms into fuzzy sets by assigning membership values to each linguistic term describing the adverse consequences and the delay duration, as

Table 5 Combinational relation Q between Large adverse consequences and Very Large delay duration

$Q1=C1xD1=$

Consequences \ Delay Duration	1	2	3
0.6	0.2	0.5	0.5
0.7	0.2	0.8	0.9
0.8	0.2	0.8	0.9
0.9	0.2	0.5	0.5

Table 6 Union Matrix V for Activity Excavation

Consequences \ Delay Duration	0	1	2	3
0.0	0.0	0.0	0.0	0.0
0.1	0.5	0.5	0.1	0.0
0.2	0.7	0.9	0.1	0.0
0.3	0.7	0.9	0.1	0.1
0.4	0.5	0.7	0.7	0.3
0.5	0.0	0.8	0.9	0.3
0.6	0.0	0.7	0.7	0.5
0.7	0.0	0.2	0.8	0.9
0.8	0.0	0.2	0.8	0.9
0.9	0.0	0.2	0.5	0.5
1.0	0.0	0.0	0.0	0.0

shown in Table 4. The user establishes membership functions representing the magnitude of the delay duration. For the selected activity as shown in Table 4, the user considers a delay duration of 3 weeks as definitely being very large, and a delay duration of 0 weeks as definitely being very small

Next, the fuzzy logic model combines the adverse consequences and the delay duration by calculating the fuzzy combinational relation matrix Q(C,D), which is a Cartesian product C×D between the fuzzy subset C, representing the adverse consequences, and the fuzzy subset D, representing the delay duration. Table 5. shows the fuzzy combinational relation Q(C,D) obtained in the case where the adverse consequences are Large and the delay duration is Very Large. Elements not shown have a membership value of zero in the fuzzy relation Q(C,D).

After all fuzzy combinational relation matrices Q(C,D) have been determined, the fuzzy model performs the union matrix of all combinational relation matrices obtained. Three combinational relation matrices are obtained in the example of Table 4, since three different scenarios have been considered with respect to the delay duration. The union V, between the fuzzy combinational relation matrices Q(C,D) is computed as follows

$$\boldsymbol{V = (C_1 \times D_1) \cup (C_2 \times D_2) \cup (C_3 \times D_3)}$$
$$\boldsymbol{= Max\ [(C_1,D_1),(C_2,D_2),(C_3,D_3)]} \quad (3)$$

Table 6. Shows the union matrix obtained for the activity Excavation.

In order to estimate the delay duration, the fuzzy logic model performs a fuzzy composition of union matrix T and V given in Eqs. (2) And (3) and shown in Table 3 and 6, respectively. Because of using dependency factors and high uncertainty in predicting increased duration of activity, two types of composition operations, Max – Min and Max – Product, can be used into the model. To illustrate model performance in the proposed excavation activity, the Max – Min operation, described by the following equation is selected.

$$T \circ V(x_i, z_K) = \underset{Y_i}{Max}\left\{Min\left[\mu_T(x_i, y_j), \mu_V(y_j, z_k)\right]\right\} \quad (4)$$

Where $T \bullet V(x_i, z_k)$= membership value of element (x_i, z_k) in composition matrix between T and V; $\mu_T(x_i, y_j)$= membership value of element (x_i, y_j) in union matrix T;

Table 7 Composition Matrix T.V using Max- Min operation for Excavation Activity

Frequency of occurrence	Delay Duration 0	1	2	3	Row Summation	Frequency product
0	0	0	0	0	0	0
0.1	0	0	0	0	0	0
0.2	0	0	0	0	0	0
0.3	0.1	0.1	0.1	0.1	0.4	0.12
0.4	0.5	0.7	0.7	0.5	2.4	0.96
0.5	0.5	0.8	0.9	0.5	2.7	1.35
0.6	0.5	0.7	0.7	0.5	2.4	1.44
0.7	0.5	0.8	0.9	0.5	2.7	1.89
0.8	0.5	0.8	0.9	0.5	2.7	2.16
0.9	0.5	0.5	0.5	0.5	2	1.8
1	0	0	0	0	0	0

and $\mu_V(y_j, z_k)$ = membership value of element (y_j, z_k) in union matrix V. The composition matrix obtained for the example activity Excavation is shown in Table 7.

To convert the fuzzy set obtained from the composition operation into a crisp (delay duration), Ayyub and Haldar (1984) proposed to choose the delay duration that maximizes the product of the row summation and the corresponding frequency. Using this approach, the row corresponding to frequency of occurrence=0.8 (subset S) is selected from the composition matrix in Table 7.

Next, the fuzzy logic model calculates the probability of occurrence for each element of the delay duration, and determines the values for the mean, μD, that represent as delay duration. The following equations are used to calculate the delay duration.

$$P(D_D = z_k) = \frac{\mu_S(z_k)}{\sum_{k=1}^{m} \mu_S(z_k)} \qquad (5)$$

$$\mu_D = \sum_{k=1}^{m} (z_k) \times P(D_D = z_k) \qquad (6)$$

For the example excavation activity, delay duration can be calculated as follows:

$$P(D=0) = 0.5 / (0.5+0.8+0.9+0.5) = 0.185 \qquad (7)$$

$$P(D=1) = 0.8 / (0.5+0.8+0.9+0.5) = 0.296 \qquad (8)$$

$$P(D=2) = 0.9 / (0.5+0.8+0.9+0.5) = 0.333 \qquad (9)$$

$$P(D=3) = 0.5 / (0.5+0.8+0.9+0.5) = 0.185 \qquad (10)$$

$$\mu_D = (0 \times P_1) + (1 \times P_2) + (2 \times P_3) + (3 \times P_4) = 1.519 \ \ weeks \qquad (11)$$

Selection of appropriate delay analysis technique

Among common delay analysis methods, including the as-planned vs. as-built, impact as-planned, collapsed as-built, and time impact analysis, the most suitable analysis method is the time impact method and that is because of the shortcoming of other methods [5, 6]. In essence some limitations that exist in some actual construction projects may weaken the power of this method and specify significant time and effort.

But in this paper the time impact analysis method is selected to incorporate into delay analysis.

The effect of weather condition in delay analysis technique

Contractors considered some provisions in execution activity to reach the appropriated time and money. For example they plan to execute activities in the best execution time to minimize cost and enhance productivity.

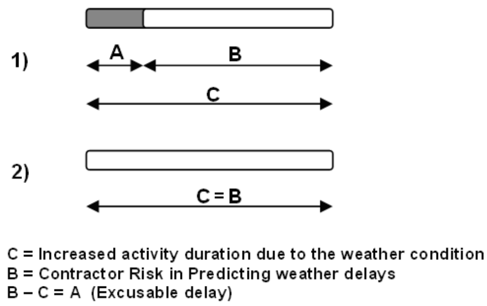
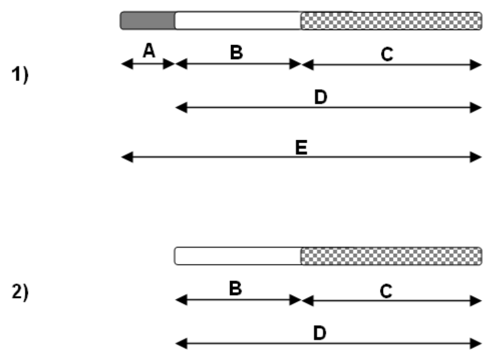


Fig. 2 weather delay analysis in a hypothetical activity



E = Increased activity duration due to the weather condition.
C = Contractor Risk in Predicting weather delays in as-planned schedule.
D = Increased activity duration according to the average weather condition in as-built schedule.
E – D = A Increased activity duration due to the unexpected portion of weather condition (excusable delay).
D – C = B Delay duration caused by changing activity conditions resulting in previous delays and will be portioned.

Fig. 3 weather delay analysis in a practical activity

However, usually due to the delays occurred and unforeseen problems, predicted provisions did not reach and activities executed in different times and conditions which caused increased duration due to unsuitable activity conditions.

As illustrated from delay analysis techniques, none of the methods consider these provisions in analysis procedures. Herein is discussed the method using the presented fuzzy logic model to overcome these shortcomings.

To explain the method, assume an activity that just has weather delays during activity implementation. So will be faced two general cases:

1.1 During the activity execution, weather condition was greater than the predicted weather that the contractor has to consider in its schedule (contractor risk). In these situations, the unforeseen portion of weather delay considered as Excusable Delays and owner must grant a time extension equal to the magnitude of the additional weather delay duration for the contractor to perform the work. (First section in Fig 2.)

1.2 Weather condition was lower than the contractor risk. So no time extension awarded to the contractor, since it must consider these delays in its schedule. (Second

Table 8 Preliminary information of the example highway construction

Activity Number	Activity Name	Original Duration	Start	Finish	Predecessor	Total Float
1	Site clearance	30	2005/06/22	2005/07/21		10
2	Foundation Excavation (Bridging)	20	2005/07/02	2005/07/21	1SS+10 days	63
3	Masonry (Bridging)	30	2005/07/22	2005/08/20	2	63
4	Reinforcements (Bridging)	15	2005/08/18	2005/09/01	3SS+27 days	63
5	Formworks (Bridging)	10	2005/08/29	2005/09/07	4SS+11 days	63
6	Pouring Concrete (Bridging)	3	2005/09/09	2005/09/11	5FS+1 day	63
7	Road Excavation	90	2005/07/07	2005/10/04	1SS+15 days	10
8	Surfacing	80	2005/07/31	2005/10/18	7SS+24 days	10
9	Warm asphalt	66	2005/09/09	2005/11/13	8SS+40 days	0
10	Side guardrail	20	2005/11/14	2005/12/03	9	10
11	Marking	20	2005/11/14	2005/12/03	9	10
12	Completion	30	2005/11/14	2005/12/13	9,6	0

section in Fig 2.)

In a real activity which as well as previous delays change the condition of activity implementation and increased activity duration, weather delays raised the activity duration, two states will be faced:

2.1 During the activity execution, weather condition was greater than the predicted weather that the contractor has to consider in its schedule (contractor risk). In these situations as a portion of increased duration caused by changing activity conditions, it must be analyzed based on previous delays; the remained portions of increased duration can divided into the contractor risk and excusable delays as discussed in the preceding hypothetical activity. (First section in Fig 3.)

2.2 Weather condition was lower than the contractor risk. Therefore since no unusual weather condition is occurred, the increased duration of activity can divided into the contractor risk and delay duration caused by changing activity condition resulting in previous delays. (Second section in Fig 3.)

It is mentioned that the predicted effect of weather event that contractors must consider in its as-planned schedule, can be calculated by measuring the effect of average weather condition in the period of time determined in contract.

Model validation using a case study

A case study of an actual project was used to collect the necessary information to test the performance of the fuzzy logic model. The project consisted of construction a highway in semi-desert plant, which thought to have minimum weather event during construction; but due to the unforeseen weather condition; great delays were occurred in rainy conditions. It is noted that since the effect of other weather events such as snow, low or high temperature and so on in activity execution were negligible, their effects did not consider into the model.

Required data in determining membership functions of the fuzzy logic model were collected using questioners and interviews of experts involved in the construction phase and familiar with the rainfall condition and soil type in the selected area in the past 3 years. Daily progress information (obtained largely from the inspector's reports and expert's interviews) was entered into the as-

Table 9 expert opinions about the effect of precipitations

Activity Name	Increased activity durations result in precipitations		
	3.6 mm	7.9 mm	20 mm
Excavation	0.5 day	2 days	3 days
Surfacing	0 day	2 days	4 days
Warm asphalt	1 day	3 days	4 days

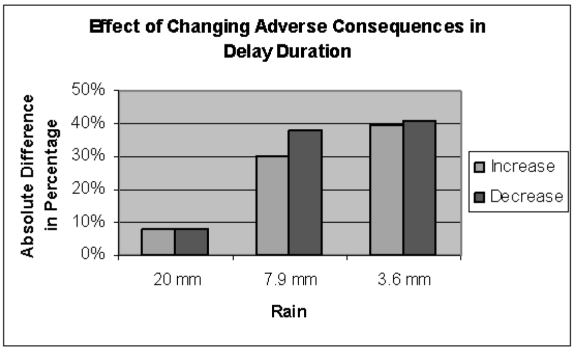


Fig. 4 An investigation on changing adverse consequences in average increased activities duration

built schedule. In addition, this information was used as a basis for updating the as-planned schedule sequentially each time a delay occurred on an activity.

Based on the information and data listed in Table 8, the project duration was 175 days. However, due to the problems occurred in execution of activities, total delays caused project to deliver 40 days later than the finish time of the contract.

It is noted that due to wide site area, rainfall patterns vary from location to location in the selected case study, so it divided into the different construction locations that have the same sensitive rainfall parameters and separated analyses were performed for each category.

To evaluate model performance, preliminary collected data using interviews with experts was entered into the fuzzy logic model programmed in a VBA domain. To validate increased activity durations resulted by different precipitation events obtained from fuzzy logic model and select appropriate composition operation, distinct interviews were accompanied by some experts which have greatest experience at the selected area in the last 2 years. Table 9. show results of these interviews.

A comparison performed between different results of composition operations used in fuzzy logic model and expert opinions showed that as the rainfall pattern decreased, error percentage free from the selected composition operation increased. To evaluate error occurrence reasons, a sensitivity analysis on adverse consequences of the proposed fuzzy logic model using Max-Min operation was performed. As shown in Fig 4. results indicate that as adverse consequences increased or decreased, small rainfall pattern results have great changes. In other words, in small rainfall patterns, the proposed model is more sensitive to variations in membership functions. So to enhance model reliance, a limit as 5 mm precipitation for rainfalls was consider to be incorporated into the proposed model.

To select proper composition operation, a comparison performed between two composition operations showed that the Max-Min operation best fits to the expert opinion in increased activity durations of the severe precipitations.

Weather delay analysis using the proposed model

To illustrate the method used in delay analysis procedure, precipitation with the amount of 20 mm was selected; according to the fuzzy logic model, the specified rain caused excavation, surfacing and warm asphalt activities to increase 3.3, 4 and 4 days relative to planned durations respectively. As this rain occurred in October, and the average amount of annual precipitation in October during a period of 20 years based on methodological data is 7.9 mm, separate model prepared to evaluate the influence of average precipitation in October. Results of the model showed that the specified rain will cause excavation, surfacing and warm asphalt activities, to increase 2.751, 2, 2.75 days relative to planned durations respectively.

To evaluate contractor risk in execution of demonstrated activates according to the contract, one should first determines percent completed of each activity before the rain event occurred and found the relative time of nominated percent in as-planned schedule. This comparisons lead to September in as-planned schedule for all the activities. Since the average amounts of annual precipitation in September is 3.6 mm, but due to the shortcomings of fuzzy logic model in determining increased activity duration on precipitations bellow 5 mm, the expert opinion as shown in table 9 was used.

As mentioned before, to analyze delay responsibilities for the proposed rain (20 mm) and due to the contractor risk (rain 3.6 mm), the following procedures will be done:

1. Increased activity duration for rain 3.6 mm will be regarded as contractor delay and no compensate will be paid.

2. To determine the portion of increased duration due to previous delays, subtract the delay durations of precipitations 3.6 mm and 7.9 mm (1.5, 2 & 2 days for excavation, surfacing and warm asphalt respectively) and then portioned them to each parties according to delay responsibilities before the rain event occurred. Since contractor and owner have 6 and 15 days delays before the rainfall occurred respectively, contractor and owner have 1.5*6/(6+15) and 1.5*15/(6+15) days delay for excavation activity. Other mentioned activities will portion as described.

3. To decide on the amount of increased duration relevant to unexpected precipitation, subtract the delay durations of precipitations 7.9 mm and 20 mm (1, 2 & 1 days for excavation, surfacing and warm asphalt respectively) and time extension will award to the contractor for the specified activity.

Fig. 5 outlined these provisions in excavation, surfacing and warm asphalt activities.

Time impact analysis

As illustrated before, time impact analysis was selected to use in delay analysis procedure. To facilitate the use of delay analysis, a computer program in VBA

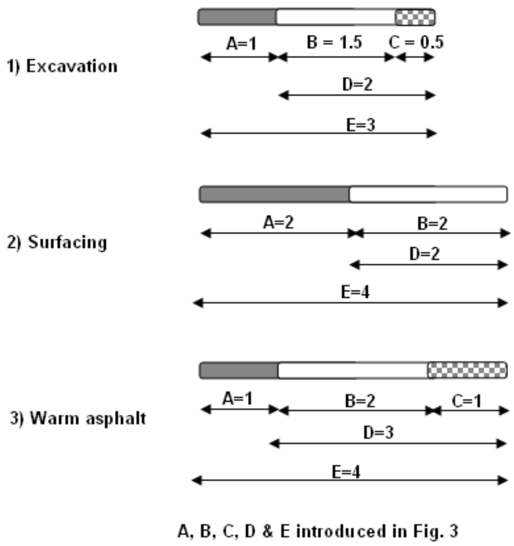


Fig. 5 Analysis of increased delay duration influenced by 20 mm rainfall

domain prepared and linked with Microsoft Project to ease entering as-planned data into Microsoft Excel. Next, having the user entered as-planned data including the demonstrated weather delay analysis into the separate sheet of Microsoft Excel; the computer program will perform the project delay analysis.

In the case of example highway project, the prepared program resulted in 29.5, 7.5 and 3 days as delay responsibility of owner, contractor and excusable delays respectively.

Conclusions and Future Development

This paper describes a practical approach to weather delay analysis that can handle the uncertainty associated with quantifying activity weather delays. The basis of this approach is the use of fuzzy logic in determining increased activity duration resulted by weather events, in analyzing activity delays and in project delays analysis using the time impact analysis. Validation of the fuzzy logic model developed with an actual case study illustrates its accuracy and effectiveness especially in heavy weather conditions.

The model therefore provides a realistic tool to assist in the process of forecasting the extent and consequences of weather delays on increased activity duration and in delay analysis procedure.

The model presented in this paper also can be used as a tool to alert the project manager new conditions in schedule considering weather effects, so they are able to react and take appropriate corrective measures to minimize future delays.

In order to use this model in management of construction projects, it needs to be integrated with historical site weather events. It also could be incorporated into a knowledge-based expert system (KBES) using a set of expert rules contained in a database to assess the combined effects of weather factor in predicting increased activity duration and recommending appropriate corrective actions.

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