Angular Fuzzy Model for Projects Delay

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Abstract

Delays in construction projects are inevitable. Different causes of delay can come into play, therefore, there is a need to identify and classify different causes of project delay. Estimation of the likelihood of delay resulting from different factors that contribute to project delay is essential to project success. There is a pressing need to estimate the likelihood of delay by implementing analysis methods and examining these methods. Fuzzy fault tree analysis is suggested by this research to estimate the likelihood of delay. The result of the fuzzy fault tree analysis is a likelihood of delay membership function that is compared to the predefined fuzzy logic model to assess the degree of severity of the likelihood of delay. Likelihood of delay membership function is further quantified using the weighted average defuzzification method. Angular fuzzy logic models are implemented into the fuzzy fault tree analysis.

Keywords
Construction Projects, Delay causes, Fuzzy angular

1. Introduction

Project that take longer than expected and run over budget are very common in the construction industry. Failure of projects to meet the planned predicted completion time is sometimes inevitable. As a result, expanded time estimates are entered into major tasks to prevent delay problems. Contingency planning is a common practice in the construction industry to prevent such problems. However, even with contingency planning on major project tasks, many projects still exceed the predicted planned time.

Several factors can contribute to delays of a project. Analyzing the causes of delays is an essential task for resolving any conflicts or claims. According to Schumacher [1] most delay claims are complicated. Although many researchers emphasize the high cost and the associated risk related to litigating delay claims, few emphasize the responsibility for project delays. To avoid delays that might result in claims and disputes, the link between the actual tasks undertaken, the time required to complete them, and the ultimate cost estimate of the resources involved all need to be examined.

This paper will analyze different causes of project delays. The delays will then be separated into three categories, based on their causes. These categories are procedural delay causes, triggering delay causes and enabling delay causes. The study will then examine the causes, and analyze those using different methods, including probabilistic and fuzzy models.

2. Literature Review

Stumpf [2] defined delay as an act or event that extends the time required to perform the tasks under a contract. Construction delays became an integral part of the project's construction life. Even with today's advanced technology, and management understanding of project management techniques, construction projects continue to suffer delays and project completion dates still get pushed back. Delays happen in most construction projects, whether simple or complex. Construction delay could be defined as the time overrun either beyond the contract date or beyond the date that the parties agreed upon for delivery of a project [3]. Analyses of delays are characterized as complex and difficult due to the large number of activities that have to be dealt with in any construction project [4]. Researchers have studied the numerous causes of delay in construction projects; Lo et al. [5] cited many significant causes of delays as: inclement weather, shortages of resources, financial difficulties faced by public agencies and contractors, poor contract management, shortages of materials, and inadequate resources.

2.1 Delay Classification

According to a work related to project schedule and project delay classification Al-Humaidi [6], classification of delay causes can follow different logic. Based on the topical literature about project delay topic, we can classify project delays according to their origin, timing, and compensability. Classification of delays according to origin is when the delay is analyzed based on the party responsible for the delay. The party responsible for the delay can be the owner, the designer, or the contractor. The second classification of delay is based on compensability of delay. Compensable delays are classified further into excusable delays or non-excusable delays. Excusable delays may be further classified into excusable compensatory or non-compensatory delays depending on contract terms and conditions. Non-excusable delays are delays that do not entitle the contractor to either time extension or cost compensation. The third classification of delay is based on timing of delay. If two or more delays occur simultaneously, then a concurrent delay takes place. If a single delay takes place at a time, then a non-concurrent delay occurs.

2.2 Causes of Delay

Identifying the party responsible for a specific delay can be difficult, especially if concurrent delays take place. Causes of delay can be classified into three categories, procedural, triggering, and enabling. Procedural causes are frequently hidden events that produce both enabling and triggering events and arise from the interrelationship among various parties involved in the project. Procedural delay causes are further classified into four categories. These four categories are managerial causes, legal causes, financial causes, and operational causes. Triggering delay causes can be defined as external delay causes such as environmental conditions (adjacent buildings, utility lines and power lines, which are external to the project but can significantly impact the progress of work). Other external causes of project delay are classified into weather conditions, underground conditions, and natural disasters. Enabling delay causes can be defined as internal delay causes such as material related causes, workers related causes and equipment related causes.

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2.3 Earlier Work about Fault Tree Analysis

Liang and Wang [7] introduced the fuzzy fault tree analysis method for safety assessment of structures. The authors base their implementation of fuzzy logic on the use of subjective judgment to analyze structural safety. Liang and Wang introduced fuzzy logic models that used Boolean linguistic variables and represent these variables mathematically. Although delays in construction projects are very important, a top down, deductive fault tree analysis has never been used to analyze their effects on projects. This study would continue with implementation of the fuzzy fault tree analysis. Furthermore, the fuzzy fault tree analysis would implement linguistic variables using angular fuzzy logic model.

3. Methodology

Project delay with all its inherent uncertainty is a prime candidate for fuzzy logic application. A fuzzy logic method employing a fuzzy fault tree to represent likelihood of project delay membership functions for a set of fuzzy values has been developed. The method can address subjective, qualitative, and quantitative uncertainties involving the estimation of project delay likelihood. The fault tree analysis requires the development of a tree-like diagram that provides possible scenarios that can result in the occurrence of the top undesired event "project delay." The outcome of interest from fault tree analysis is the occurrence probability of the top undesired event. In large fault trees, computation of the occurrence probability of the top undesired event could be difficult because of the size of the fault tree. In such cases a minimal cut set defines the path or the scenario that leads to the occurrence of the top undesired event. Minimal cut set is defined by Vose [8] as "a set of basic events where the joint occurrence of these basic events results in the occurrence of the top event."

3.1 Fuzzy Set Theory

Lotfi Zadeh [9] first introduced the theory of fuzzy sets in 1965 in his paper "Fuzzy Sets." Zadeh defined a fuzzy set as "a class of objects with a continuum of grades of membership." In a fuzzy set, each object is assigned its own membership value, which determines the degree to which the object belongs to a fuzzy set. Membership values range between zero and one. Fuzzy set theory proposed a paradigm shift from ordinary crisp sets with a membership value of either zero or one. In fuzzy sets linguistic terms are quantified by the implementation of rules of fuzzy set theory.

3.2 Fuzzification

Fuzzification is the process of converting crisp and deterministic values into fuzzy and uncertain values. If vagueness and imprecision are inherent in the linguistic term being described, then the variable is fuzzy. Different fuzzy set models can describe a fuzzy set.

3.3 Fuzzy Set Angular Model

Angular models with rotational characteristics have been developed by Hadipriono and Sun [10]. In the angular model, linguistic values are represented with angles; consequently each value has a different angle. Hence the membership value is a function of an angle Θ. The angular model is represented by a half circle with an angle that rotates between $+\pi/2$ and $-\pi/2$. The undecided linguistic value is represented by a horizontal line with the angle $\Theta = 0$. The angle of $\Theta = \pi/2$ represents the linguistic value of absolutely positive, or no risk. The line corresponding to the linguistic term absolutely negative is opposite to the absolutely low line with an angle of $\Theta = -\pi/2$. Negative terms such as fairly negative, negative, and very negative indicate negative conditions of different causes of project delay. These positive values are represented by lines with angles ranging between $\Theta = 0$ and $\Theta = \pi/2$. Linguistic terms and their positive or negative ratings are represented by the angular model shown in Figure 1.

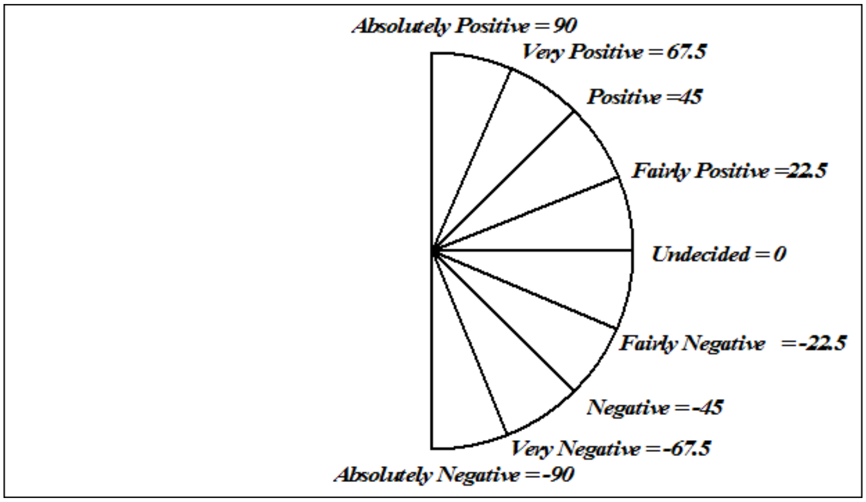

Figure 1: Linguistic Terms and their Values Using Angular Model

Simple trigonometric equations are applied to determine the membership value. The following equations are implemented to determine the membership value, $\mu\theta$, of any given linguistic term, which ranges from very positive ($\theta = +3\pi/8$) to very negative ($\theta = -3\pi/8$).

$$\text{Tan}(\theta) = \mu\theta / x \quad (1)$$
$$\mu\theta = x \tan(\theta) \quad (2)$$

The calculation of the membership value can be illustrated using Figure 2 where simple trigonometric calculation is implemented to determine the membership value of any given linguistic term.

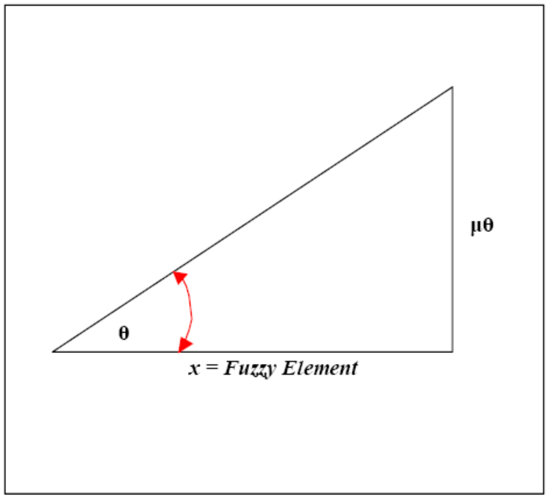

Figure 2: Calculation of Membership Value using the Angular Model.

For example, if weather condition is bad (Negative) an angle with θ = -π/4 or θ = -45o is assigned to this linguistic term. Furthermore, an expert might state that weather has a fairly effective (negatively effective) affect on the overall project likelihood of delay. As an example to capture the weather condition and the degree of effectiveness of weather on the project delay, the membership functions of weather condition and effectiveness of weather on the likelihood of project delay are written as:

Weather condition: $\mu\theta = x \tan(-45o)$ $\mu\theta = x * (-1)$

Effectiveness: $\mu\theta = x \tan(-22.5o)$ $\mu\theta = x * (-0.4142)$

In the rating space, the class of rating space R(r, x) consists of continuous functions with parameter r that satisfies the following equation:

$$R(r,x) = rx \qquad 0 \le x \le 1; -\infty < r < \infty \tag{3}$$

Where x is the domain of the rating space and r is a rating value. The linguistic terms and the rating values are represented in table 1.

3.4 Fuzzy Fault Tree Gates

Fault tree analysis uses a top-down approach to generate a logic model that provides for both qualitative and quantitative evaluation of system reliability. The undesirable event at the system level is referred to as the top event. The top undesired event generally represents a system failure mode or hazard for which predictions are required. The lower level events in each branch of a fault tree are referred to as basic events. They represent internal (enabling), external (triggering), and human (procedural) failures for which the probability of failure is given based on historical data. In fuzzy fault trees, the likelihood of the top event is determined based on lower level events, which are the basic events that are determined based on experts' opinions and subjective judgments. Basic events are linked via logic symbols (gates) to one or more undesirable top events. In general, three fuzzy gates can be implemented to link basic events, AND, the OR and the Fuzzy Mean gates.

3.5 Standard Fuzzy Set Operations

In general, standard fuzzy set operations are the standard intersection and the standard union. Furthermore, the weighted average or the fuzzy mean is another operation on fuzzy sets. The following section describes these fuzzy set operations in further details.

Standard Intersection	$(A \cap B)(x) = \min[A(x), B(x)]$	(4)
Standard Union	$(AUB)(x) = \max[A(x), B(x)]$	(5)
Weighted Average (Fuzzy Mean)	$(A\sim B)(x) = [wa.A(x), wb.B(x)]; wa + wb = 1$	(6)

The intersection of two fuzzy sets, A and B, is specified by a binary operation on the unit interval; that is, a function of the form.

$$i: [0, 1] \times [0, 1] \rightarrow [0, 1] \quad (7)$$

For each element x of the universal set, this function takes as its arguments the memberships of x in the fuzzy sets A and B, and yields the membership grade of the element in the set constituting the intersection of A and B.

$$(A \cap B)(x) = i\,[A(x), B(x)] \quad (8)$$

This operator, i, must have certain properties in order ensure that fuzzy sets produced by i are intuitively acceptable as meaningful fuzzy intersections of a given pair of fuzzy sets. Fuzzy intersection can be applied to different causes of project delay using four different fuzzy logic models. If experts are on the pessimistic side and think that different factors will all take place at the same time, a fuzzy AND operation is implemented to capture these different causes. Figure 3 provides implementation of fuzzy intersection using angular fuzzy logic model.

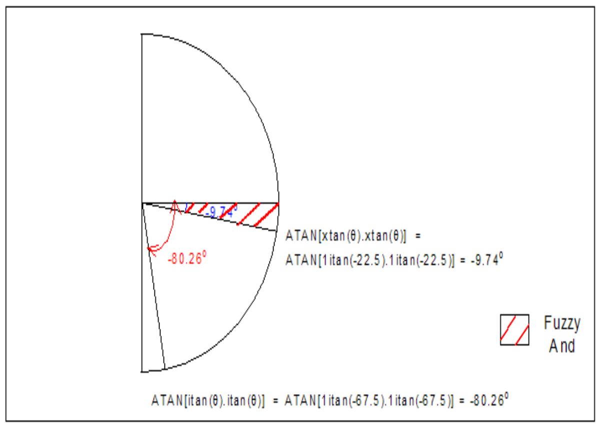

Figure 3: Fuzzy Intersection using Angular Model

The general fuzzy union of two fuzzy sets A and B is specified by a function as the following equations show.

$$U: [0, 1] \times [0, 1] \rightarrow [0, 1] \quad (9)$$

$$\text{Or} \quad (A \cup B)(x) = U\,[A(x), B(x)] \quad (10)$$

Fuzzy unions can be applied to different causes of project delay using angular fuzzy logic models. If experts are on the optimistic side and think that different factors will not all take place at the same time, but one factor or the other are likely to occur at a specific point of time, a fuzzy OR operation is implemented to capture these different causes. Figure 4 provides implementation of fuzzy union using the angular fuzzy logic model.

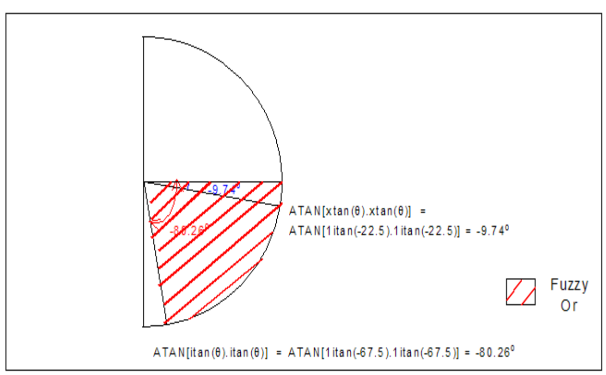

Figure 4: Intersection using Angular Model

The weighted average or the fuzzy mean is captured using the weighted average equation:

$$(A \sim B)(x) = [wa.A(x),\ wb.B(x)];\ wa + wb = 1 \qquad (11)$$

Fuzzy mean can be applied to different causes of project delay using angular fuzzy logic models. If experts consider the average of different factors that contribute to project delay, a fuzzy mean operation is implemented to capture these different causes. Figure 5 provides implementation of fuzzy mean using angular fuzzy logic model.

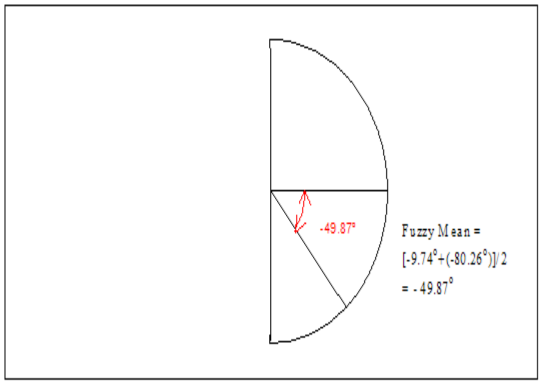

Figure 5: Fuzzy Mean of Angular Model

3.6 Defuzzification

Transformation from a fuzzy set to a crisp number is called a defuzzification. It is not a unique operation as different approaches are possible. The weighted average method is a defuzzification method that is most frequently used in fuzzy application due to its computational efficiently Ross [11]. Among the different defuzzification methods, the weighted average method is selected as a defuzzification method that is used in this research. This selection is due to the fact that different fuzzy logic models are implemented to model project delay. Among these different models, there is a need to implement a method that is applicable to the fuzzy logic models. For simplicity and due to the fact that the weighted average method is the most widely used Ross [11] we would implement the weighted average method.

Table 1 Linguistic variables and corresponding rating spacr

Linguistic Term	Rating Value [R]
Very Negative	-2.414
Negative	-1
Fairly Negative	-0.414
Undecided	0
Fairly Positive	0.414
Positive	1
Very Positive	2.414

4. Results and Discussion

Computer software has been developed using Visual Basic to assess the likelihood of project delay. The software uses the linguistic variables that describe causes of project delay and the effectiveness of each cause on the overall project delay. In case a positive condition of causes of delay is encountered in a given project for example, if weather condition is good or if the delay cause does not affect the overall project delay, then this delay cause is excluded from the analysis. The user selects the state of the bottom events, which describe different causes of delay including triggering delay causes, enabling delay causes and procedural delay causes. The various states of the delay cause are: very negative, negative and fairly negative. The user also needs to select the degree of effectiveness of each contributing cause of delay on the overall project delay.

The computer software user can make a selection among the angular fuzzy logic model to assess the likelihood of project delay. Figure 6 shows the likelihood of project delay using the AND fuzzy logic operation. Figure 7 shows the likelihood of project delay using the OR fuzzy logic operation. Figure 8 shows the likelihood of project delay using the Fuzzy Mean logic operation.

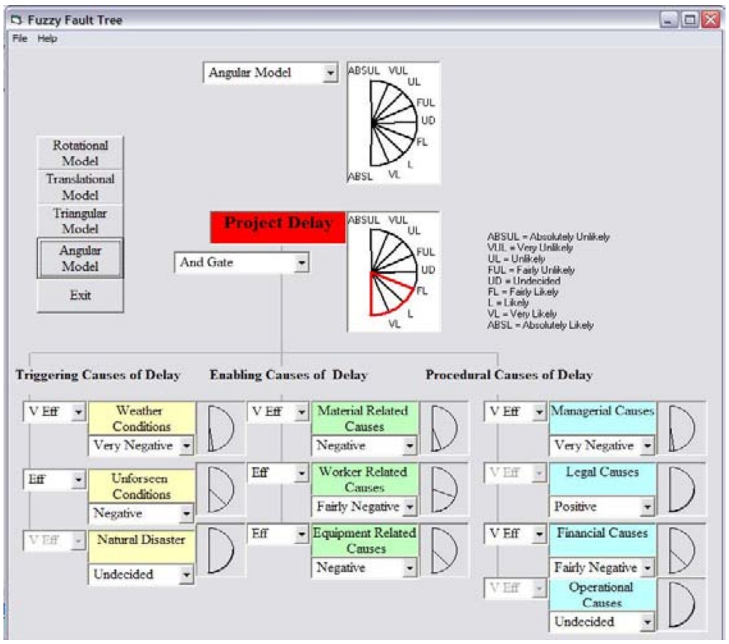

Figure 6 Likelihood of Project Delay with AND Operation using the Fuzzy Angular Model

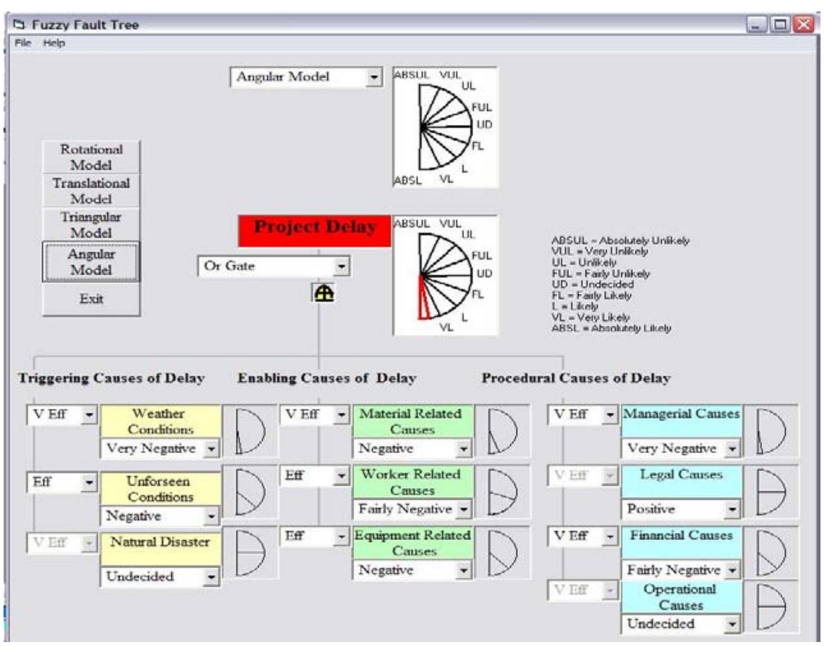

Figure 7 Likelihood of Project Delay with OR Operation using the Fuzzy Angular Model

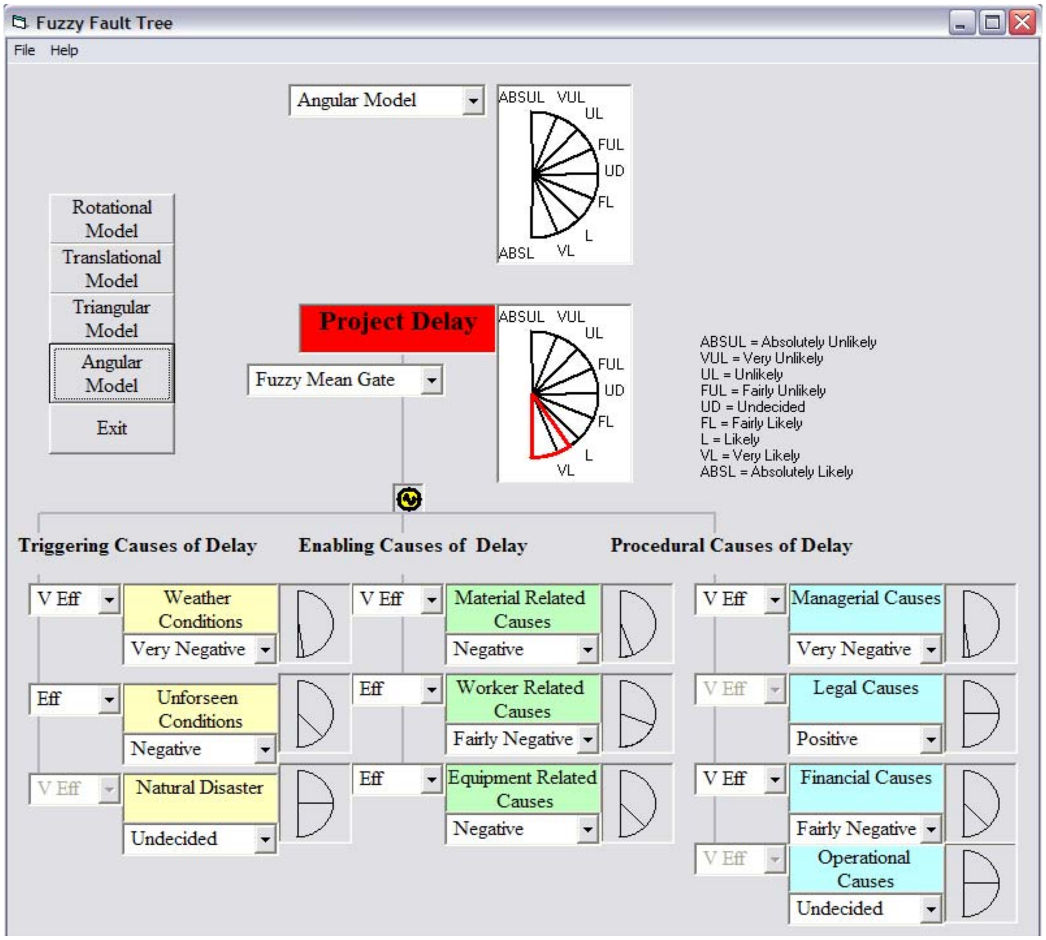

Figure 8 Likelihood of Project Delay with Fuzzy Mean Operation using the Fuzzy Angular Model

5. Conclusion

The fuzzy fault tree analysis is a tool that provides users with a proactive tool of assessing the likelihood of project delay. Managers and construction planners can implement the fuzzy fault tree computer program to assess the likelihood of project delay at early stages and can take preventive actions to mitigate and sometimes eliminate project delays. The fuzzy fault tree program introduced in this study is a very simple and easy to use tool that does not require prior knowledge of fuzzy logic. Planners and managers can simply select the contributing sources and causes of delay that might occur in a given project and they can assess the effectiveness degree of these different contributing delay causes using linguistic terms and they can determine the relationship among these different contributing factors using Fuzzy AND, Fuzzy OR or Fuzzy MEAN gates depending on their opinion. In case the management is optimistic, and believe that only one cause would take place at a time, the OR gate can be selected. In case the management is on the pessimistic side and they think that all contributing causes of delay would take place simultaneously, the AND gate can be selected. If management would take the average of different contributing factors the fuzzy mean gate can be selected. Flexibility in setting the scenario of what could take place can provide management with a computer model that mimics reality. Such modeling can be helpful in assessing the likelihood of project delay and in taking proactive procedures to minimize or completely eliminate the likelihood of project delays.

Determining the model that is best suited for a given project is beyond the scope of this study. In order to further study and compare the different fuzzy logic models, a sensitivity analysis study needs to be conducted. Future research should focus on these illustrative examples that can be suggested based on the sensitivity analysis studies.

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